기본연구 2000-17

A Study on the System Design and Operations of Automated Container Terminal

2000. 12

양창호, 김영훈, 최상희, 배종욱, 이정은

KMI 한국해양수산개발원
KOREA MARITIME INSTITUTE

Contents

<요 약> 1

PART Ⅰ : Development of the Automated Containter Terminal System

1. Introduction 25

1.1 Research Background and Objectives 25
1.2 Research Scope and Methodology 28

2. VLCS and Productivity Requirements 30

2.1 Background 30
2.2 Increasing Ship Size 31
2.3 Required Terminal Productivity Change 33
2.4 Shipping Line's Preferences 38
2.5 Can the Required Level of Productivity be Achievable? 40

3. Automated Container Terminal System 49

3.1 Definition of Automated Container Terminal 49
3.2 Development at the ACT Systems 51
3.3 PSA (Port of Singapore Authority) 55

3.3.1 Outline / 55
3.3.2 PSA Terminal Facilities / 56
3.3.3 Automated Operation of PPT (Pasir Panjang Terminal) / 57
3.3.4 Quay Zone / 68
3.3.5 Yard Zone / 68
3.4 Thamesport 72
3.4.1 Outline / 72
3.4.2 Facilities / 72
3.4.3 Operation of Automated Terminal / 73
3.4.4 Future Developments and Prospects of Thamesport / 76
3.5 CTA of HHLA 78
3.5.1 Outline / 78
3.5.2 Facilities Plan / 78
3.5.3 Operation Plan for Automated Terminal / 81
3.6 Comparison of Automated Systems in Major Terminals 82
3.6.1 Comparison of Automated System Modes / 82
3.6.2 Comparison of Automated Yard Equipment / 85
3.6.3 Comparison of Yard Operation Types / 87
3.6.4 Classification of Automated Container-Handling Systems / 89
3.6.5 Comparison of Productivity of C/C / 92
3.6.6 Comparison of Yard Layout Type / 92
3.6.7 Comparison of Stacking Height and Rows / 94
3.6.8 Comparison of Terminal Capacity in Terms of Quay Length and Area / 94
3.7 Selection of Recommended System 96
3.7.1 Superiority of Automated System / 96

3.7.2 Selection of Recommended Automated System / 97
3.8 Analysis of Causes for Failed Automation of Terminals 99
3.8.1 PSA, Pasir Panjang Terminal / 99
3.8.2 Kawasaki Terminal / 101

4. The Handling Technology of ACT ——————— 103

4.1 Dual Hoist Systems 103
4.1.1 Paceco-Mitsui Supertainer / 106
4.1.2 Elevating Girder / 109
4.1.3 Independent Double-Trolley Design / 110
4.2 Full Automation - (RMGs, ASCs, OHBCs) 111
4.2.1 Introduction / 111
4.2.2 RMGs / 112
4.2.3 Overhead Bridge Cranes / 114
4.3 Automated Guidance Vehicles AGVs 115
4.3.1 Introduction / 115
4.3.2 AGVs at ECT / 117
4.3.3 PSA's AGV Trial / 119
4.3.4 The HHLA Altenwerder Terminal / 121
4.3.5 Other AGV Prototypes / 122
4.3.6 Merits and Potential of AGVs / 125
4.4 Terminal Operating Systems 127
4.4.1 Introduction / 127
4.4.2 Typical Structure of Terminal Operating Systems / 129
4.4.3 Inputs and Outputs to a Terminal Operating System / 131

4.5 Communications Technology 133
4.5.1 Introduction / 133
4.5.2 Radio Frequency Data Communication / 134
4.6 Gate Operations - Personnel Identification Systems 141
4.6.1 Machine-Readable Card Systems / 142
4.6.2 Biometric Identification / 143

PARTⅡ : A Study on the Operational Control and Layout Design of the ACT

5. Operational Control of an ACT ——— 147

5.1 Port Resource Assignment 147
5.1.1 Equipment Assignment / 147
5.1.2 Berth Assignment / 170
5.1.3 Gate Lane Assignment / 176
5.1.4 Summary / 177
5.2 Yard Operation Strategy 178
5.2.1 Outline / 178
5.2.2 Purposes of Yard Operation / 180
5.2.3 Yard Space Planning / 182
5.2.4 Decision of Stacking Position / 188
5.2.5 Summary / 196
5.3 Basic Plan for Operations & Logistics of a Terminal 197
5.3.1 Outline / 197
5.3.2 General Functions and Operations of Terminal / 198

5.3.3 Container Handling Equipment in an Automated Container Terminal / 199
5.3.4 Automated Container Handling Systems / 216
5.3.5 Yard Layout Plan for an Automated Container Handling System / 222
5.3.6 Logistics Flow and Container Handling Equipment / 229

6. Design and Evaluation of an ACT ——— 261

6.1 Outline 261
6.2 Simulation Scenarios 261
6.2.1 Parallel Layout / 262
6.2.2 Perpendicular Layout / 262
6.3 Berth and Yard Capacity Analysis 262
6.3.1 Criteria on Deciding Capacity Through Simulation / 262
6.3.2 Procedures of Analysis / 263
6.3.3 Results of Quay Capacity Simulation / 266
6.3.4 Simulation Results of Maximum Storage Capacity(TGS) / 270
6.4 Terminal Simulation Analysis 276
6.4.1 Yard Block Analysis / 276
6.4.2 Design in Each Layout Alternative / 283
6.4.3 Terminal Layout Drawing / 284
6.4.4 Comparative Analysis of Terminal Layout / 291
6.4.5 Target C/C Productivity / 293
6.4.6 Analysis of Equipment Required Perpendicular Layout / 294
6.4.7 Analysis of Productivity and Equipment Required for Parallel Layout / 299

6.5 Gate Analysis 303
6.5.1 Gate Operation Conditions / 304
6.5.2 Gate Simulation Analysis Results / 308
7. Economic Feasibility Study ——— 314
7.1 Logistic Control of Automated Container Terminal 314
7.2 Analysis of Simulations 318
7.3 Economic Feasibility Study 323
7.3.1 Comparison of Investment and Expense Items / 324
7.3.2 Comparison of Investments and Expenses by Present Value / 332
8. Conclusion ——— 334
References ——— 337

Table Contens

<Table 2-1> Above 6,000TEU Containerships on Float 33
<Table 2-2> Actual Vessel Production 36
<Table 2-3> Vessel Production Required (Estimation) 37
<Table 2-4> Vessel Production Required 37
<Table 3-1> Stages of Development on Computerization in Container Terminals 49
<Table 3-2> Container-handling Operations in Terminals 51
<Table 3-3> Terminals Operated by PSA 57
<Table 3-4> Cranes at PPT 59
<Table 3-5> Handling Capacity of PPT 59
<Table 3-6> Area of PPT 60
<Table 3-7> PSA's Future Plan 71
<Table 3-8> Thamesport Terminal 73
<Table 3-9> Basic Date of CTA Terminal 78
<Table 3-10> Major Automated Terminals 83
<Table 3-11> Comparison of Automated Yard Equipment 86
<Table 3-12> Classification of Automated Container - Handling Systems 91
<Table 3-13> Unitary Capacity of Automated Terminal in Terms of Quay Length and Area 95
<Table 4-1> KoneCranes Double-trolley Specifications 105

<Table 4-2> The Paceco Supertainer - Dimension Options 107

<Table 4-3> The Paceco Supertainer - Speed Options 108
<Table 4-4> Kamag AGV Specifications 124
<Table 4-5> Narrow Band/Spread Spectrum Comparison 141
<Table 5-1> Description of States of Each Handling Equipment 156
<Table 5-2> Comparison of Stochastic Model and Simulation Model 160
<Table 5-3> Basic Measures of Performance for M/G/1 (Receiving operation) 162
<Table 5-4> Comparison of Total Number of Expected Rehandling 191
<Table 5-5> Specifications of Quayside Container Handling Equipment 206
<Table 5-6> Illustrations of a Dual Hoist System 207
<Table 5-7> Specifications of CATCs 209
<Table 5-8> Specification of an OHBC 211
<Table 5-9> Specifications of Yard Cranes 212
<Table 5-10> Transporter Dimension (By Manufacturer) 214
<Table 5-11> Specification of a Terminal Tractor 215
<Table 5-12> Transporter Dimension (By Equipment) 216
<Table 5-13> Comparison of Yard Layouts 227
<Table 5-14> Comparison of Yard Layout Considering Combination of Equipment 228
<Table 6-1> Simulation Analysis of 1 million TEUs Traffic 268
<Table 6-2> Simulation Analysis of 1.2 million TEUs Traffic 269
<Table 6-3> Simulation Analysis of 1.35 million TEUs Traffic 269

<Table 6-4> Simulation Analysis of 1.5 million TEUs Traffic 270

<Table 6-5> Maximum Storage at Medium Peaking 271
<Table 6-6> Maximum Storage Space at High Peaking 273
<Table 6-7> Maximum Storage Space (TGS) 275
<Table 6-8> Comparison of C/C Productivity in Each Section Scenario (lifts/hr) 277
<Table 6-9> Comparison of Purposes for Using Productivity 281
<Table 6-10> Number of ATCs Required for Scenarios of Number of Block Rows 282
<Table 6-11> Number of AGVs and Productivity of C/C for Scenarios of Number of Block Rows 282
<Table 6-12> Result of Storage Capacity Analysis 283
<Table 6-13> Block Specs for Each Layout Alternative 283
<Table 6-14> Test Results of Productivity Analysis (Perpendicular Layout 1) 297
<Table 6-15> Test Results of Productivity Analysis (Perpendicular Layout 2) 298
<Table 6-16> Required Number of Equipment and C/C Productivity 298
<Table 6-17> Results of Simulation 303
<Table 6-18> Estimation Number of Maximum Gate-in & Gate-out Trucks at Daily Peaks of Export & Import Containers 304
<Table 6-19> Daily Maximum Export & Import of Gate-out & Gate-in Containers and Classification of Containers 304
<Table 6-20> Estimation of Empty Containers to be Re-distributed

..... 305

<Table 6-21> Estimation of Gate-in & Gate-out Bare Chassis Trucks 305
<Table 6-22> Total Number of Gate-in & Gate-out Trucks at Daily Peaks 306
<Table 6-23> Average Gate Pass Time 307
<Table 6-24> Entry Mixes 307
<Table 6-25> Result of Gate-in Queue Analysis 309
<Table 6-26> Average Operation Time 310
<Table 6-27> Simulation Result of Queue in Yard 311
<Table 6-28> Maximum Queue Length (99% Percentile) 312
<Table 6-29> Simulation Result of Truck Turn Around Time 313
<Table 7-1> Civil Engineering Costs 325
<Table 7-2> Equipment Purchase Price for Automated Container Terminal 327
<Table 7-3> Equipment Purchase Price for Conventional Container Terminal 328
<Table 7-4> Annual Labor Cost 330
<Table 7-5> Estimation of Power Cost 331
<Table 7-6> Maintenance Ratios for Assets 332

Figure Table

<Figure 2-1> Post Panamax Containership 32
<Figure 2-2> Factors Influencing Lay Time 33
<Figure 2-3> LPC by Vessel Size 34
<Figure 2-4> Number of C/Cs by LPC 35
<Figure 2-5> Lay Time by LPC 35
<Figure 2-6> Pusan Terminal Case 38
<Figure 2-7> Shipping Line's Preference 39
<Figure 2-8> Far East/ Europe Route 40
<Figure 2-9> Alternatives to Archive Productivity Improvement 42
<Figure 2-10> Vertically Circulating Container Crane 42
<Figure 2-11> RMG Runs Parallel or Perpendicular to Quay 44
<Figure 2-12> Impact of Block Length 44
<Figure 2-13> Amount of Yard Trailers per C/C 45
<Figure 2-14> Impact of Y/C Cycle Time 45
<Figure 2-15> Effect of Dual-cycle Operation 46
<Figure 2-16> Terminal Operation System 47
<Figure 2-17> Rehandling Rate per Vessel(%) 48
<Figure 3-1> Detailed Layout of 1st Phase PPT 60
<Figure 3-2> Overview of PPT 61
<Figure 3-3> Flow of Remote Control of Bridge Crane at PPT 62
<Figure 3-4> Bridge Cranes Established at PPT 62

<Figure 3-5> Bridge Crane and Yard at PPT 63
<Figure 3-6> Discharging by Bridge Crane at PPT 63
<Figure 3-7> Discharging by RMG Crane at PPT 64
<Figure 3-8> Flow of Bridge Crane Remote Control at PPT 64
<Figure 3-9> Overview of Thamesport 76
<Figure 3-10> Layout of Thamesport 77
<Figure 3-11> Overview of HHLA CTA 79
<Figure 3-12> Bird's-eye-view of HHLA CTA 79
<Figure 3-13> Layout of HHLA CTA 80
<Figure 5-1> Procedure of an Operation Agent Initiated Negotiation 153
<Figure 5-2> Procedure of a Resource Agent Initiated Negotiation 155
<Figure 5-3> State Diagram in Case of One AGV 158
<Figure 5-4> System Diagram of Berth Assignment and C/C Assignment 171
<Figure 5-5> Allocation of Section in Yard in Parallel Layout 185
<Figure 5-6> Storage Space by Ship in Perpendicular Layout 187
<Figure 5-7> Classification of Storage Bay in Block by Use 193
<Figure 5-8> Flow of Yard Operation Strategy 197
<Figure 5-9> Analysis of Factors Related to Container Handling Equipment 200
<Figure 5-10> Single Trolley System 201
<Figure 5-11> Double Trolley System 202
<Figure 5-12> Dual Hoist System 204
<Figure 5-13> Supertainer System 206

<Figure 5-14> CATC Drawing(1) 208
<Figure 5-15> CATC Drawing(2) 210
<Figure 5-16> AGV Drawing 215
<Figure 5-17> Logistics of Parallel Layout 224
<Figure 5-18> Perpendicular Layout 226
<Figure 5-19> Flow of Developing Logistics System 229
<Figure 5-20> Analysis of Factors for Quay 230
<Figure 5-21> Zone Between Backreach and Yard in ECT Type 232
<Figure 5-22> Backreach of CTA Type 234
<Figure 5-23> Analysis Stage of Container Yard 236
<Figure 5-24> Analysis of Container Storage Space and Related Factors 238
<Figure 5-25> Stages of Analysis of Rail Terminal 246
<Figure 5-26> Stages of Analysis of Gate Yard 247
<Figure 5-27> Analysis of Factors Related to Gate Yard 248
<Figure 5-28> Overview of Gate 256
<Figure 5-29> The Flow of 1-step Gate Operation 257
<Figure 5-30> The Flow of 2-step Gate Operation 258
<Figure 5-31> The Flow of 3-step Gate Operation 259
<Figure 6-1> Ship Arrival Pattern 266
<Figure 6-2> Ship Arrival Simulation Results (In Case of Peak) ... 267
<Figure 6-3> Berthing Position of Ship 267
<Figure 6-4> Storage Space Required 272
<Figure 6-5> Storage Space Required 272
<Figure 6-6> Storage Space Required 273

<Figure 6-7> Storage Space Required 274
<Figure 6-8> Storage Space Required 274
<Figure 6-9> Storage Space Required 275
<Figure 6-10> Comparison of C/C Productivity to Number of Sections 278
<Figure 6-11> 1 Cycle Time Distribution of ATC in Perpendicular Layout 1 295
<Figure 6-12> 1 Cycle Time Distribution of ATC in Perpendicular Layout 2 296
<Figure 6-13> C/C Productivity in Perpendicular Layout 299
<Figure 6-14> Result of Distribution Estimation(Mean Value) 299
<Figure 6-15> C/C Productivity of Parallel Layout 1 301
<Figure 6-16> C/C Productivity of Parallel Layout 2 302
<Figure 6-17> Truck Arrival Pattern by Time Zone 306
<Figure 6-18> Gate-in Queue Length (99% Percentile)-4 Lanes 309
<Figure 6-19> Maximum Queue Length(99% Percentile)-Perpendicular Layout 1 311
<Figure 6-20> Maximum Queue Length(99% Percentile)-Parallel Layout 1 312
<Figure 7-1> Flow Chart of Yard Simulation 321

<요 약>

1. 개 요

1.1 연구배경 및 목적

○ 컨테이너선의 대형화에 따른 항만생산성 향상 및 컨테이너항만의 경쟁력 강화를 위해 인건비 절감 및 터미널 토지 활용성 제고가 필요하며, 이와 같은 필요성으로 인해 자동화 컨테이너터미널 건설이 하나의 대안으로 부각되고 있음

○ 우리나라도 자동화 컨테이너터미널을 광양항에 건설하기로 하고 기본계획을 수립 및 설계중에 있으며, 관련 핵심기술을 개발하고 있음

○ 본 연구는 자동화 컨테이너터미널의 운영통제 방식, 평면배치 레이아웃, 시설규모 및 소요장비, 동선배치 방법을 연구하여 자동화 컨테이너터미널이 건설될 경우 운영전략 및 레이아웃 실시설계시 필요한 이론적 배경 및 로직개발을 주목적으로 하며, 또한 시뮬레이션 모델을 이용한 자동화 터미널 설계를 목적으로 함

○ 자동화 컨테이너터미널이 국제적 관심분야인 점을 감안, 향후 동 분야 연구의 국제적 참여를 위해 영문보고서로 작성함

1.2 연구범위 및 방법론

○ 본 연구는 두 Part로 나뉘어짐. Part Ⅰ은 네 개의 장으로 구성되며

자동화 컨테이너터미널의 개발필요성을 검토한 후, 개발동향을 세계 주요 터미널의 자동화 사례로 분석하며 자동화터미널 관련 기술개발 동향을 분석하였음. Part II는 5장 이하 세 개의 장으로 구성되며 자동화터미널을 설계하기 위해 필요한 터미널 물류흐름과 운영방식을 분석·실험하였고, 시뮬레이션 모델을 이용하여 최적 평면배치 대안을 제시하였음

○ 제2장에서는 초대형 컨테이너선(VLCS)의 항만생산성 향상 요구수준을 부산항의 실적자료를 기초로 회귀분석 기법을 사용하여 추정하였음

○ 제3장은 현재 건설되었거나, 추진중에 있는 세계 자동화 컨테이너터미널의 현황을 분석하고 장단점을 비교하였으며, 특히 PSA와 Kawasaki터미널의 실패사례를 분석하였음

○ 제4장은 자동화 컨테이너터미널에 적용될 수 있는 장비 및 시스템, S/W 기술동향을 분석하였음. C/C, AGV, RMG 등의 장비기술, 터미널운영시스템, 게이트시스템 등의 해외 주요 기술개발 동향을 정리하였음.

○ 제5장에서는 아직 세계적으로 연구가 심도 있게 이루어지고 있지 않은 자동화터미널의 운영로직을 자원할당, 야드적치 전략으로 나누어 연구, 제시하였고 수평배치와 수직배치로 구분하여 각각 문헌연구를 통해 야드 운영전략을 제시하였으며, 자동화 컨테이너터미널의 물류흐름을 제시하였음

○ 제6장에서는 제5장에서 제시한 운영전략 및 물류흐름을 갖고 실제로 자동화터미널의 평면배치 대안을 설계하였고 각각에 대해 시설규모 및 소요장비 등을 시뮬레이션 모델에 의해 분석함. 여기에서는 안벽능력 분석, 장치장 분석, 야드배치 분석, 소요장비 분석, 게이트

분석 등을 수행하였음

○ 제7장은 재래식 터미널과 자동화 터미널을 동일한 규모로 건설할 경우의 투자비 및 운영비를 비교함으로써 타당성을 분석함

2. 컨테이너선의 대형화에 따른 터미널 생산성 수준 검토

2.1 생산성 수준 분석

○ 1999년 기준 부산항의 연간 총 작업시간당 생산성은 약 20box임

○ 8,000TEU 컨테이너선 및 12,000TEU선의 LPC는 각각 3,600lifts와 5,500lifts로 추정

○ 8,000TEU와 12,000TEU 선박에 C/C를 각각 5대와 6대를 할당할 경우 1999년 부산항 생산성 기준으로 laytime은 각각 43시간, 63시간이 소요

○ laytime을 24시간으로 제한할 경우 8,000TEU와 12,000TEU 컨테이너선의 요구생산성은 C/C당 30box와 38box가 되어야 하며, 12,000TEU의 경우는 laytime을 30시간으로 할 경우 생산성이 30box가 되어야함

○ 따라서 VLCS에 대비한 터미널의 생산성은 현재 시간당 20box에서 최소 30box로 약 50% 향상이 필요

2.2 생산성 향상 대안으로서의 자동화 컨테이너터미널

○ 자동화 C/C, AGV, RMG 등의 장비, 야드 운영통제방식의 개선, 자동화된 터미널 운영시스템을 적용하는 자동화 컨테이너터미널이 생산성 향상의 대안으로 제시됨

○ C/C측면에서 기존 재래식 Single Trolley C/C의 이론적 생산성이 40 45box/hr인데 비해 Dual Hoist C/C나 수직순환식 C/C의 경우 60 100box/hr까지 향상이 가능

○ 야드 운영통제방식에서는 장비풀링(equipment pooling)이나 듀얼사이클(dual cycle)과 같은 복잡하고 정교한 야드운영이 자동이동장비(AGV)와 무인 야드크레인을 사용하는 자동화터미널에서 가능하며, 이로 인한 생산성 향상은 20% 정도임

○ 또한 자동화터미널에서는 무인 자동화장비를 사용하기 때문에 장비들의 시간예측이 가능해 real-time system의 자동화된 터미널 운영시스템 적용이 가능함

- 야드내 rehandling을 줄일수 있음
- 실시간으로 최적의 자원할당, 양적하 작업 수행
- pooling system이나 dual cycle과 같은 복잡한 야드통제 가능 (fixed rule → adaptive rule)
- 야드운영 여유 향상 가능 (50% → 80%)
- cargo-closing time없이 최적의 planning 가능 (서비스 향상 및 yard space 약 20% 절감 가능)

3. 자동화터미널의 발전 및 주요 터미널 비교분석

3.1 세계 주요 자동화터미널 현황

○ 네덜란드 ECT의 DSL, DDE의 AGV-ASC 자동화터미널 시스템, 터미널내 logistics control 등을 분석, DDW와 FAMAS project를 검토

○ 싱가포르 PSA의 PPT AGV-OHBC-RMG 자동화터미널 시스템, 영역별 운영현황, logistics control 향후계획 등을 검토

○ 영국 Thamesport의 터미널 운영현황, logistics control 및 향후계획 등을 검토

○ 동일 HHLA의 CTA 자동화터미널 계획, 운영방안 및 logistics control을 분석

3.2 자동화시스템 비교분석

○ 세계 주요 자동화터미널의 야드장치 장비, 야드 운영형태, 처리시스템, 안벽크레인, 장치장 배열 형태 등을 비교

<표 요약-1> 주요 자동화터미널의 현황

구 분		ECT/DSL	싱가포르(PPT)	Thamesport	HHLA
자동화시스템 형태		AGV-RMG(ASC)형	AGV-OHBC/RMG	AGV-RMG	AGV-2RMG
자동화구간	안 벽 크레인	·대선박 : 유인 ·대AGV : 자동	·대선박 : 유인 ·대Y/T : 유인	·대선박 : 유인 ·대Y/T : 자동	·대선박 : 유인 ·대AGV : 자동
	YT (이 송)	·AGV : 자동운영	·Y/T : 유인	·Y/T : 유인	·AGV : 자동운영
	YC	ASC : ·대AGV : 자동 ·야드내 : 자동 ·대SC : 자동	무인OHBC : ·대 Y/T : 반자동 ·야드내 : 원격 RMG : ·반출입 : 유인 ·야드내 : 유인	무인RMG : ·대Y/T : 반자동 ·시프트 : 자동 ·야드내 : 자동	무인RMG : ·대AGV : 자동 ·야드내 : 자동
	외부차량과 접 점	·SC : 유인	무인RMG : 원격조정/유인	무인RMG : 원격조정/반자동	무인RMG : 원격조정/반자동
수동구간	철 송	·MTS : 유인			
	비 규 격	·ASC/M : 특수 스프레더, 유인	-	-	YT : 유인
	공 컨	·RS/SL : 유인	-	-	-
야드형태		·단일형 ·수직배열	·buffer야드 ·수평배열	·buffer야드 ·수평배열	·단일형 ·수직배열
장치단적수		3단 6열	8단 10열	4단 9열	4단 10열

3.3 자동화터미널 실패사유 분석

○ 싱가포르PSA가PPT를건설하면서AGV-OHBC-RMG의자동화시스템을 계획하였으나 아직 AGV를 채택하지 못한 사례를 검토

○ 일본 Kawasaki터미널이 자동화터미널로 건설한 터미널을 AGV를 사용하지 않고 자동화 RMG만 사용한 실패사례를 검토

4. 자동화 컨테이너터미널에 적용되고 있는 기술개발 동향분석

4.1 Dual Hoist Systems

○ ECT에서 사용된 Dual Hoist C/C를 최근 독일이 자동화터미널로 건설중인 CTA터미널에서도 사용함에 따라 Dual Hoist C/C의 적용사례와 종류, 에이프론 설계에 필요한 제원 및 운영방식 기술 등을 검토

○ ECT방식은 rail-span내에 AGV 주행로 위치, CTA방식은 backreach하부에 AGV주행로 위치

4.2 자동화 Yard Crane(RMG, ASC, OHBC)

○ ECT, Thamesport, PSA에서 사용하고 있는 자동화 야드크레인을 Nelcon사, NKK사, MITSUI사, ABB사 별로 관련 기술동향 분석

4.3 AGV

○ ECT, PSA, CTA의 AGV 운영 및 기술동향을 분석

○ 기타 Huisman-Itrec AGV, Kamag AGV, MES AGV의 기술을 분석

○ AGV의 성능 및 장단점을 비교 분석

4.4 자동화된 터미널 운영시스템

○ 자동화터미널 운영시스템 개발동향
- NAVIS사 COSMOS사 HPC사

○ 터미널 운영시스템의 구조개발동향 분석

5. 자동화터미널 운영통제 및 터미널내 흐름 분석

5.1 자원할당

○ 각 작업에 대해 시설, 취급장비 그리고 인력을 어느 시점에 얼마만큼 할당할지와 어떻게 계획 · 운영할 것인가에 대한 의사결정

○ 자원능력을 효율적으로 분배함으로써 어떠한 자원도 시스템의 한계요소가 되어 전체 생산성을 저하시키는 경우가 없도록 하는 것이 목적

○ 터미널의 처리능력, 효율성 등은 여러 작업부하와 장비의 결합이 어떻게 이루어지는가에 의존함

○ 취급장비 할당, 선석할당, 게이트 할당의 세 부분으로 나누어 운영전략을 다루었고 계획 측면에서의 장비배분과 운영 측면에서의 장비배차로 단계화시켜 접근

○ 기존 터미널과 비교하여 정보시스템의 역할이 보다 강화되고 작업자의 개입 없이 이루어지는 의사결정이 증가됨. 이러한 특성을 반영할 수 있는 의사결정 구조로서 분산형 구조를 제안하였고 의사결정의 효율성을 위한 이론적 방안을 제시

○ 자동화 컨테이너터미널에서 선석할당과 게이트 할당은 기존 터미널과 비교하였을 때, 차이점이 크지 않음. 따라서 이들에 대해서는 기본적인 운영방안과 사례를 중심으로 정리

5.1.1 취급장비 할당

1) 자동화 컨테이너터미널을 위한 의사결정 구조

(1) 분산형 구조

○ 자동화 컨테이너터미널에서는 자원할당을 위한 의사결정의 상당부분이 작업자의 개입 없이 대규모의 장비를 제어하면서 이루어질

것으로 예상

○ 기존 터미널에서 적용되는 중앙집중형 의사결정 구조는 다양한 요구사항을 수용하면서 동시에 대규모의 장비를 실시간 운영하기가 힘듬. 따라서 분산형 의사결정 구조가 자동화 컨테이너터미널에 적합할 것으로 예상

○ 분산형 구조는 복잡한 시스템의 변화에 대한 대응이 빠르고 문제 발생시 시스템 전체가 정지되는 상황을 예방하는 데 유리하지만 이에 맞는 효율적인 의사결정 과정을 개발·적용하기 힘듬

(2) 경매 절차

○ 분산형 구조를 위한 의사결정 과정의 대안으로 교섭기반 경매(negotiation based bidding)를 제시. 이는 가격협상을 통한 거래 체결과정과 유사하며 자원을 필요로 하는 작업담당 자치적 객체(operation agent)와 작업을 수행할 수 있는 자원담당 자치적 객체(resource agent)의 교섭과정을 묘사

○ 자치적 객체란 독자적인 의사결정을 수행하는 단위로서 시스템의 구성에 따라 개별 과업이나 장비 또는 작업이나 장비군을 관리·통제하는 software로 구현됨

○ 작업담당 자치적 객체는 작업종류에 따라 본선하역작업 자치적 객체와 반출입작업 자치적 객체로 구분함

○ 작업담당 자치적 객체 발의 교섭 : 새로운 작업의 시작, 작업의 지연 또는 장비의 고장 등의 이유로 장비를 추가로 요청하는 경우

○ 자원담당 자치적 객체 발의 교섭 : 장비가 할당작업을 마치고 유휴상태가 되면서 새로운 작업을 요구하게 되는 경우

2) ATC 배분

○ ATC 배분을 위해 작업부하를 산출하는 방법은 작업특성을 고려하여 본선하역작업과 반출입작업으로 구분

○ 장치장 배치형태별로 ATC의 운영방법이나 고려요소가 다르므로 각각에 대한 운영전략을 제시

○ 수평배치의 경우는 ATC의 작업영역에 대한 결정이 같이 이루어져야 함. ATC의 움직임을 최소화하는 것을 목적으로 하기 때문에 동일한 ATC가 동일한 C/C를 집중적으로 서비스할 가능성이 많음

○ 수직배치에서는 ATC의 작업영역이 고정적이므로 작업부하의 균형화 측면이 보다 중요함. 따라서 장비배분의 문제보다는 장비배차의 문제가 효율성에 영향을 많이 미침

3) AGV 배분

○ 고정배차로 사용하느냐 아니면 공유배차로 사용하느냐에 따라 다른 의사결정 규칙이 필요함. 공유배차를 사용하는 경우에는 몇 대의 C/C를 범위로 설정할 것인지가 중요함. 고정배차의 경우에는 작업조건에 따라 차별화할 수 있음

4) ATC 배차

○ 배차(dispatching)란 특정 장비에 구체적인 작업을 할당하는 것을 말함. 장비의 활용도를 극대화하고 작업의 지연이나 대기시간을 최소화하는 것이 배차의 목적임

○ 수평배치에서 본선하역작업, 반출입작업을 처리하기 위한 경우와 수직배치에서 본선하역작업의 경우를 다루었음

5) AGV 배차

○ 중앙집중형 AGV 배차전략은 효율적인 의사결정을 할 수 있는 반면

과정이 복잡한 단점이 있음. 따라서 분산형 AGV 배차에 대한 접근방법을 검토

5.1.2 선석할당

○ 터미널에 입항하는 선박들의 접안시간과 접안위치를 결정하고 본선하역작업을 수행하는 C/C의 수를 결정하는 문제임

○ 각 선박들이 최대한 안벽상의 선호위치에 접안할 수 있게 하며 각 선박들이 원하는 입항시간과 출항시간을 최대로 만족시키는 선박의 접안시점을 결정. C/C 할당과 함께 결정하는 것이 바람직함

○ 선석할당의 전략은 재래식 터미널의 경우와 유사함. 이는 하역작업의 전면적인 자동화가 아직 힘들고 터미널의 통제범위를 벗어나는 다양한 상황과 요구조건이 발생하기 때문임

1) 선석배정

○ 터미널에 입항예정인 선박들의 접안시간과 접안위치를 정하는 의사결정시 고려해야 할 여러 특성을 분석하고 라그랑지 완화법을 이용한 수리적 모형을 제시

2) C/C 할당

○ 계획된 접안시간내에 본선하역작업이 완료될 수 있도록 C/C를 할당하며 각 C/C에 대하여 선박에서의 작업 시작시간과 완료시간을 결정

3) C/C 작업일정 재조정

○ 작업 진행사항을 수시로 파악하여 작업지연으로 인한 선박의 지연이 예상될 때에는 C/C 사용시간 또는 선석배정 스케줄을 재조정

5.1.3 게이트 할당

○ 운송 트럭이 터미널의 반 · 출입 게이트에 도착했을 때 진입 레인을 결정하는 문제

○ 작업 종류, EDI 사용 유무, 그리고 전용레인 운영 여부 등의 정보를 이용하여 각 트럭이 진입할 레인 위치를 할당

5.2 야드적치 전략

○ 장치장의 상황을 고려하여 컨테이너의 저장위치를 정하는 의사결정으로 장치장 적재상태뿐만 아니라 취급장비의 이동 및 작업영역에 대한 작업부하의 배분과도 밀접한 관계가 있음

○ 장치능력하에서 장비의 작업능력이 최대화될 수 있게 작업부하를 배분하는 장치장 운영은 터미널의 생산성을 최대화하는 과정임

○ 장치장 운영의 의사결정을 계획단계의 장치공간계획과 운영단계의 장치위치 할당의 계층적 구조로 구성하였음. 저장공간계획은 개별 컨테이너가 도착하기 이전에 선박별 작업물량과 예정작업시각을 고려하여 사전에 장치공간을 배정하는 단계이고 장치위치 할당은 컨테이너가 도착하는 시점에 특성과 장치장의 현재 상황을 고려하여 계획된 저장공간내에서 장치위치를 실시간으로 결정하는 단계임

○ 하역장비의 설계능력, 이송장비의 주행 여건, 컨테이너의 흐름 등과 이에 따른 생산성의 차이를 고려하여 장치장이 수평배치인 경우와 수직배치인 경우에 대해서 각각 장치장 운영전략을 구분하여 제시

5.2.1 장치장운영의 목적

○ 작업시간의 단축

○ 장치장 활용도의 증대

○ 작업부하의 평준화

5.2.2 장치공간계획

○ 컨테이너 각각에 대해서 구체적인 장치위치를 결정하지는 않고 필요한 공간만큼 장치장의 저장능력을 배분하는 의사결정

○ 장치위치를 결정할 때 초기 탐색범위가 될 뿐이지 각 위치에 대한 사용순서나 정확한 장치물량을 결정하지는 않음

○ 선박별 장치공간 할당은 선석할당의 내용과 관련됨. 선박의 접안위치는 장치공간의 영역에 관계되고 할당 C/C 수는 본선 하역작업이 ATC의 작업과 연동되어 수행되므로 장치공간이 어느 정도 확보되고 분산화되어야 하는지를 결정할 때의 고려요소임

○ 미래의 불확실한 상황과 예측자료의 변동으로 인해 의사결정의 자동화가 힘들며 수시로 재계획 · 수정 · 보완하는 과정이 필요. 따라서 수리적 모델들의 단점을 고려하여 현장경험을 중심으로 알고리즘을 제안

1) 수평배치 장치장

○ 용도별 영역구분 전략과 접안위치별 장치장 블록의 구역화 전략을 다루었음

2) 수직배치 장치장

○ AGV의 이동시간을 고려한 장치공간계획이 적절함

○ 장치위치의 산포가 ATC의 작업 cycle time에 미치는 영향은 수평배치인 경우에 비해 적고 장비의 작업간섭에 의한 생산성 저하 가능성도 적음

○ ATC의 작업부하를 평준화시켜 이송장비에서 대기시간이 발생하지 않도록 하는 것이 보다 효율적임

○ 반입의 경우는 선석에서 일정한 거리의 범위에 드는 블록을 대상으로 하되 그 일정한 범위라는 것은 선박의 접안예정위치와 배정될 C/C의 수에 따라 정해짐

5.2.3 장치위치 할당

○ 실제 장치계획을 적용할 경우에는 불확실한 변동 요인들이 많아 수시로 재계획을 통해 조정

○ ATC, AGV 그리고 외부트럭의 상호 연계작업을 전제로 장치위치가 할당되므로 장비의 작업할당과 관련이 크고 의사결정 시점에는 이들의 상황을 충분히 고려하는 것이 필요

○ 장치계획에서처럼 장치장의 배치형태나 컨테이너의 종류에 따라 고려요소가 달라지므로 먼저 배치형태에 따라 수평인 경우와 수직인 경우를 구분하고 이를 다시 수출컨테이너와 수입컨테이너로 나누어 각각에 대한 장치위치 전략을 제안

○ 의사결정 문제는 두 가지가 있는데, 하나는 장치베이를 결정하는 것이고 다른 하나는 베이내에서의 적재위치를 결정하는 것임

1) 장치베이결정

○ 적하작업이 보다 신속하게 진행될 수 있도록 되도록 비슷한 특성을 가지는 컨테이너들을 가능한 한 ATC가 이동하지 않고 연속적으로 작업수행이 가능한 장치 공간내에 모아두거나 서로 근접한 영역에 장치

○ 선박별 할당공간의 제약과 예측물량의 불확실성을 고려할 때 수시 변동가능한 방식으로 결정되어야 함. 따라서 제약만족 알고리즘과 같은 유연한 방식을 채택하는 것이 바람직함

2) 베이내에서의 적재위치 결정

○ 지정된 장치베이내의 적재위치 결정과정에 필요한 근거를 제시하고 작업시간에 대한 재취급의 영향을 분석

3) 수평배치의 수출컨테이너

○ 장치공간계획의 결과를 반영한 스택(stack) 중심의 장치위치 결정이 고려됨

4) 수평배치의 수입컨테이너

○ C/C별로 선점 베이(primary bay)를 결정하고 특정 C/C에서 내려오는 컨테이너는 해당 선점 베이에 계속하여 장치하는 방법을 쓰며, 만일 선점 베이가 다 찬 경우에는 다음 선점 베이를 선택하는 식의 실시간 위주의 운영이 적합

5) 수직배치의 수출컨테이너

○ 접안예정선박의 접안위치와 배정예정 C/C의 수를 근거로 장치 블럭 수와 블럭의 범위를 결정

○ 반입 컨테이너는 이들 중에서 가능한 한 균등하게 분포되도록 장치 블럭을 선정함으로써 저장공간과 장비의 부하를 균등하게 배분

○ 블럭내에서의 베이결정은 DOS(duration-of-stay)에 근거한 공유저장 정책의 적용이 바람직함

6) 수직배치의 수입컨테이너

○ 작업의 신속성이 가장 중요한 기준임. 대상 블록들 중에서 현재까지 지시된 작업부하가 가장 적으면서 동일 선박에서 양하된 컨테이너의 개수가 어느 한계를 넘어서지 않은 블록을 지정함

○ 장치위치는 반출작업이 용이하도록 선석의 반대쪽 지역에 가능한 한 장치하되 재취급 작업을 고려하여 동일 베이에는 많은 컨테이너를 양하하도록 하는 것이 유리함

○ 양하컨테이너와 적하컨테이너는 서로 다른 베이에 장치함. 이는 재취급을 대비하기 위한 것임. 타 선박에서 양하된 컨테이너와는 동일한 스택에 장치되지 않도록 하는 것이 재취급의 가능성을 줄임

○ 일정한 기간이 지난 양하컨테이너가 장치될 베이에는 컨테이너의 단수가 낮아져 있기 때문에 한가한 시간을 이용하여 정리작업을 수행

7) 완충영역 장치장

○ 자동화 하역장비와 외부트럭의 직접적인 작업을 방지함으로써 내부 자동화영역의 독립성을 확보하기 위한 전략

○ 반입작업과 반출작업을 구분하여 장치방안과 취급장비의 운영을 다루었음

○ 일정시점 이후에 실시되는 이적작업을 위한 작업계획 수립방안과 효과를 다루었음

5.3 터미널 로지스틱스

○ ACT의 각 영역(안벽영역, 야드영역, 철송영역, 서비스영역, 게이트 영역)에서 필요한 시설들을 점검하여 터미널 운영 및 물류체계의 기본계획을 수립

○ ACT의 로지스틱스와 기존 터미널의 로지스틱스를 비교하였을 때 터미널의 일반적 기능과 운영과정은 큰 차이가 없음. 다만, 자동화 장비의 운영에 따라 반출입 차량을 위한 버퍼야드, 하역장비와

이송장비의 전송지점 등의 추가설비와 처리과정이 요구됨

○ 장치장 배치형태별로 장비구성, 특성 등을 분석하였고 장비조합별로 장단점을 제시함으로써 ACT의 설계 및 운영을 위한 기본자료를 제공

○ ACT에 적용할 수 있는 취급장비의 종류 및 특성과 적용사례를 조사하였고 장치장 배치형태별로 구성장비 선정시 고려요소와 작업 흐름을 분석·제시

6. 자동화 컨테이너터미널 설계를 위한 시뮬레이션 분석

6.1 안벽용량 및 소요장치량 분석

1) 안벽용량 분석

○ 분석의 주요 목적
- 안벽길이 1,050m일 때의 안벽물동량 검토
- 시나리오별 C/C 소요대수, 안벽점유율 산정
- 안벽물동량에 따라 컨테이너 장치장 소요규모 결정

○ 분석내용
- 안벽물동량에 대한 LPC(lifts per call)의 영향
- 효율적 운영을 위한 소요 안벽크레인의 수 추정
- 안벽점유율
- 저장 가능한 소요장치장 비교

○ 시뮬레이션 수용여부 판단기준
- norm-time 초과비율 5% 이내
- 선박대기 척수비율 1% 이내

- 피크시 선석점유율이 99%까지 최대 접근 때의 능력을 기준

○ 분석결과 1,050m 안벽에서 서비스 수준을 만족할 수 있는 대안은 연간 135만TEU를 처리하고, C/C는 11대를 투입하는 것이 적정한 것으로 실험되었음

2) 최대장치 소요량 분석

○ 야드장치장에서의 Ground Slots 수로 표시되는 최대 소요장치량은 TEU로 표시된 최대 소요장치량을 최대장치 높이로 나눔으로써 산출

○ 최대 장치재고량은 시뮬레이션 결과 14,802VAN으로 나타났으며 이를 화물종류별로 나누고 재유통 컨테이너를 포함시켜 소요TGS를 구한 결과 총 9,565TGS로 산출

6.2 터미널 시뮬레이션 분석

1) 야드블록 분석

○ Section수를 2개로 할 경우 한 블록의 길이가 500m정도로 길어지기 때문에 ATC의 작업 cycletime이 길어지고 AGV 대기에 따라 C/C생산성을 적절히 뒷받침해 주지 못하는 것으로 분석

○ C/C당 AGV 대수에 관계없이 Section 3 배치가 Section 4 배치에 비해 C/C 생산성이 높음. 이와 같은 결과는 Section 수가 4개로 늘어나면서 AGV의 평균 cycle time이 증가된 데 기인하는 것으로 판단

○ 한편 블록열수 분석결과는 C/C당 AGV 대수가 5대, 6대, 7대인 경우 모두 C/C생산성은 9열 및 12열에 비해 15열 시나리오가 가장 우수한 것으로 나타났음

2) 배치 레이아웃 대안별 설계

○ 안벽능력 및 소요장치량 분석(capacity analysis)과 야드재고량 분석, 블록분석을 통한 자료를 기초로 자동화터미널 평면배치를 수직배치 레이아웃과 수평배치 레이아웃으로 나누어 총 네 가지의 대안을 설계

○ 평면배치 대안별 장비구성, 블록, 주행, 운영시스템, 장비운영, Logistics 비교분석

○ 수평배치 대안의 경우 AGV의 Navigation이 복잡하고 외부트럭과의 교차를 방지하기 위해 고가도로나 버퍼구역을 설치해야 할 뿐만 아니라, 외부트럭과 자동화 야드장비와의 연계를 위한 정밀 통제방식이 요구됨

○ 수직배치 대안은 ECT나 CTA에서 이미 사용 또는 계획중인 것으로 AGV Navigation의 기술적 신뢰성이 높은 대안이나, 자동화 야드장비(ATC)가 AGV 대신 고속 이동을 해야하는 단점을 갖고 있음

3) 소요장비 분석

○ 수직배치와 수평배치안 모두 새로운 개념의 자동화시스템이므로 생산성 수준과 소요장비 수준을 판단하기 어려움. 따라서 생산성에 큰 영향을 미치는 ATC의 작업 cycle time을 본선작업과 반출입작업 발생을 통해 분포 추정

○ C/C의 요구생산성을 만족하는 AGV-ATC 소요대수 추정 시뮬레이션 수행

○ 분석결과 각 대안별로 모델에서 요구하는 생산성을 낼 수 있는 이송장비 및 야드장비의 조합을 실험

6.3 Gate Simulation

○ 분석목적
- 반출입 게이트 레인 수 결정
- 야드내 게이트 통과트럭 대기영역 규모 산정

○ 주요 분석내용
- 게이트 진입시 대기트럭 Queue 길이 분석
- 야드내 대기트럭 Queue 길이 분석
- 외부트럭 turn-around time 분석

○ 분석결과 외부트럭의 게이트 밖, 그리고 야드내 대기 수를 최소화하는 게이트 레인 수를 제시하였고, 또한 평면배치 대안별로 외부트럭 turn-around time은 20분 이내였음

7. 자동화터미널 경제적 타당성 분석

○ 5만톤급 컨테이너선 4선석을 재래식으로 건설할 경우 토목비 및 운영설비(장비 등) 등 상부시설비가 6,179억원이 소요되나, 자동화로 건설할 경우 총 6,546억원이 추가 소요되어 전체 공사비의 약 6.2% 정도가 더 드는 것으로 나타남

○ 특히 장비비는 재래식에 비해 자동화터미널의 경우 약 14% 정도 더 투자되는 것으로 산정

○ 그러나 자동화터미널의 경우 연간 인건비가 재래식 터미널에 비해 46% 수준에 불과해 연간 약 214억원 정도 인건비 절감효과가 발생

○ 연간 운영비 전체로는 자동화 방식이 약 564억원으로 재래식의 758억원에 비해 약 25% 정도 절감

○ 재래식과 자동화터미널의 연간 비용을 현재가치로 환산하여 누적시켜갈 때 터미널 개장 이후 11년부터는 자동화터미널 비용이 재래식 터미널 비용보다 낮아지게 됨

8. 결 론

○ 본 연구는 자동화 컨테이너터미널의 운영통제 방식, 평면배치 레이아웃, 시설규모 및 소요장비, 동선배치 방법을 연구하여 현재 광양항에 개발토록 계획되어 있는 국내 최초의 자동화터미널의 운영전략 구축 및 레이아웃 실시설계에 필요한 운영로직 및 이론적 배경을 제공하고, 제시한 안들에 대해 항만 전용시뮬레이션 모델로 모의실험을 수행하여 실제 의사결정에 도움이 될 수 있는 정보를 제시하고자 하였음

○ Part Ⅰ에서는 우선 자동화 컨테이너터미널의 개발 필요성을 초대형 컨테이너선의 출현에 대비한 터미널의 생산성 수준향상이라는 목표를 통해 분석하였음. 또한 세계 자동화 컨테이너터미널 개발 추세를 분석하여 이들의 사례로부터 성공한 부분과 실패한 부분을 검토하여 우리의 자동화터미널 개발에 벤치마킹 할 수 있는 점을 도출하였음

○ 또한 터미널의 자동화에 관련된 야드장비, 이동장비, 게이트, 정보통신, 각 세부 자동화기술의 동향과 장단점을 분석하여 우리의 자동화터미널에 적용할 자동화시스템을 제시하였음

○ PartⅡ에서는 자동화 컨테이너터미널의 배치에 따른 운영로직과 통제방식을 제시하고 이를 대안별 모의실험을 통해 실증분석 하였음

○ 이 중에서 수평배열의 경우 자동화 야드크레인(ATC)의 배분 및 AGV의 배차로직, 수직배열의 경우 수출입화물별 장치베이 등 위치

할당규칙, 그리고 자동화터미널의 화물흐름(로지스틱스)제시 및 버퍼블록 운영방식 등이 주요한 연구 내용임

○ 자동화 컨테이너터미널 설계를 위한 시뮬레이션 분석을 안벽용량 및 소요장치량 분석(capacity analysis), 야드 시뮬레이션 및 소요장비 분석(terminal simulation anclysis), 게이트 분석(gate simulation)으로 수행하였음

○ 실험결과 수평배열과 수직배열의 4가지 설계대안별로 생산성(C/C생산성, AGV waiting time) 및 서비스 수준(선박 대기시간비율, 외부트럭 turn-aroundtime)을 만족시키는 장비조합 및 운영방식을 제시하였음

○ 이상과 같이하여 자동화 컨테이너터미널의 생산성은 총 작업시간당 생산성으로 재래식터미널에 비해 34% 향상되고(22.4 lifts/hr → 30 lifts/hr), 부산항의 재래식 터미널 피크시 처리 물동량과 비슷한 수준인 선석당 45만TEU를 처리할 수 있는 가능한 시스템을 설계하였음

○ 또한 동북아 Hub 항만의 기능을 수행할 수 있도록 기존 터미널에 비해 서비스 수준을 향상시킨 시스템을 설계하였음. 즉 선박 대기비율을 기존 5%에서 1%로, 그리고 외부트럭의 야드내 체류시간을 기존의 30분에서 20여 분으로 단축시킨 시스템을 제시하였음

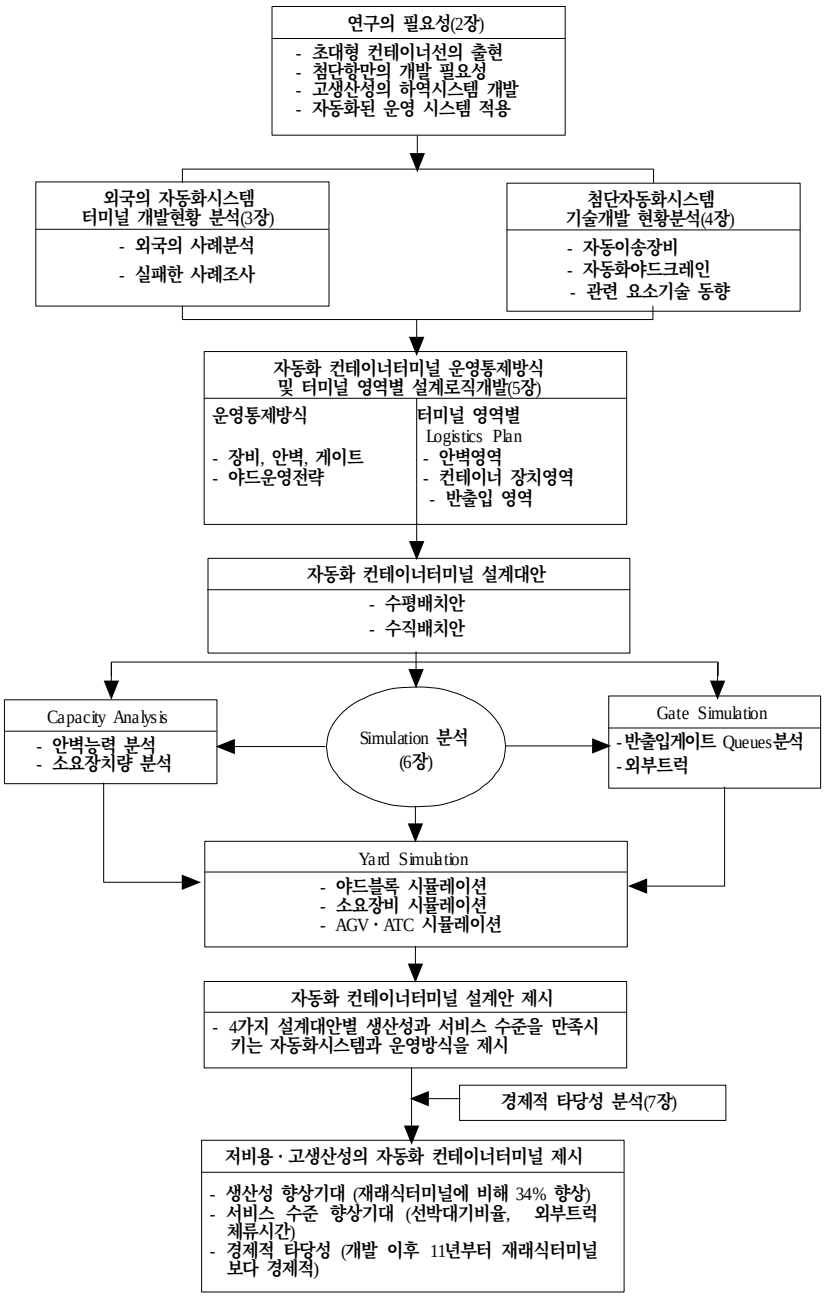
○ 마지막으로 기존 재래식 컨테이너터미널에 비해 자동화터미널의 건설이 경제적으로 타당한지 여부를 분석하였음. 분석결과 초기 투자비는 자동화터미널이 약 6%정도 더 소요되나 연간 운영비면에서 인건비 절감 등의 요인으로 약 25% 정도 절감되어 누적 현재가치로 환산할 경우 개장 이후 11년부터는 자동화터미널의 비용이 재래식 터미널에 비해 낮아지는 것으로 나타났음

○ 컨테이너선박의 초대형화가 해운에서의 추세라면 항만에서는 이를

뒷받침 해줄 수 있는 생산성 높은 터미널의 건설이 불가피한 추세이다. 첨단기술의 자동화 컨테이너터미널이 인력을 절감하고, 토지활용도를 높일 수 있다는 알려진 효과 이외에도 고생산성 터미널이 가장 현실적인 대안으로 연구되고 건설되고 있는 것도 이 같은 흐름 때문이다.

- 본 연구가 우리나라 자동화 컨테이너터미널 건설에 도움이 되고 나아가 향후 건설될 외국의 자동화터미널 연구 및 설계에도 일조를 했으면 하는 바램이다

연구흐름도


연구의 필요성(2장)
- 초대형 컨테이너선의 출현
- 첨단항만의 개발 필요성
- 고생산성의 하역시스템 개발
- 자동화된 운영 시스템 적용
외국의 자동화시스템 터미널 개발현황 분석(3장)
- 외국의 사례분석
- 실패한 사례조사
첨단자동화시스템 기술개발 현황분석(4장)
- 자동이송장비
- 자동화야드크레인
- 관련 요소기술 동향
자동화 컨테이너터미널 운영통제방식 및 터미널 영역별 설계로직개발(5장)
운영통제방식
- 장비, 안벽, 게이트
- 야드운영전략
터미널 영역별 Logistics Plan
- 안벽영역
- 컨테이너 장치영역
- 반출입 영역
자동화 컨테이너터미널 설계대안
- 수평배치안
- 수직배치안
Capacity Analysis
- 안벽능력 분석
- 소요장치량 분석
Simulation 분석 (6장)
Gate Simulation
- 반출입게이트 Queues분석
- 외부트럭
Yard Simulation
- 야드블록 시뮬레이션
- 소요장비 시뮬레이션
- AGV · ATC 시뮬레이션
자동화 컨테이너터미널 설계안 제시
- 4가지 설계대안별 생산성과 서비스 수준을 만족시키는 자동화시스템과 운영방식을 제시
경제적 타당성 분석(7장)
저비용 · 고생산성의 자동화 컨테이너터미널 제시
- 생산성 향상기대 (재래식터미널에 비해 34% 향상)
- 서비스 수준 향상기대 (선박대기비율, 외부트럭 체류시간)
- 경제적 타당성 (개발 이후 11년부터 재래식터미널 보다 경제적)

머 리 말

세계 항만운영사와 하역장비 제작사들의 회합인 TOC의 최근 2 3년간 회의에서 대부분의 참석자들은 향후 10년내 항만에서 발생할 가장 중요한 변화 중의 하나로 초대형 컨테이너선의 출현에 대비해 신속한 양적하 작업을 할 수 있는 새로운 개념의 컨테이너터미널 개발을 꼽고 있다.

그리고 향후 10년 동안은 세계 항만산업에서 초대형 컨테이너선 출범에 대비한 새로운 터미널 개발(Port Infrastructure)과 고생산성의 항만하역 장비 및 시스템(Cargo Handling Port Facilities) 기술개발이 급진전되는 시기가 될 것으로 예측하고 있다.

또한 동 회의 참석자들은 대부분 컨테이너항만의 생산성 향상과 함께 인건비 절감 및 터미널 토지 활용성 제고를 통한 컨테이너항만의 경쟁력 강화를 위해 자동화 컨테이너터미널 건설을 한 대안으로 제시하고 있다.

우리나라에서도 동북아 물류거점 항만의 위상을 높이고 인근 항만과의 경쟁력 우위를 확보하기 위해 광양항에 자동화 컨테이너터미널을 건설하기로 하고 기본계획을 수립 및 설계중에 있으며, 관련 핵심기술도 개발하고 있다.

본 연구는 자동화 컨테이너터미널의 설계 가능한 대안을 제시하고, 대안별로 각각의 시설규모 및 소요장비, 동선배치 방법을 연구하여 자동화 컨테이너터미널 설계시 의사결정에 도움이 될 수 있는 이론적 배경을 제시함을 주목적으로 한다. 특히 항만에 새로운 하역시스템을 적용할 경우에는 실제 건설 이전에 시스템의 특성을 흡사하게 구현하여 시설규모와 소요장비, 생산성을 실험하는 시뮬레이션 과정이 필수적이다.

본 연구에서는 자체 개발한 항만 전용시뮬레이션 모델을 이용하여 자동화터미널의 설계 대안으로 시설규모 모의실험(Capacity Simulation Analysis), 야드시스템 모의실험(Yard Simulation Analysis), 게이트 모의실험(Gate Simulation Analysis)을 수행하였다.

또한 세계적으로 아직 깊이 있는 연구가 이루어지고 있지 않은 자동화 컨테이너터미널의 운영로직을 자원할당, 야드적치 전략으로 나누어 제시하였고, 터미널내 물류흐름을 설계 대안별로 제시하였다. 이와 같이 하여 생산성이 높고, 경제적으로 타당성이 있는 자동화 컨테이너터미널 설계 대안을 제시하였고, 이러

한 설계 대안이나 운영로직이 실제 자동화 컨테이너터미널을 건설하려는 국내외 터미널에 활용될 수 있도록 제시하였다.

앞으로 본 연구가 자동화 컨테이너터미널의 설계나 운영로직에 대한 향후 연구 및 토론을 위한 초석으로 활용되기를 기대한다.

본 연구보고서는 본원의 양창호 항만시스템연구실장이 연구책임을 맡고, 같은 실의 김영훈 책임연구원, 배종욱 책임연구원, 최상희 연구원, 이정은 연구원이 공동으로 집필하였다. 자동화 컨테이너터미널 운영로직에 대해서 부산대학교 김갑환 교수의 도움을 크게 받았다. 연구 심의회를 통해 좋은 지적과 조언을 주신 서울산업대의 장성용 교수, 한국해양대의 남기찬 교수, 그리고 본원의 임진수 기획조정실장에게도 심심한 감사를 드린다. 영문보고서를 꼼꼼히 읽고 고쳐준 Mr. Zemba에게도 감사 드리며, 이 밖에 연구수행에 도움을 준 김현정씨에게도 감사 드린다.

끝으로 본 보고서의 내용은 전적으로 필자들 개인의 연구의견이며, 한국해양수산개발원의 공식적인 견해가 아님을 밝혀둔다.

2000년 12월

韓國海洋水産開發院
院 長 李 廷 旭

PART I
Development of the Automated Container Terminal System

1. Introduction
2. VLCS and Productivity Requirements
3. Automated Container Terminal System
4. The Handling Technology of ACT

1. Introduction

1.1 Research Background and Objectives

With the beginning of the new millennium developments in containerization will certainly continue. Globalized production and demands of consumers and the continuing increase in population are causing a continuous growth in container transportation.

The expansion in containerization has resulted in a larger vessel (Very Large Container Ship : VLCS) up to 8,000 TEU, and a worldwide network of high capacity container terminals. The economy of scales has caused a tremendous price decline in maritime transportation and also container terminals are exposed to a continuous demand for better service and larger volumes to be handled at lower cost.

The tendency to increase in size of containerships in major trunk lines has been remarkable during 1990s. Containerships having over 8,000 TEU capacity have appeared already. Furthermore, as the fixed day weekly services have been usual practice for most container trades, the hours to berth at calling ports for respective ships have to be strictly kept in order to maintain ships' schedules. Consequently, the quantity of containers to be handled (LPC : Lifts Per Call) at container terminals per hour will be remarkably increased in proportion to increased capacity of ships, as the allowable hours to handle these containers at the terminals will not be increased but decreased in future.

The professors of Delft University studied the concept of an very large container ship such as 12,000 TEU(suez-max) and 18,000 TEU(malacca-max) container vessel.[1)]

---

1) Niko Wijnolst, Marco Scholtene, Frane Waals, *Malacca-max*, Delft university press, 1999.

Ocean Shipping Consultants reported recently 12,000 TEU vessel will be launched in a decade.[2)]

At the side of the container port operator, better cost control and higher productivity and improved service levels focused on the following topics are necessary.

- To more highly utilize the terminal area
- To handle containers efficiently
- To save man-power efficiently
- To perform automated operation thoroughly

The stevedoring business including container-handling is considered to be labour-intensive industry, in principle. Accordingly, labour cost which is estimated to rise sharply by the increment of containers handled in future, will surely occupy the greater parts of container-handling cost than others. This is the biggest motive that automated container terminals should be studied and developed by all the staffs in the world of container business. By saving workers in the yard due automated handling equipment, reasonable container-handling cost will be attained in the 21st century.

Futhermore, automated container terminals will be also expected to resolve a severe problem of a shortage of workers in container terminals especially in industrialized countries in the 21st century.

Europe Combined Terminals (ECT) in the port of Rotterdam decided to go ahead with the development of automated container terminal in 1988. Their choice fell on the automated terminal shows the investment costs of an ACT are 10 15% higher, but the savings achieved are far greater. Not only do these savings consist of direct labor costs, but also training costs.[3)]

Together with the upgrading of container crane capacities, the increasing

---

2) Ocean Shipping Consultants, *North European Containerization,* 2000. 8.
3) "Rotterdam's Automated Container Terminals", *Engineers,* 1998. 8.

size of container ships requires an improvement of the ground handling and distribution systems. An increase of the efficiency of those systems is mandatory to achieve further reduction of terminal operating costs on the one hand and to ensure sufficiently short lay time for the ships in port on the other.

Research and development is focusing on the aspects of efficient container stacking, terminal transportation and control technology. Automated transportation systems have already been introduced successfully to some advanced ports, such as ECT and PSA.

Container terminals will also face severe problems on the initial investment in the 21st century. As a very large area along the shore lines will be required for container terminals, generally speaking, it will be very difficult to find suitable site for many Asian countries, including Korea, to construct new terminals in coastal zones over the world. As a result, the construction costs of container terminals will increase greatly due to big reclamation work of land in deep sea areas or due to deep dredging work in areas of shallow sea bottom. Therefore, container terminals in the future should be designed to perform high utilization of land area. High stacking of containers in a terminal brings high utilization of land area, but sometimes this invites difficulty by disregarding the selectivity of respective containers.

In conclusion, the automated at a container terminals based on the strong motive to keep the container-handling cost at a competitive level, have to perform efficient operations of container-handling and high utilization of land area by saving workers in order to cope with the above-mentioned situations in the 21st century.

The main objective of this research is to review the system design and operations of automated container terminal in our study, particular emphasis

has been put on the operational control logics and yard layouts of automated container terminal.

The quay and yard operation are important activities of all terminal operations, since it has a considerable influence on the performance of the automated container terminal.

In terms of operational control of ACT, several other topics to be examined in this research are: resource allocation and yard storage policy, and terminal logistic of new concept of ACT compared with conventional ones. And using a simulation model owned by KMI, yard layouts of ACT are to be examined including capacity analysis.

Finally, a feasibility study has to be performed between ACT and the conventional container terminal.

1.2 Research Scope and Methodology

This research consists of 2 parts. The first part describes the development of Automated Container Terminal systems and technologies. The second part analyses the operational control and layout design of the Automated Container Terminal.

The first part consists of 4 chapters describing the elaboration of the various subjects. Chapter 2 deals with the trend of jumbo container ships. It contains a lay time and required productivity level when the next generation of ships comes into the terminal, analyses technical solutions including container crane, yard operation, terminal operating system. Based on historical data of Pusan container ports, lifts per call and productivity required level are predicted by regression method.

Chapter 3 summaries the development of the automated container terminal system and ACT under operation and construction around the world including ECT, PSA, Thamesport, CTA. Based on the details of previous experience

of ACT, it is concluded with a comparison of the systems and lessons.

Chapter 4 deals with the handling technologies of automated container terminals around the world. First, container crane requirements are outlined and usage trend and technology of Dual Hoist C/C are given. Second, automated yard crane and automated guided vehicles(AGV) technology trends are described. Third, automated terminal operation system which is an important element to the higher performance of the ACT is also included.

The second part of this research mainly focuses on the study of the new way of operational control of ACT. Of the analyses, a number of issues including ACT layout design alternatives, capacity analysis, productivity and performance are evaluated.

Chapter 5 analyses the required operational control logics of ACT. The main subsystems of the operational control logics are : resources allocation, yard storage policy, terminal logistics.

Chapter 6 deals with the planning and basic design of automated container terminal with 1,050m quay length(3-berths). This chapter contains sections on various simulation results. First, the result of the simulation of capacity analysis is presented. With the result of capacity analysis we proposed several types of ACT layout designs. Based on these layout alternatives terminal simulation and gate simulation are performed to get the equipments needed, routing system, gate facilities needed, etc. A tool for the simulation is a set of simulation models developed by KMI.

Chapter 7 presents the feasibility study of ACT. The main aim of the study is to provide detailed investment and the operational costs of the proposed ACT system in this research with the conventional container terminal.

2. VLCS and Productivity Requirements[4)]

2.1 Background

Economics of scale plays an important role in container shipping. This was evident from the developments in container shipping from the beginning. The tendency towards large ships has accelerated in recent years and can be observed with intercontinental liner vessels as well as feeder vessels. In particular, as business operations get more and more globalized, reducing costs of transporting raw materials, parts, finished goods have become one of key factors of corporate competitiveness. To meet such shippers' demand for reducing shipping freight cost, large shipping companies are not only developing strategic alliances with each other to promote shipping efficiency but also launching jumbo ships to have competitive superiority to others in the international shipping market.

Accordingly, it is natural to seek for improving operations of container terminals for promoting more efficient transportation at more competitive cost. Operations of container terminals are influenced by not only communications technology and information systems but also basic technologies of transportation, equipment handling, system application, etc. Development of automated loading/unloading systems at container terminals is implemented as a part of efforts to improve productivity in operating the terminals, aiming at development of advanced terminals escaping from conventional terminals.

---

4) This chapter is based on the next material. Chang-Ho Yang, "Examining the Impact of Next Generation Ships on Terminal Operations and How Terminals Are Adapting Quayside Operations to Service to Serve the Vessels", *Developments in Container Handling Automation & Technologies*, IIR, Feb. 2000.

The impact of next generation ships, very large container ship(VLCS) on terminal operations is reviewed, and how terminals are adapting operations to service the vessels are examined. So jumbo vessel's lay time and required productivity level are examined by using the Pusan container terminal historical data. Some alternatives to service the jumbo vessel in terms of automated equipments and operation are suggested.

- What lay time would be?
- Assessing the productivity levels
- Shipping line's preference
- Examining technical solutions

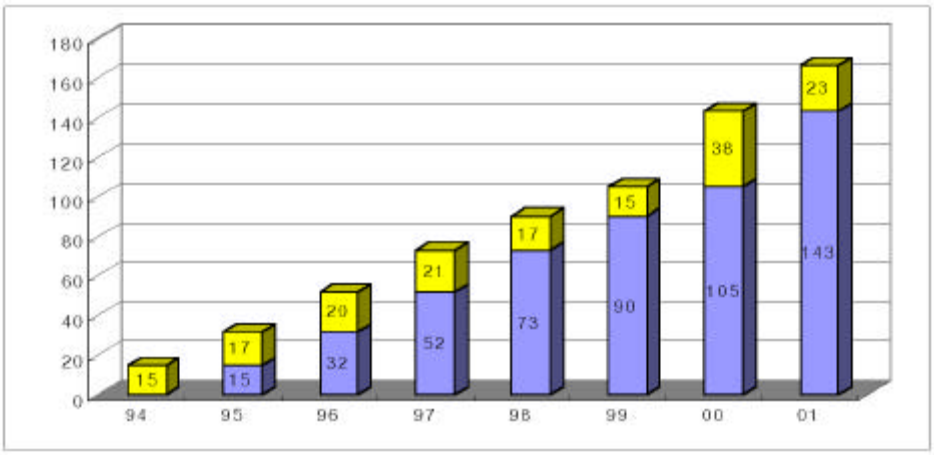
2.2 Increasing Ship Size

Post-Panamax Ships today have developed to a capacity of 8,000TEU and ships with 12,000TEU are on the drawing board. This tendency towards more and larger ships is supported by a continuing healthy growth of container volume practically on all major trade routes of the world. This is expected to continue despite any potential of asian economic disturbances.

Until now, about 170 Post-panamax vessels are put into the market or being ordered, and these are ordered by series vessel of 5-6 ships to be put on the transpacific trade, far east/europe trade, and transatlantic trade. The seaborne trade volume of the Transpacific Trade, Far East/Europe Trade, and Transatlantic Trade have been increased by 6.5% 7.5% on the average during last 20 years. For this reason, shipping lines increased the number of vessels or constructed larger vessels to accomodate increased tonnage. But with effectuation of U.S Shipping Act of 1984, the collapse of monopoly and oligopoly of the liner conference affected tariffs in competition and therefore, the tariff of deep sea trade has been fallen. Consequently liner

shipping companies started to make bigger vessels to prepare for increase of throughput and to get price competitiveness. If this situation doesn't change for the time being, the enlargement of vessels will be continued.

<Figure 2-1> Post Panamax Containership



Most of newly built container vessels which are put on the major trade can load over of 5,000 or 6,000TEU. Major liners have planned to put on 36 ships within this year, and after the year of 2001, 55 ships.

In the case of Global Alliance, OOCL and P&O, they put 12 ships of 5,500TEU and 1 ship of 6,800TEU on transpacific trade. They have plan of putting another 5 jumbo ships after the year of 2001. Totally 18 ships of 104,200TEU vessel will be put on.

By merging in the latter half of 1999, Maersk-SeaLand have created the world largest liner company. Maersk-SeaLand have plans to put 4 ships of 6,200TEU and 3 ships of 7,100TEU in 2000, 1 ship of 6,200TEU in 2001; totally 8 ships of super-sized newly built vessels. Evergreen of Taiwan shipping line have plan to put totally 7 ships of super-sized newly built vessels.

<Table 2-1> Above 6,000TEU Containerships on Float

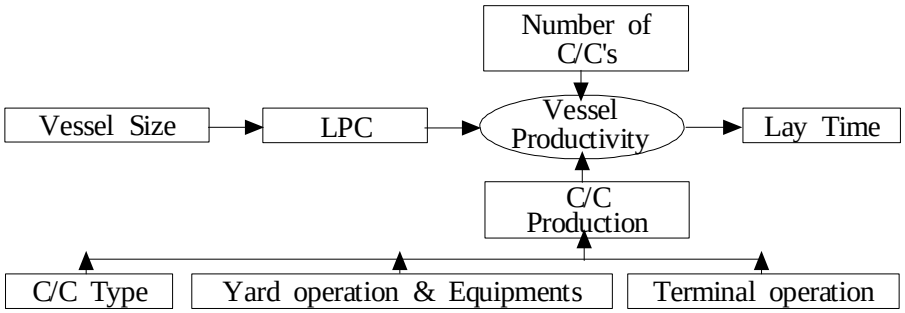
	2000		2001	
	TEU	Vessels	TEU	Vessels
OOCL, P&O Nedlloyd	6,800	1	6,800	3
Hyundai Merchant Marine			6,400	5
Maersk-SeaLand	7,100	3	6,200	1
	6,200	4		
CMA CCM			6,500	8
Evergrren			6,000	5
Total		8		22

Ten years after 3,000TEU vessels appeared, during the period of 1972 1984, 4,000TEU vessels appeared, and after another 10 years(1984 1995) 5,000TEU vessels appeared. With this trend, 10 years after the year of 1988, when 6,000TEU vessel appeared, building vessels of 6,000 8,000TEU were generalized, and before and after the year of 2010, 12,000 15,000TEU vessel may be built.

2.3 Required Terminal Productivity Change

To guess the laytime of jumbo container vessel, we have to look at the lifts per call(LPC) and vessel production of every vessel size. Next chart shows the breakdowns of factors that influence lay time. C/C production depends on the C/C types, yard operation methods, and terminal operation system.

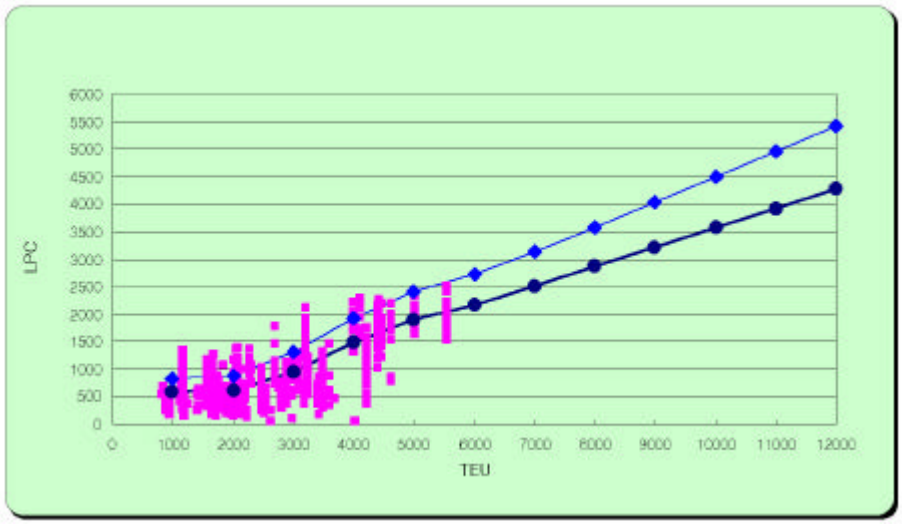
<Figure 2-2> Factors Influencing Lay Time



Using data of Pusan container terminal, lay time and required level of quay crane productivity have been forecasted to service the jumbo vessel in time.

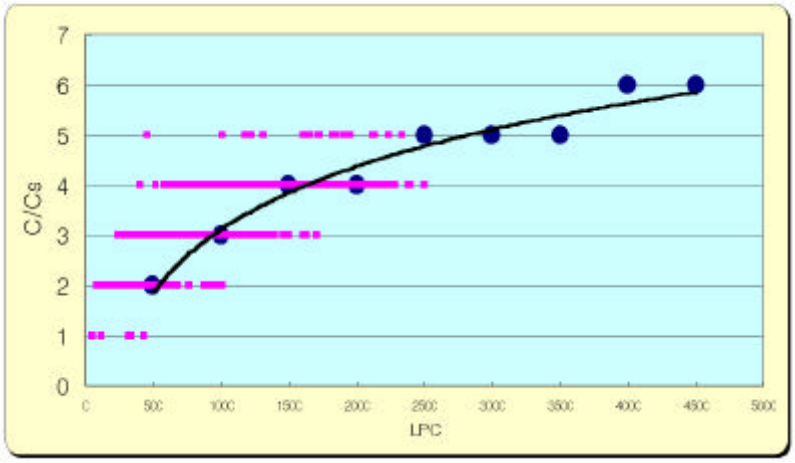
The next chart shows the relation between vessel size in TEU and lifts per call. Plotting are actual one, and the extension lines show regression results from the actual result. The below line is average LPC by vessel size. And upper line is maximum LPC by vessel size with 95% confidence interval. It means 3,600 lifts per 8,000 TEU vessel, and 5,500 lifts per 12,000 TEU vessel.

<Figure 2-3> LPC by Vessel Size



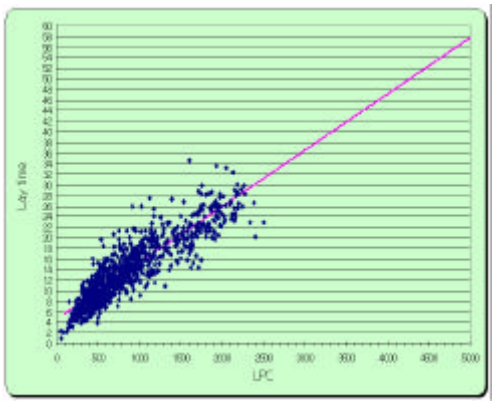
The next chart shows the number of C/Cs used in stevedoring by vessel size, indicated by LPC. The plotting points are the actual result, and the curve tells the trend with extension to 5,000 LPC. In this case, we may presume that about 5 C/Cs can be assigned to 8,000 TEU vessel of 3,600 LPC, and about 6 C/Cs to 12,000TEU vessel of 5,500 LPC.

<Figure 2-4> Number of C/Cs by LPC



This chart is the lay time plotting; total terminal time with vessel size indicated by LPC in Pusan Port from January to December, 1999. The regression result is shown with linear line from this chart. In this case, with the current facilities and operating system, total terminal lay time should be 43 hours with 8,000 TEU vessel of 3,600 LPC and 63 hours with 12,000 TEU vessel of 5,500 LPC. Unfortunately, when jumbo vessels arrive, this level of lay time will not be permitted by shipowner.

<Figure 2-5> Lay Time by LPC



Vessel production can be calculated by dividing LPC per vessel size into lay time, and C/C production by dividing vessel production into the number of C/Cs.

In the case of Pusan Port, the lay time of 5,000 TEU vessel is about 30 hours. From the above formula, the result of vessel production is about 80 lifts per hour and C/C production is about 20 lifts per vessel.

<Table 2-2> Actual Vessel Production

Vessel Size(TEU)	Lifts per Call(LPC)	Number of C/Cs	Lay Time (hour)	Vessel Production	C/C Production
1,000	800	3	13.1	61.1	20.4
	574	3	11.4	50.4	16.8
2,000	870	3	13.8	63.0	21.0
	606	3	11.6	52.2	17.0
3,000	1,300	4	18.4	70.7	17.7
	936	3	13.9	67.3	22.4
4,000	1,900	4	24.8	76.6	19.2
	1,470	4	19.3	76.2	19.0
5,000	2,400	4	30.1	79.7	19.9
	1,905	4	24.9	76.5	19.1

<Table 2-3> shows the presumed result of vessel production per jumbo vessel size with over 6,000 TEU affected on the relation between vessel size and LPC, LPC and the number of C/Cs, and LPC and Lay time.

Referring to the current data of Pusan Port, it can be predicted that with the arrival of an 8,000 TEU the lay time is 43 hours and with 12,000 TEU vessel, the lay time could be 63 hours, and the number of C/Cs assigned to are 5 and 6 for each case.

<Table 2-3> Vessel Production Required(Estimation)

Vessel Size(TEU)	Lifts per Call(LPG)	Number of C/Cs	Lay Time (hour)	Vessel Production
6,000	2,700	5	33.3	81.1
	2,156	4	27.5	78.4
8,000	3,600	5	42.8	84.1
	2,861	5	35.0	81.7
10,000	4,500	6	52.4	85.9
	3,566	5	42.5	83.9
12,000	5,500	6	63.0	87.3
	4,271	6	50.0	85.4

When this kind of very large container ships(VLCS) arrive with lay time of 24 hours, the required vessel production is to process 150 lifts/hr with 8,000 TEU vessel. In this case the production per C/C per hour should be 30 lifts.

When a vessel of 12,000 TEU arrives, the vessel production should be 230 lifts, C/C production should be 38 lifts. If the stevedoring job can be finished within 30 hours, vessel production should be 180 lifts, productivity per C/C per hour should be 30 lifts.

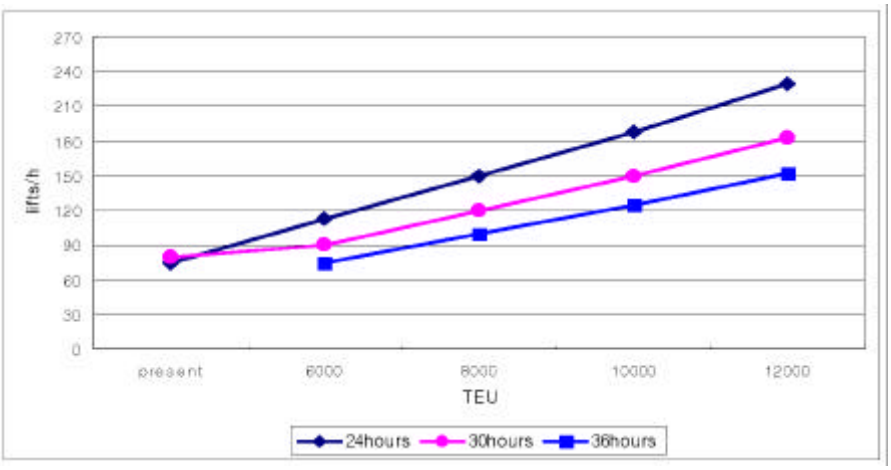
<Table 2-4> Vessel Production Required

Vessel Size(TEU)	24 Hours		30 Hours	
	Vessel P .	C / C P.	Vessel P.	C / C P.
6,000	112.5	22.5	90.0	18.0
	89.8	22.5	71.9	18.0
8,000	150.0	30.0	120.0	24.0
	119.2	23.8	95.4	19.1
10,000	187.5	31.3	150.0	25.0
	148.6	29.7	118.9	23.8
12,000	229.2	38.2	183.3	30.6
	178.0	29.7	142.4	23.7

In the case of an 8,000 TEU vessel, it needs 150 lifts/h productivity level to complete loading and unloading within 24 hours (putting the 5 C/Cs at the same time, C/C production would be 30 lifts/h). In case 12,000 TEU vessel, vessel production should be 183 lifts/h (30 hours)(6 C/Cs at the same time, C/C production would be 30 lifts/h).

Pusan Terminal Case, it needs to increase C/C productivity up to 50%(20 lifts/h → 30 lifts/h)

<Figure 2-6> Pusan Terminal Case



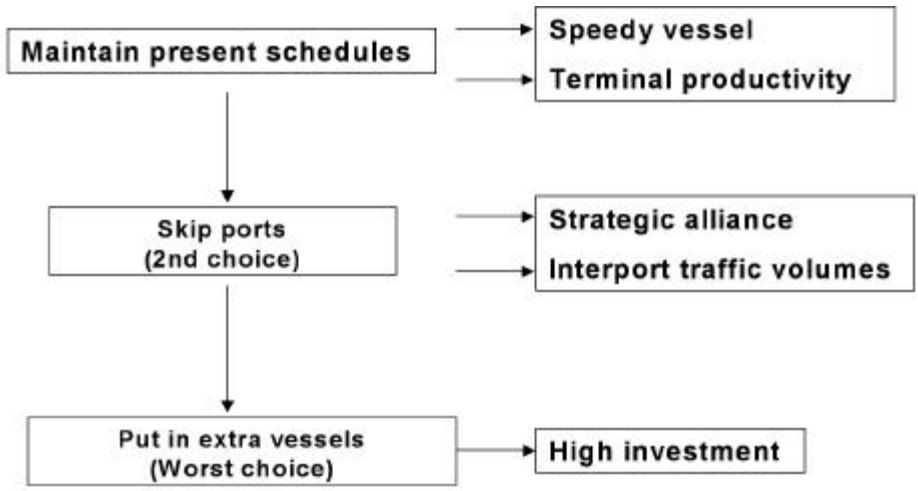
2.4. Shipping Line's Preferences

It is obvious that in the container shipping industry, shipping lines will remain under constant pressure to contain costs from the shipper and from severe competition between liners. This is why liners will increase the supply of jumbo vessels in order to bring the transport cost down per TEU.

However, using jumbo vessels increases lay time. There are several ways to cope with this: building faster vessels, skipping the port which strategic alliance or interport traffic volumes are low. In this case, the port with relatively

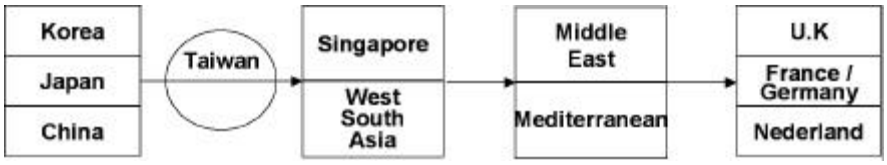
lower throughput would be skipped rather than the port with large throughput, big enough to handle. But putting extra vessels with high investment would be the worst choice.

<Figure 2-7> Shipping Line's Preference



Currently, individual liner companies use 8 ships as a fleet of vessels to service Far East/European trade with 9 11 ports calling. However, when shipping lines are in strategic alliance with each other, each shipping line could be specialized in one region for its market, in the region of origin(for example MOL for Japan, HMM for Korea) and destination area also, and could skip some intermediate port calling. This means a shipping line can reduce port calling to 5-7 in FE/Europe trade.

<Figure 2-8> Far East/ Europe Route



In this case, even the regional ports should be prepared for the arrival of a jumbo vessel because the fleet of container vessels may include at least 1 or 2 ships with the size over 8,000 TEU.

In the case of an 8,000 TEU vessel, outreach of C/C should be over 20 rows, depth over 16.5m. Also the terminal facility should be prepared for the increase of working load of C/C with the increase of hatch cover according to the increase of the width of vessel.

2.5 Can the Required Level of Productivity be Achievable?

Let's look at the case of Pusan Port. What the alternative plan may be to improve the terminal productivity up to 50%?

The ship operation is the most important activity of all the terminal operations, since it has a considerable influence on both the day-to-day performance attained in the container terminal, and the quality of service provided to the shipowner.[5] Thomas[6] pointed out the importance of the ship operation when he stated:

'The ship loading and discharging operation is often referred to as the

---

5) Tao, Chen et al., "Empirical Studies on Yard Operations Part 2 : Quantifying Unproductive Moves Under Taken in Quay Transfer Operations", *Maritime Policy & Management,* Vol.27, No.2, 2000, pp.191 207.

6) Thomas, B. J., *Port Productivity and Costs with Particular Reference to the Handling of Iron and Steel Products*(Ph. D Thesis), University of Wales, 1980.

"Dominant System", since all incoming and outgoing cargo must pass through it, irrespective of the route it takes through the port. So, this very important operation obviously affects the performance of all the other cargo handling activities at the berth'.(p. 238)

At the same time, an efficient ship operation is heavily dependent upon an efficient quay transfer operation.

Improving the efficiency of the quay transfer operations will, therefore, have immediate beneficial effects on the ship's operation performance rates and will enhance the performance of cargo handling procedures.

First of all, what we consider as one of the most important alternatives is adapting a higher capacity quay crane. The C/C with a semi-automatic operation method has been developed as a pilot or designed conceptually already.

However, transport equipment and yard equipment, and yard block planning and layout would be very effective to support C/C productivity. Yard operation method should be developed to support the C/C productivity also.

For the improvement of C/C productivity, terminal operation system should be integrated to control the planning and operation very specifically.

Automatic Container Terminal that is finely planned and operated could be a possible solution to improve terminal productivity.

There are many C/Cs with higher capacity around the world. The semi-automatic operation method C/C which CreaTec Company of Korea developed is described below.

This C/C named as Technotainer is a vertically circulating container crane.

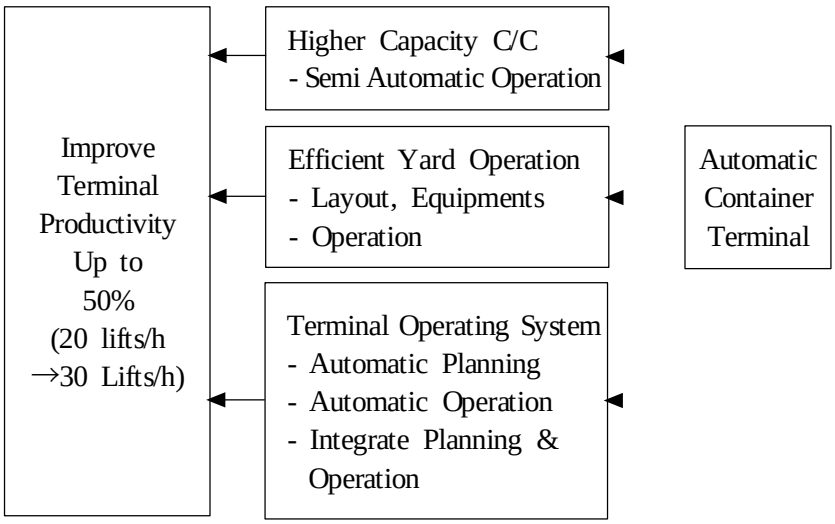
- 2 Hoists, 2 Hooks, 5 Trolleys, 6 Spreaders & 2 Elevators
- Semi-automatic operation
- No-sway, No-pointing Time

- 100 Vans production per hour

• . Maximize the performance with 5 set of trolley/spreader

• . Continuous operation by using 4 tracks simultaneously

<Figure 2-9> Alternatives to Archive Productivity Improvement



<Figure 2-10> Vertically Circulating Container Crane



The boom, composed of two box-type girders, together with the main tower, constitutes the main skeleton of the crane. Four tracks are mounted on the boom for the movement of the trolley, hoist, cable transport and spreader, from bottom to top, respectively. The trolley track at the bottom is for the transport of the container, while the spreader track on top of the boom leads the trolley-spreader unit back to the original loading position, either landside or seaside.

Elevators are installed at each end of the boom for the trolley-spreader unit to change tracks, either from trolley track to spreader track or vice versa.

The hook, spreader and trolley repeat the operations in combination with and in separation from each other in the course of transporting containers.

(1) Trolley + Spreader

This combination is the fundamental unit which returns to the starting position after unloading the container, moving from the seaside boom end to the landside loading position via the spreader track on top of the boom. This combination is secured by four twist locks and four connecting pins.

(2) Spreader + Hook

The container is attached to the spreader, while the hook holding the spreader is wound up or unwound down by the hoist. Thus, the spreader and hook operate as one unit while performing all the up and down movements.

(3) Spreader + Hook + Container

This combination occurs only when lifting the container by the landside hoist and lowering it by the seaside hoist.

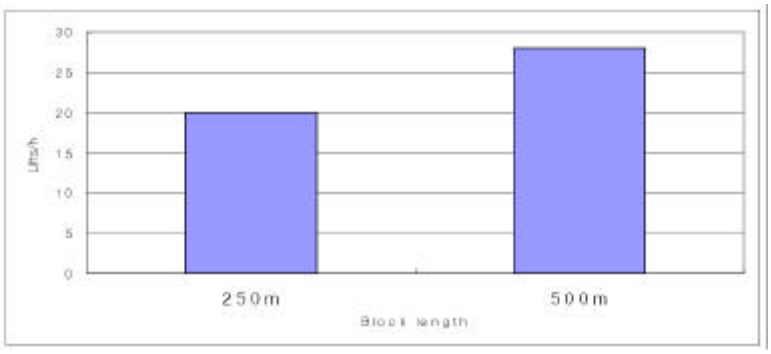
C/C productivity can be improved when combined with efficient yard operation (without delay or bottleneck in yard operation). So factors to improve

C/C productivity have been estimated by simulation model.

The next charts show the analyzed result of how layout and length of yard block affect C/C productivity. The layout that RMG runs are parallel to quay is superior to that of RMG runs perpendicular to quay. This is because gate trucks have their destination behind the runs only with perpendicular layout. As the block length gets longer, the cycle time gets longer and C/C productivity drops down. Therefore, we have to find adequate block length to serve C/C.

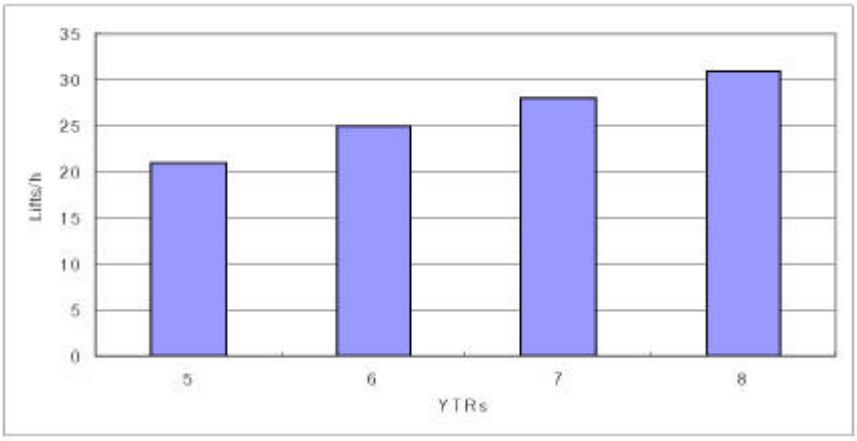


<Figure 2-12> Impact of Block Length

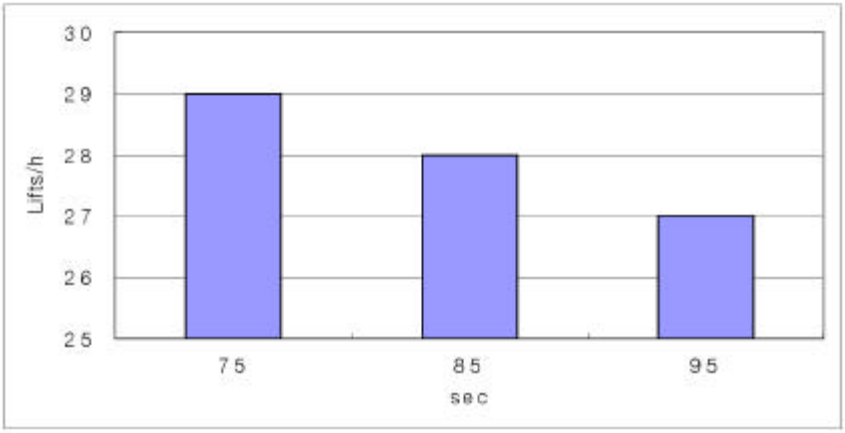


As the number of yard trailers increases, C/C productivities are improved. However, if we increase the number of yard trailers per C/C, this may cause congestion in quay, so we have to consider this is harmony with the stevedoring operation. C/C productivity can be increased as the one cycle time of YC becomes shorter.

<Figure 2-13> Amount of Yard Trailers per C/C



<Figure 2-14> Impact of Y/C Cycle Time

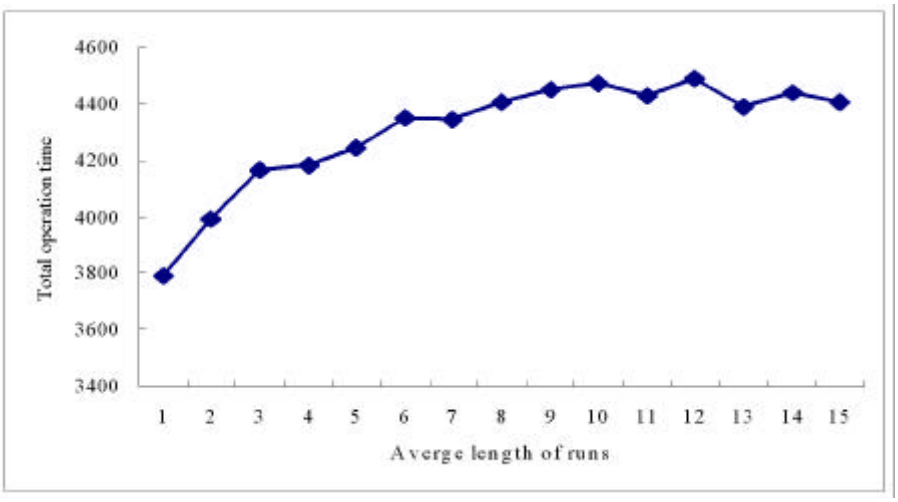


The dual-cycle seaside operation is expected to reduce the total operation time of C/C and the completion time of the entire ship operation.[7] In order to quantify the ratio of the dual-cycle operation to the entire ship operation, the concept of "length of runs" is introduced.

A "length of runs" could be defined as the number of consecutive ship operations of the same type (loading or discharging). A short "length of runs" indicates a high ratio of dual-cycle operation to all of a ship's operations. In order to test the effects of the average "length of runs" on the total operation, ten different series of operation times for a single C/C are generated at each different level of the average "length of runs".

The chart below shows that the total operation time increases as the average "length of runs" increases. The ratio of the minimum total operation time to the maximum total operation time was 84%.

<Figure 2-15> Effect of Dual-cycle Operation



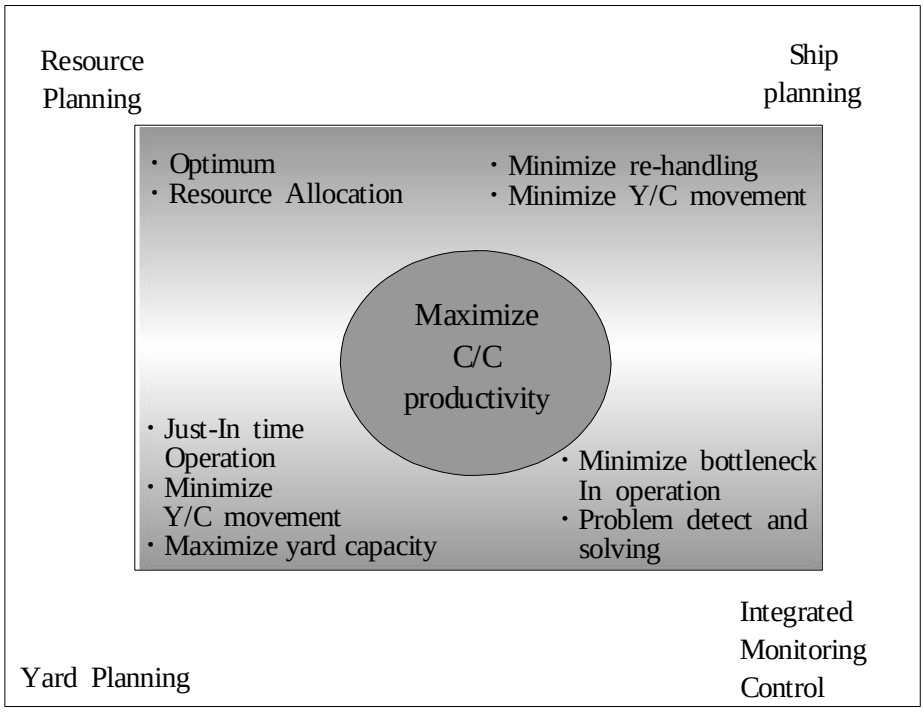
7) Jong Wook Bae, Kag Hwan Kim, "A Pooled Dispatching Strategy for Automated Guided Vehicles in Port Container Terminals", *International Journal of Management Science,* Vol.6, No.2, Nov. 2000.

Many liners are evaluating that HIT of Hong Kong has raised C/C productivity per vessel of 75 increased up to 95 lifts by improving the terminal operation system and yard operation method.

Automated terminal operation system will optimize the terminal resource, minimize rehandling on vessel and yard, maximize yard capacity, and execute the controlling of the terminal in an integrated way.

Especially with expert system coping with exceptions such as machine breakdown or accident, automated terminal operations system could be a solution to improve terminal productivity.

<Figure 2-16> Terminal Operation System



Total Soft Bank Ltd. of Korea has developed CATOS (Computer Automated Terminal Operation System). This system optimizes assigning terminal

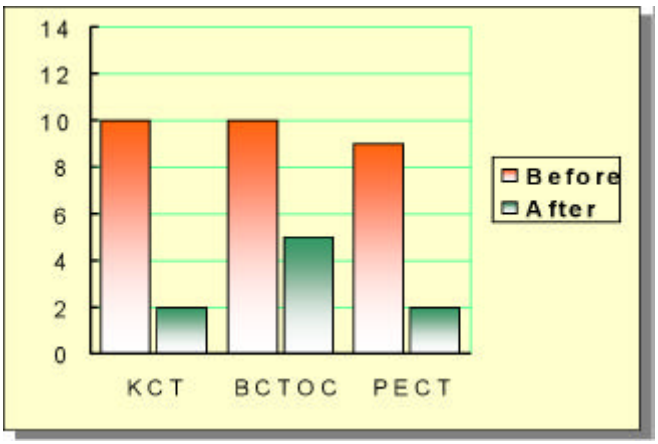
productivity, yard utilization, minimizes external truck cycle time, and supports full automatic terminal operations.

○ CATOS of Total Soft Bank(Korea) :
(Computer Automated Terminal Operation System)
- To support Full Automatic Terminal Operation
- To maximize Terminal Productivity
- To optimize Yard Utilization
- To minimize Cargo closing time

○ Effects on Productivity
- Ship planning time : 6 ~ 7 hours(manual planning)
3 hours(computer-aided) → 0.5 hours(automated ship planning)
- C/C productivity can be increased up to 25 ~ 30%

When using automated terminal operation system, rehandling rate per vessel of 9 10% drop down to 2%, and planning time per vessel of 2.5 3.5hours drop down to 0.5 1hour.

<Figure 2-17> Rehandling Rate per Pessel(%)



3. Automated Container Terminal System

3.1 Definition of Automated Container Terminal

An age of the automated container-handling systems has just started, and the systems have been adopted in several ports and harbours in the world, such as Rotterdam, Thames, and Singapore. Furthermore, every staff engaging the container operation business over the world has begun to have keen interest in the automated container-handling systems. This is due to the astonishing progress of container systems. For the time being, the computer systems are indispensable to the efficient and punctual container operations in the terminals. However, the container-handling systems, integrated with computer systems cannot be called the automated container-handling systems. In order to clarify the exact meaning of the automated container-handling systems, a technical analysis on the relation of the computer systems with container-handling systems in container terminals by developing stages is summarized in <Table 3-1>.

<Table 3-1> Stages of Development on Computerization in Container Terminals

Stage	Range of Annual Throughput of Containers (TEUs)	Control, Planning & Documentation Systems	Data Transmission Systems to Handling Equipment in Yard	Driving Systems of Handling Equipment in Yard
I	~60,000	Manual	Work Order Sheets & Verbal Radio	Manual
II	60,000~150,000	Computerized		
III	150,000~		Real Time among Computer Terminals	Manual (Providing Computer Local Terminals)
IV				Automatic by Computer

Watanabe, I(1996)., An Approach to the Automated Container Terminals, Seminar on Automated Container Terminals by Korea Institute of Machinery & Materials.

In the early stage of containerization, container-handling systems were manually controlled in terminals, as can be seen in local small container terminals even now. However, manual control seems to be difficult, especially in cases when the terminal throughput exceeds 60,000 TEUs. This is named Stage I. In Stage I, all the container-handling equipment is completely driven by manual or hand transmission, needless to say, and data transmission systems on operations among the control center and individual equipment are based on work order sheets supports provided by verbal communication of radio so-called walkie-talkie.

But, in most existing container terminals, computers are applied only for terminal control and planning systems, and related documentation, as ranked as the Stage II in <Table 3-1>. This means that individual equipment handling in a yard is manually driven based upon work order sheets which are outputted in batch by computers beforehand, and assisted by verbal communication by radio. This is not real time operations but is a step towards full computerization.

In accordance with increase of containers to be handled in the terminals, real time communication will be required to handling equipment in the yards, in order to upgrade their productivity and to prevent their own local computer terminals will be incorporated into the computer network of the terminal. However, the driving of this equipment handling is still manual. This is the Stage III for the computerization.

Finally, all major equipment handling in the yard will be not only incorporated into the computer network of the terminal but also driven by computers based on mechatronics, in order to perform highly efficient, fool-proof and labor-saving operations. This is the Stage IV in <Table 3-1>. A container terminal of Stage IV is strictly defined as an automated container terminal.

At present, most container terminals in the world are classified in the Stage

II. Many container terminals in industrialized countries, however, are upgrading into the Stage III. Furthermore, the automated container terminals in the Stage IV have appeared. They are ECT/Sea-Land Terminal in Rotterdam Port and Pasir-Panjang Terminal in Singapore is under construction. Container terminals in Thamesport which is ranked as Stage III for the time being, will be also upgraded to the automated container terminals of the Stage IV, after finishing the final tests on automated systems and equipment, within two or three years.

3.2 Development at the ACT Systems

The automated container-handling systems are generally considered to consist of both of hardware and software. The hardware is container handling machinery/equipment either of conventional manual type or of completely or partially automated type based on the mechatronics. In order to operate this machinery/equipment efficiently and precisely, the technology on software is very important. The software requires data transmission systems, and equipment and its position identification systems in addition to the conventional container-handling systems based on computer network for automated systems in container terminals.

The container-handling operations in the ordinary container terminals consist of sea-side and land-side operations, in general, as shown in next Table.

<Table 3-2> Container-handling Operations in Terminals

	(For containers by sea transport)
Sea-side Operations	Container-handling with ships at quay-side Container-shifting between quay-side and marshalling yard Container-handling in marshalling yard
	(For containers by inland-road & rail-transport)
Land-side Operations	Container-handling in marshalling yard (Container-shifting between yard and interchange slots/rail-yard) (Container-handling at interchange slots/rail-yard) Container-checking at gates

Sea-side operations are divided into three kinds of operations. That is, 1) container-handling with ships at quay-side, 2) container-shifting between quay-side and 3) marshalling yard and container-handling in marshalling yard. The first operation of container-handling with ships at quay-side is performed by container cranes in most cases other than roll on/roll off operations. Yard-use tractors and trailers are used for shifting containers between quay-side (berth apron) and the marshalling yard in most cases. Container-handling in the marshalling yard is performed by various container-handling equipments such as rubber-tyred gantry cranes, straddle carriers, forklift trucks, etc., in conventional terminals. In case of adopting straddle carriers, they are used for shifting work between berth apron and yard, in addition to handling work in the yard, in most cases.

Land-side operations are usually divided into two kinds of operations, that is to say, container-handling in marshalling yard and container-checking at gates. In case of providing the interchange slots or rail-yard for receiving and delivering operations from/to inland transport, however, work of container-shifting between the marshalling yard and the interchange slots/rail-yard and of container-handling at the interchange slots/rail-yard is additionally required. Container-handling equipment used in the marshalling yard for the land-side operations is just same as those for sea-side operations, needless to say. For the work to shift containers between the marshalling yard and the interchange slots/rail-yard, yard-use tractors and trailers are mainly used, and straddle carriers are also used. The equipments to shift containers to/from interchange slots such as straddle carriers, top-lifters, etc. is also used for container-handling at the slots. But, in the rail-yard, the container-handling equipment like rubber-tyred(RTGs) or rail-mounted gantries(RMGs), is separately provided in most cases.

The automation on the container-handling work with ships at quay-side

is considered to be very difficult in case of not providing any special fitting with calling ships, because only the technology of quay-side container cranes have to cope with any movements or changes of draft of berthed ships by tide, wind, changes of loading conditions, etc. But it is nearly impossible in actual operations to provide such special fittings for automated operations with respective calling ships. This is the reason why there are no completely automated quay-side container cranes in the world, for the time being. Only the partial automation on the some operations of container-handling, but with drivers is usually adopted by the latest quay-side container cranes.

Shifting work to shift containers between the quay-side and marshalling yard has been automated by using automated guided vehicles (AGV). But, the special devices such as chassis-loader system of ECT have to be required for container-handling of AGV with container cranes at quay-side. The other idea of automation of container-shifting is not to use any vehicles for the purpose, but to perform direct shifting of containers between quay-side container cranes and cranes in the marshalling yard by using traversers, like a system in port of La Spezia.

Container-handling operations in the marshalling yard for both of sea and land-side operations are considered to be possible for complete automations based upon present technology. For this purpose, the technologies on position identification systems for both containers to be handled and equipment to handle containers and on precise control systems of handling equipment are indispensable. In case of using container-handling equipment in the marshalling yard for receiving and delivering operations directly with public-way tractors and trailers with drivers by the improvement of layout to adjoin the interchange slots to the marshalling yard, special devices like remote manual operation on the automated equipment are required for safety and exact spotting.

Container-shifting operations between the yard and the interchange slots

or rail-yard are also possible to be automated by adopting AGVs. Container-handling operations in the rail-yard are also possible to be automated by the same handling equipment as those in the marshalling yard. However, there is the same problem on the automated operations of handling equipment in the interchange slots for receiving and delivering operations with public-way tractors and trailers with drivers as the case described in the section of marshalling yard operations.

The checking operations at the gates usually consist of documentation and physical inspection of container conditions are considered. This is considered nearly impossible to adopt complete automation techniques. Recently, an independent control from traffic lanes instead of booths for respective lane-sides for dealing with gate documents became popular together with pre-gate system, in order to save the number of gate-clerks. The Automatic Equipment Identification System (AEIS) which is standardized as ISO 10374, consisting of a tag on each container and a reader by micro-wave at each lane of gate is considered to be very effective for the saving of work force at the gate.

On the other hand, the inspection of physical conditions of containers requires man-power to make the final judgment, even using ITVs for remote inspection. Again the complete automation of the gate operation is considered to be nearly impossible.

The enlarged size of containerships requires the enlargement of quay-side container cranes such as their outreaches, lifts, etc., and the increase in handling the larger quantity of containers requires upgrading of performance including lifting and traversing speed of quay-side container cranes to prevent against the drop in their productivity. Futhermore, the increase in handling and stowing quantity of containers in terminals by expanded container traffic requires the enlargement of and upgrading of performance including lifting and

traversing speed of container-handling equipment in the yard. Thus, quay-side container cranes and container-handling equipment in the yard have been enlarged and upgraded, year by year, since the beginning of containerization.

However, both of the enlargement of size and the upgrading of the performance for cranes and equipment are considered to make their automation more difficult.

Although the existing container-handling systems consist of the handling equipment which is provided with parts of mechatronics in some cases, based on the conventional technology and computer systems to support equipment, the automated container-handling systems are usually integrated with the conventional handling equipment of high-technology, consisting of electronics and the computer system. The systems on the data transmission, the identification of containers and equipment, the detection of equipment positions, etc. are considered to be the fundamental high-technology having strong possibility to be adopted for automated container-handling systems.

3.3 PSA (Port of Singapore Authority)

3.3.1 Outline

Singapore is located at a strategic point on a major sea route and plays an important role as an advanced port with well-developed port facilities, effective shipping service, excellent terminal facilities and competitive rates. Unlike other ports, it is advancing to the top tier of international ports with successful port planning and development and effective operations.

Today, proper timing is considered the most important point in marine transportation and port operation. The success of a transshipment port depends on the ability to transport containers from one ship to another. Singapore

is providing shippers with the fastest transport system.

The PSA was privatized as of the end of October 1997 after closing operation as a public firm for 33 years from 1964 to September 1997. It is handling the largest volume of containers for a certain time - 2,000 containers for 12 hours for each ship.

In addition, it is maximizing its competitiveness through continuous setup of revolutionary automation and intelligent systems, and concentrating on establishment of the EDI(Electronic Data Interchange) consisting of PORTNET (Electronic Data Communication System), CITOS (Computer Integrated Terminal Operations System) and CIMOS (Computer Integrated Marine Operation System).

The PSA has 4 terminals including Tanjong Pagar Terminal, Kepple Terminal, Brani Terminal and Pasir Panjang Terminal. It is continuously making huge investments in setting up sophisticated container handling equipment to catch up with the introduction of the newest next-generation ships. It will establish a next-generation extra-large container terminal within 10 years. The 4 berths constructed in 1998 under the first phase of the new PPT (Pasir Panjang Terminal) project do not handle as many containers as expected and are subject to continuous correction and strengthening of the system through introduction of automation systems. However, most of them are equipped with the newest remote controlled facilities. Two other berths launched operation in 1999.

3.3.2 PSA Terminal Facilities

The 4 terminals operated by the PSA are summarized in the <Table 3-3>.

<Table 3-3> Terminals Operated by PSA

Item	Tanjong Pagar Terminal	Keppel Terminal	Brani Terminal	Pasir Panjang Terminal
*Area (ha)	80	96	79	84
*Water Depth (m)	11-14.8	9.6-14.6	12-15	15
*Berth	6(main) 2(feeder)	3(main) 11(feeder)	5(main) 4(feeder)	4(main) 6(feeder)
*Fleet Size	C/C : 29 YC : 95	C/C : 36 YC : 117	C/C : 29 YC : 98	C/C : 24 YC : 59
*Ground Slot	15,940	19,428	15,590	14,443
*Reefer (point)	840	936	1,344	648
**1997 Throughput (million TEU)	4.53	5.43	4.17	-
**Throughput per Vessel per Hour (Lift)	140	134	-	-

Source : * Internet Homepage of PSA, 2000. 12.
** Internet Homepage of PSA, 1998.

This study is performed centering on the PPT operated with the newest automated equipment.

3.3.3 Automated Operation of PPT (Pasir Panjang Terminal)

The PPT (Pasir Panjang Terminal) is the newest and most advanced terminal in Singapore. It is located about 15 minutes away from other terminals including Keppel, Tanjong Pagar and Brani terminals. The PPT is designed to be collectively operated together with the other 3 terminals.

All 4 terminals will be operated as an extra-large terminal. Containers will be transported within an hour between the PPT and other terminals. When the second phase of the PPT project is completed, it will come to have 26 berths and more than 100 container cranes. Four berths have been in operation since 1998 and 2 berths were added in 1999. The strong point of the PPT is that the PSA is not satisfied with the current service level for shippers but making many efforts to enhance its ability.

The PPT is designed to accommodate new facilities and technologies for the next-generation ships to be introduced in the 21st century. Each of the 4 berths which are currently operated is designed to handle 750,000 TEUs per year and increase its handing capacity by about 25%. Quay cranes are equipped with the next-generation functions and technologies and are able to handle extra-large ships having 18 rows of containers. The new OHBCs (Overhead Bridge Cranes) in the PPT are the world's first remote controlled yard cranes, in which an operator is located at the center of each crane. The OHBC stores containers in one-over-eight stacking to enhance land use and berth productivity. Formerly, the OHBC was tested in the Brani Terminal. The key to such a new terminal is that the handling work is performed as designed. The required points are that the whole terminal operation system was tested accurately and all the working facilities were well balanced.

1) Equipment of PPT

The PPT is equipped with C/C, OHBC, RMGC and AGV, but the AGV is not operated at present. In 4 berths, there are 12 C/Cs, 16 OHBCs and 15 RMGCs. When the first phase of the project is completed, the numbers rise to 24, 44 and 15, respectively.

<Table 3-4> Cranes at PPT

Unit : Fleet Size

Equipment	Fleet Size (4 Berth : 1998yr)	Current Fleet Size of Phase 1 (8 berth)
C/C	12	24
OHBC	16	44
RMGC	15	15
AGV	-	-

Source : Internet Homepage of PSA, 1998 2000.

2) Handling Capacity of PPT

The PPT has been operating 4 berths since 1998, with total handling capacity of 2.77 million TEUs. The 2 berths launched in 1999 can handle 1.38 TEUs and its handling capacity will be doubled later. When the second phase of the development project is completed, the total handling capacity will reach 18 million TEUs.

<Table 3-5> Handling Capacity of PPT

Unit : Million TEUs

Item	Phase 1			Phase 2	Total Throughput
	1998	1999	After		
Berth	4	2	2	18	
Throughput	2.77	1.38	1.38	12.47	18

Source : Japan Container Association, *Study on the Automated Container Terminal in Japan*, 1996.
Internet Homepage of PSA, 1998 2000.

3) Area of PPT

The total area of the PPT is 650,000㎡, of which 110,000㎡ is the apron, 397,000㎡ the yard, and 143,000㎡ the administrative building and auxiliary

facilities. The yard is equipped with 9,400GS including the capacity to contain 648 refrigerator containers.

<Table 3-6> Area of PPT

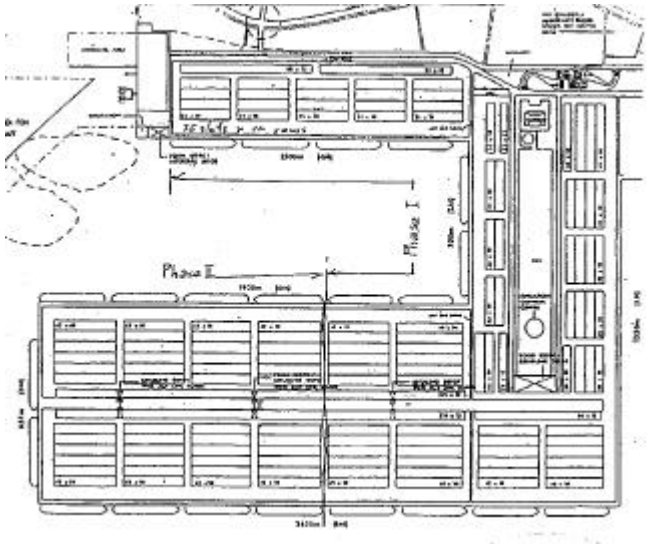
Unit : 10,000㎡, GS, %

Item	Phase 1 (4 Berth)	Ratio or Item to total Area	Total (Phase 1 + Phase 2)
Total Area	65.0	100	354
Yard Area	39.7	61.08	-
Apron Area	11.0	16.92	-
Operation Building and other Facilities	14.3	22.00	-
Yard Capacity	9,400(648 Reefer)		-

Source : Japan Container Association, *Study on the Automated Container Terminal in Japan,* 1997.

4) Layout of PPT

<Figure 3-1> Detailed Layout of 1st Phase PPT



<Figure 3-2> Overview of PPT



5) Operation of PPT by Zone

In the PPT, the yard bay is in parallel with the normal line of the quay. Each berth has 4 lanes of OHBCs along the sea and a lane of RMGCs on land. The AGV is designated to be used for transport within the yard, and the OHBC (Over Head Bridge Crane) as the yard crane.

The flow of containers is summarized as below:

- Outbound container: Gate → RMGC → AGV → OHBC → AGV → C/C
- Inbound container: C/C → AGV → RMGC → External Truck
- Transshipment container: C/C → AGV → OHBC → AGV → C/C

<Figure 3-3> Flow of Remote Control of Bridge Crane at PPT



<Figure 3-4> Bridge Cranes Established at PPT



<Figure 3-5> Bridge Crane and Yard at PPT



<Figure 3-6> Discharging by Bridge Crane at PPT



<Figure 3-7> Discharging by RMG Crane at PPT



<Figure 3-8> Flow of Bridge Crane Remote Control at PPT



① CITOS system selects containers to be stevedored by C/C



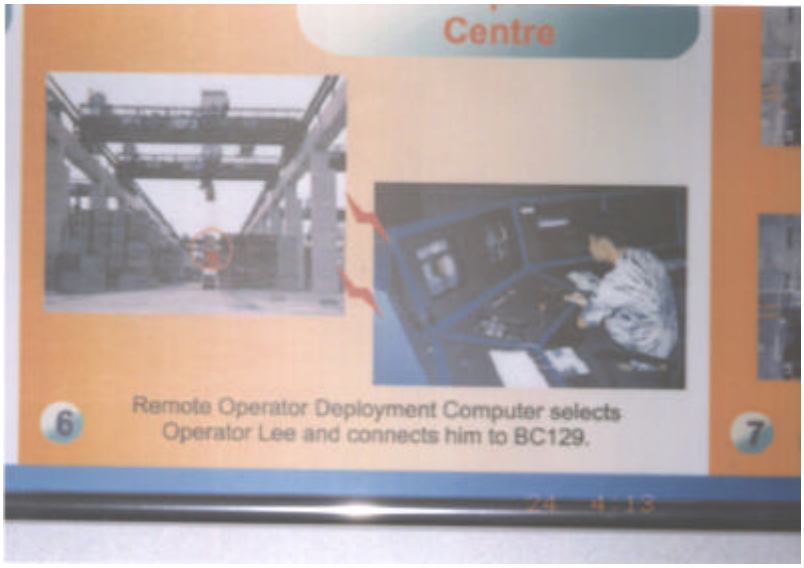
② Automatic work allocation and instruction for containers to be stevedored



③ Confirmation of changes in OHBC position and stevedoring point to yard truck



④ Remote control of OHBC by computer



⑤ Work allocation and instruction for OHBC remote control operators



⑥ Work by OHBC remote control operators



⑦ Instruction of works following OHBC remote control

3.3.4 Quay Zone

1) Sub-C/C Zone

This can be roughly divided into 2 zones - AGV transport zone and truck transport zone. The AGV transport zone between container rails has 6 lanes for transporting containers, and the truck transport zone for transporting special containers has 2 transport lanes between C/C rails. Accordingly, a guard wall is established for preventing a trespass between truck and AGV.

2) C/C Backreach Zone

This is the zone where the AGV perpendicularly transports into the quay. The zone excluding the AGV transport route is used for placing the hatch cover.

3.3.5 Yard Zone

1) Yard Operation

(1) OHBC Yard Zone

Outbound and transshipment containers are to be stacked in the OHBC yard zone in maximum 8 tiers. The total width of OHBC is 45m wide, and OHBC 30m is comprised each of 5 rows of stack at right and left sides and 3 rows of AGV transport lanes in the center. The 3 rows of AGV lanes in the center are used for linear transport without a trespass. Each AGV lane each at right and left side of OHBC zone is designed to be used for OHBC and stevedoring works.

(2) AGV Transport Lane in Yard

The zone between the OHBC and the RMGC transport zones is designed to have 4 AGV lanes. This AGV lane is used as both the AGV zone transporting

inbound containers to the RMGC and the AGV transport route transporting outbound containers temporarily stacked on the RMGC to the OHBC. This lane is not used as a separate transport lane for discharging containers from a ship but used as its extension.

(3) RMGC Yard Zone

The inbound containers on a ship are transported to the RMGC yard with the AGV, and the RMGC yard is designed as the buffer zone for outbound containers. The RMGC is 2-side cantilever type, and connected to the AGV in 2 lanes and external trucks in a lane. The RMGC is designed to store containers in 12 rows and one-over-eight stacking.

(4) External Truck Transport Zone

For smooth traffic of incoming and outgoing external trucks, there are 8 transport lanes, or 4 round-trip lanes.

(5) Refrigerator Container Yard

Refrigerator containers are to be stored in one-over-six stacking. They are not stored in the dedicated yard but stacked on either the OHBC or RMGC lane. Refrigerator containers are monitored with the remote control system.

2) Others

(1) Remote Control with CCTV

The remote control system CCTV is designed to operate yard cranes in a remote office. An operator can control several yard cranes in the office with the CCTV cameras that are set up in the cranes and the monitors that are set up in the office without operators riding on the cranes.

(2) AGV Operation

The PSA is testing 5 units of AGV developed for use at the PPT in the Brani Terminal. In recognizing pictures, the navigation system of "Tadiran Co". of Israel didn't used the transponder type of ECT but used the paint mark type. This system is known to be more cost-effective. In the first phase of the PPT project, Y/T has been used instead of AGV, because the use of foreign laborers at low cost has reduced the necessity of AGVs. However, efforts have been continuously made for developing it to a fully automated unmanned terminal using AGVs.

3) Future Developments and Prospects

The PSA, boasting the world's largest transshipment port, is handling the larger part of containers to and from adjacent developing countries including Malaysia, Indonesia, Thailand, etc. As very large container carriers of 6,000 TEU class are increasingly placed in commission, and the number and time of calls at ports will be reduced in the future, the PSA is expected to enjoy more advantages as a large hub port. With the growth of economy in the countries mentioned before, they are planning to construct more container terminals. The Port Kelang (Malaysia) having geographical advantages in Asia sees the number of calls gradually grow and the Global Alliance has begun to call at the Laem Chabang Port (Thailand). They will try to challenge the PSA, and the competition between adjacent ports will get fierce in the future. In addition, whether the project to develop a new large terminal will finally reach the fourth phase as planned will depend on long-term economic growth in Asia and port development policies of those countries. Meanwhile, the PSA has begun to provide consulting for not only maintenance of domestic ports in Singapore but also construction of ports in foreign countries, and is also trying to positively advance abroad the accumulated knowhow of

constructing and operating container terminals. The PSA constructed a container terminal in joint venture with the Dailian Port Authority in March 1996, and will continue to play a pivotal role in constructing and operating other ports abroad in the future.

The PSA is planning an extra-large terminal comprising the terminals currently in operation and the ones to be developed in the future. The PSA's plans by phase are summarized in the <Table 3-7> below:

<Table 3-7> PSA's Future Plan

Item	Phase Ⅰ		Phase Ⅱ	Total
	Phase 1	Phase 2		
Number of Berth	4	4	18	26
Quay Length (m)	1,500	1,400	6,100	9,000
Area (10,000㎡)	65	61	226.6	353.6
Throughput (10,000TEU)	227	276	1,247	1,800
The Year of Completion	1998	2 Berths : 1999 2 Berths : Later	2009	
Investment Cost (100million $)	20		50	70

Source : Japan Container Association, *Study on the Automated Container Terminal in Japan*, 1996.
Note : $ indicates Singapore Dollars.

In the Phase Ⅱ, the PSA plans to develop a terminal to handle 12.47 million TEUs with 18 berths and quay length of 6,100m by investing $5 billion by 2009. Including Phase Ⅰ, it will emerge as the world's largest terminal with the number of berths rising to 26, the quay length 9,000m, total area 353.6㎡, and handling volume 18 million TEUs.

3.4 Thamesport

3.4.1 Outline

The Thamesport, having launched operation in 1990, is one of the container terminals growing fast in Europe. The operation techniques of Thamesport has been developed and automation systems are now being adopted. The throughput of Thamesport in 1990 was 9,600 TEUs, and it was increased to 139,500 TEUs in 1991. In 1996, the throughput drastically grew to 350,000 TEUs. Moreover, throughput of 450,000 TEUs was handled in 1997 and annual throughput will reach that of 600,000 TEUs. The container mix by transportation comprise 75% of road, 10% of rail, and 15% of feeder.

3.4.2 Facilities

The Thamesport has the area of 40ha and is located in the Grain Island of the Kent Province. The quay length is 550m and it is being extended to 650m. The port is designed to accommodate 2 container carriers of Post-Panamax class at the same time. The water depth of the front ranges from 13.5m to 15.0m.

The Thamesport has the following facilities:

5 quay cranes, 16 RMGCs (2 units for yard X 7 Lanes = 14 units, 2 units for rail), 22 yard tracers, 70 yard chassis, 2 top lifts (of 35t), etc.

<Table 3-8> Thamesport Terminal

Item	Thamesport Terminal
Area (ha)	40
Water Depth (m)	13.5-15.0
Berth	2
Quay Length (m)	550
Equipment	C/C : 5 RMGC : 16 Y/T : 22 Y/S : 70 T/L : 2
Throughput in 1996(10,000 TEU)	35

Source : Japan Container Association, *Study on the Automated Container Terminal in Japan*, 1996.

The terminal has 7 runs in parallel with the 405m of quay wall, and each run is equipped with 2 RMGCs. The whole yard is divided into 2 sectors in function, and the RMGCs are also differently automated.

The western sector of the yard stacks outbound and inbound containers, where external chassis are exchanged.

The eastern sector, the upper zone of the yard, stacks containers discharged from a ship, where yard chassis get into during handling. Accordingly, transport works are required between the western and eastern sectors of the yard.

Each of the 14 automated yard cranes is able to handle 25 containers per hour, and the number rises to 70 containers per hour on per average in case of large ships. The Thamesport is operated 24 hours a day and 365 days an year.

3.4.3 Operation of Automated Terminal

1) Quay Operation

There are 5 units of manually operated high speed Post-Panamax class

container cranes in the quay, and the crane's air draft is 30m and outreach can cover 16 rows. It is also said that they are planning to establish a container crane to cover 17 rows. The guidance vehicle is used for transporting containers between the quay and the container yard. Thamesport has participated in developing and testing AGV. However, AGV is not used presently for operation of the terminal. The long-term goal of Thamesport is to develop a fully automated unmanned container handling system.

2) Quay-Yard Operation

For loading containers to a ship from the quay crane and the yard, yard chassis are used.

When stacking transported containers, the yard tractor operator works with wireless remote control to operate spreader. Chassis are transported and parked simply along the yellow line on the ground, and the stevedoring point is set up with the remote controller and notified to the tractor operator. Originally, the system was developed so as to install the laser transmitter on the RMGC, attaching the reflector on the chassis and guide the chassis below the RMGC. Due to the cost matter, however, the former method has been adopted.

The remote controller attached to the vehicle body is of such simple design as the TV remote controller used at home. If AGV is adopted to transport containers in the future or problems occur in connection with qualities of yard tractor operators, the laser guidance system may be revived.

The matter of adopting the AGV is withheld due to lack of funds, but its test results are said to have been successful.

3) Operation of Yard

The container yard is operated with fully automated cranes. In the yard,

there are 14 automated RMGCs capable of storing containers in one-over-seven stacking. A run is 650m long and containers are stored in 9 rows and one-over-four stacking. The crane was manufactured by Morris (UK) and can automatically adjust its position within the limit of 25mm. Each crane is independently operated on the ground and the quay to maximize their capacity. The yard can stack 25,000 TEUs and is extended for storing in one-over-seven-to-nine stacking. Containers are received and dispatched automatically, and the final loading of containers on external trucks is remotely performed by the vehicle operator at the transporter exchange bay. Transport of containers between the crane zones is performed by the traditional guidance vehicle.

Inbound containers are discharged and dispatched by the computer by run and stacked in small number of tiers basically. Outbound containers are basically stored in one-to-four stacking and transported to the final waiting place of the upper zone, unless the traffic is jammed in the terminal. In case the chassis having transported outbound containers takes inbound containers on its return way, it temporarily stacks outbound containers neighboring inbound containers to reduce transport of the RMGC. The 2 RMGCs allocated to the same lane can be operated close at the least distance.

In receiving/delivery operations, the RMGC is basically operated in the unmanned manner. The dispatching personnel on the ground notifies the external chassis of the proper parking point, and operates the spreader with the wireless remote controller at the final stage of stacking containers. A person operates multiple number of RMGCs.

The terminal computer draws out the proper handling method by processing the updated information including stackings at lanes, RMGC operations, gate operation time, waiting time at the gate, etc. at an interval of 2 minutes.

Operators continue to communicate with the supervisor for proper control of handling.

3.4.4 Future Developments and Prospects of Thamesport

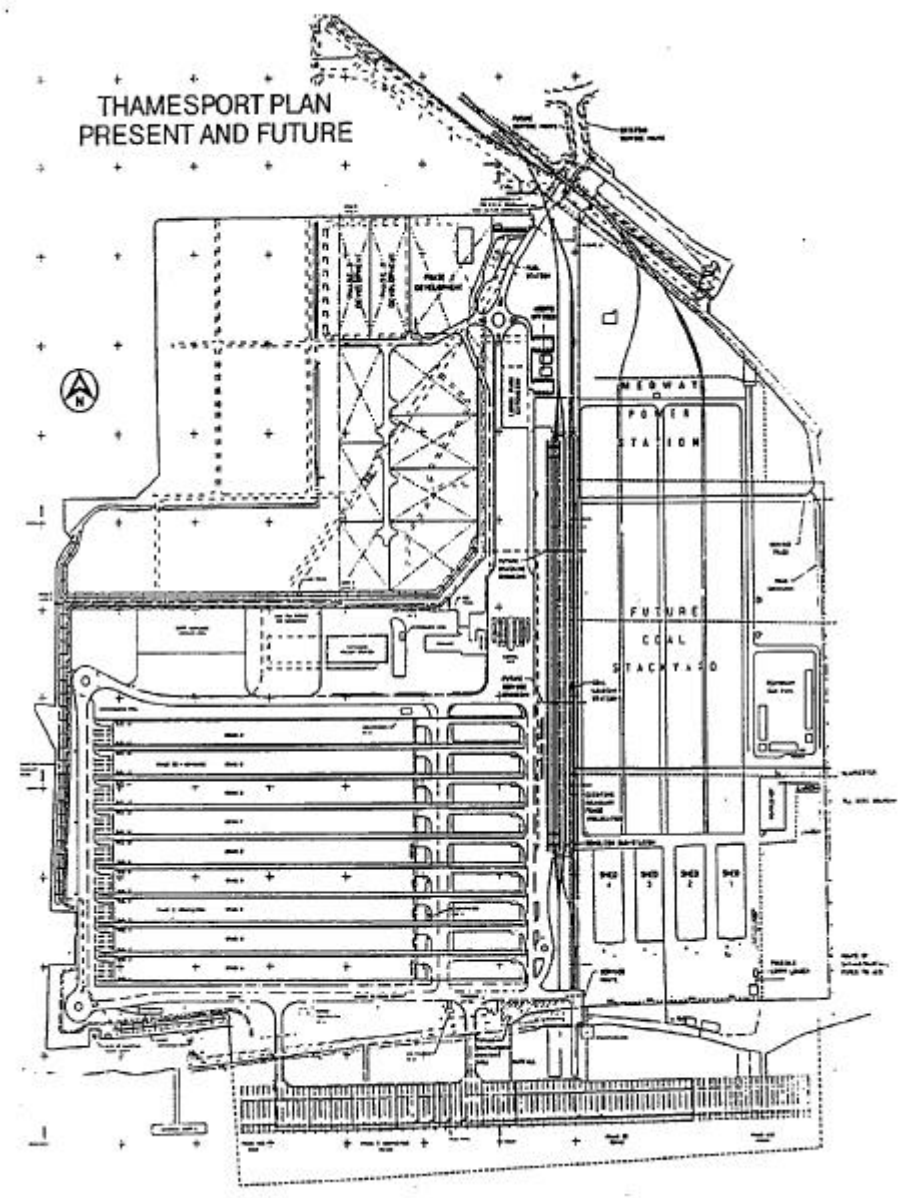
The Thamesport aims to grow be one of the largest container terminals in Europe. It has been already extending its quay by 100m and constructing 2 new lanes in the container yard. Accordingly, its storage capacity is expected to grow over 26,000 TEUs in the future.

In the future, it plans to construct a container yard of about 10 acres, and establish a space of 50 acres for transport, repair, and other related businesses. The model of the AGV of the UK is expected to be introduced at the Thamesport. These AGVs are expected to replace the guidance vehicle at the terminal in the near future.

<Figure 3-9> Overview of Thamesport



<Figure 3-10> Layout of Thamesport



3.5 CTA of HHLA

3.5.1 Outline

In 1997, the City of Hamburg granted HHLA the right to operate the Alternweder Container Terminal in order to develop an automated terminal enabling them to improve productivity and service and reduce container handling cost. It planned to increase the container handling volume to about 1.1 million TEUs by the end of the first phase of the project and 1.9 million TEUs in the second phase.

3.5.2 Facilities Plan

- ○ Quay length: 1,400m
- ○ Quay height: 7.5m from the water surface
- ○ Water depth: 16.5m
- ○ Yard width: About 600m

<Table 3-9> Basic Date of CTA Terminal

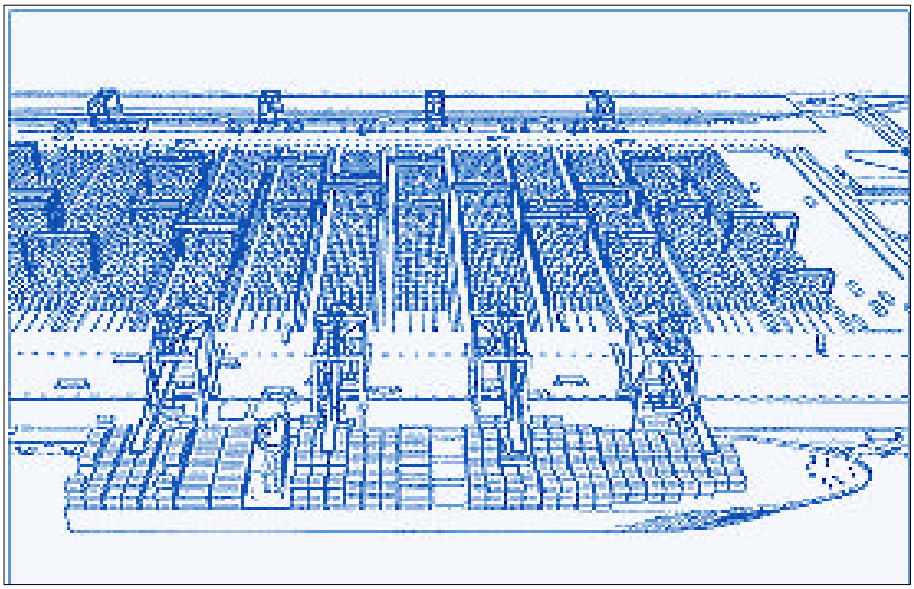
Item	Phase Ⅰ	Phase Ⅱ	Total
Quay Length	810m	590m	1,400m
Area	530,000qm	230,000qm	760,000qm
Seaside Capacity	700,000bx/a	500,000bx/a	1,200,000bx/a
Stowage Capacity	15,000TEU	15,000	30,000
Personnel (Person)	300	170	470
Investment Cost	300 million DM	270 million DM	470 million DM
Completion	April 2001	April 2003	

Source : IIR, *Optimizing Container Terminal Layout, Logistics & Equipment Control 29 30th,* November 1999.

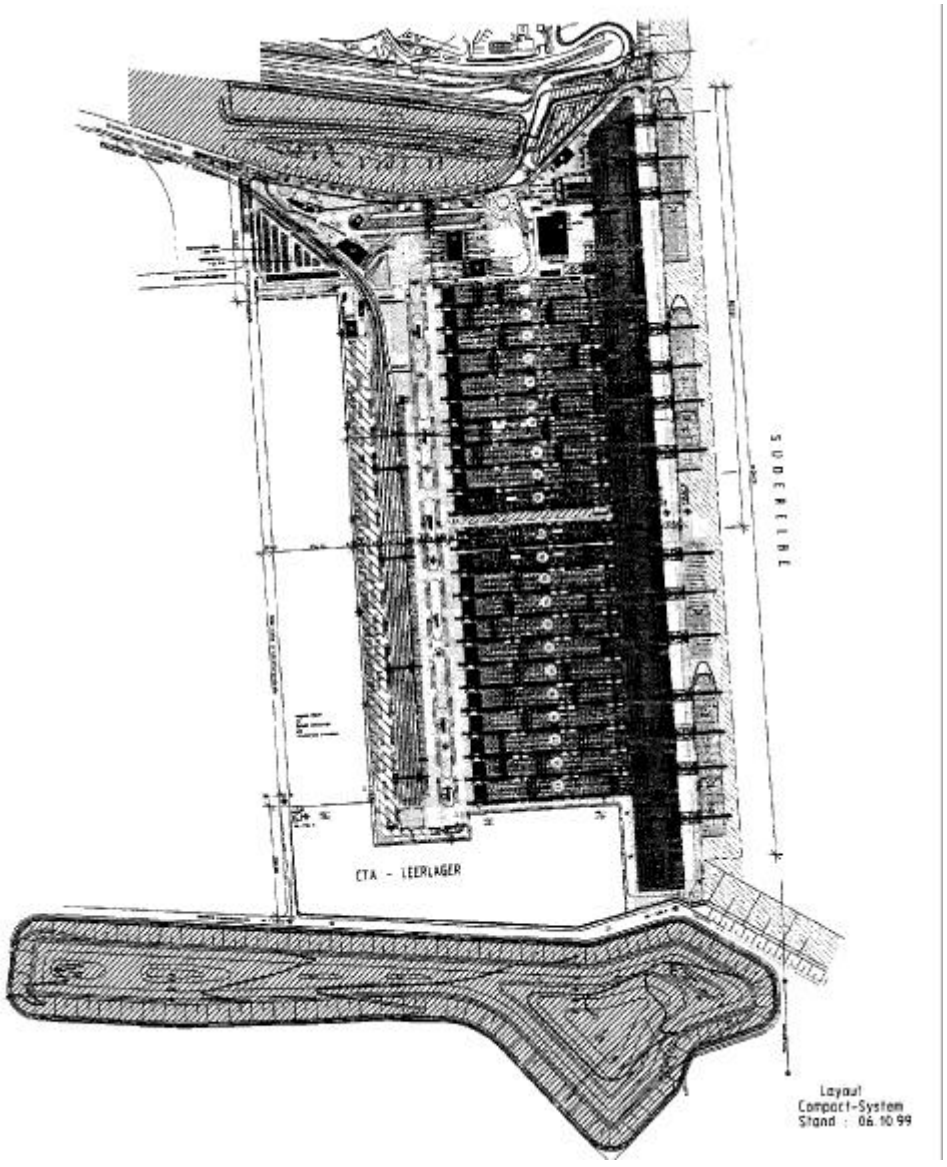
<Figure 3-11> Overview of HHLA CTA



<Figure 3-12> Bird's-eye-view of HHLA CTA



<Figure 3-13> Layout of HHLA CTA



3.5.3 Operation Plan for Automated Terminal

The CTA is planning to establish the effective and reliable container handling system by adopting the most advanced technologies, sophisticated EDP (Electronic Date Processing) and the simplified system.

1) Quay Operation

The CTA plans to guarantee rapid stevedoring of containers by installing gantry cranes for Post-Panamax size container carriers. Height of such a crane is 72m, its rotation diameter is 35m, height of its arm is 37m and its weight is 53 tons. The features of the gantry crane recently developed are as follows. Two travellers of different function transport containers. In the semi-automatic mode, the cat toward the sea transports containers from a ship to the perpendicular lashing platform on the gantry platform. In the automatic mode, the fully automated traveller takes containers and transports on the remote controlled unmanned vehicle.

2) Quay-to-Yard Operation

Sixty unmanned transporters will be installed for transport of containers between the quay and the yard. Its speed is 6m/s, and the transport line is made up with the help of the electronic sensors established on the ground. Any person is prohibited from entering the transporting site for safety. The electronic sensors are designed to operate when the unmanned transporter passes. The traffic control center monitors effective transport.

3) Yard Operation

The RMGC will be used for stevedoring the containers transported to the

yard. The yard is planned to have an area of 225,000m^2 (112,000m^2 by the end of the Phase I), consist of 22 storage blocks (11 blocks by the end of the Phase I) and store 30,000 TEUs (11,000 TEUs by the end of the first phase). Containers are planned to be stored in one-over-four stacking and 10 rows.

4) Future Developments and Prospects of HHLA CTA

The HHLA CTA plans to combine proved factors of ships and berths with new structures in order to control complicated co-relations between separate system configuration factors based on the EDP. When such a plan is effectively implemented, it is expected to grow to a terminal having the highest handling rate per hour. It is making every effort to introduce revolutionary handling technologies and set a standard for advanced next-generation container terminal by installing the newest and large-scale facilities.

3.6 Comparison of Automated Systems in Major Terminals

3.6.1 Comparison of Automated System Modes

- Comparing automated systems in major automated terminals, it is noted that yard cranes are mostly automated, but the ECT and HHLA terminals adopt AGVs as transporters and other terminals adopt Y/Ts as transporters.

<Table 3-10> Major Automated Terminals

Item		ECT/DSL	Singapore(PPT)	Thamesport	HHLA
Type of Automation System		AGV-RMG(ASC)형	AGV-OHBC/RMG	AGV-RMG	AGV-2RMG
Automation Zone	Quay Crane	·Large vessel : Manned ·Large AGV : Automated	·Large Vessel : Manned ·Large Y/T : Manned	·Large Vessel : Manned ·Large Y/T : Automated	·Large Vessel : Manned ·Large AGV : Automated
	YT (Transfer)	·AGV:Automated	·Y/T:Manned	·Y/T:Manned	·AGV:Automated
	YC	ASC: ·Large AGV:Automated ·In Yard:Automated ·Large SC:Automated	Unmanned OHBC: ·Large Y/T:Semi-Auto ·In Yard:Remote RMG : ·Import/Export:Manned ·In Yard:Manned	Unmanned RMG: ·Large Y/T: Semi-Auto ·Shift:Automated ·In Yard:Automated	Unmanned RMG: ·Large AGV:Automated ·In Yard:Automated
	Contact Point with External Truck	·SC:Manned	Unmanned RMG: Remote Controlled/ Manned	Unmanned RMG: Remote Controlled/ Semi-Auto	Unmanned RMG: Remote Controlled/ Semi-Auto
Manual Zone	Rail	·MTS:Manned	-	-	-
	Off-Standard	·ASC/M:Manned	-	-	YT:Manned
	Empty Container	·RS/SL:Manned	-	-	-
Yard Type		·Single Type ·Perpendicular	·buffer Yard ·Parallel	·buffer Yard ·Parallel	·Single Type ·Perpendicular
Stack Height		3Tiers 6Rows	8Tiers 10Rows	4Tiers 9Rows	4Tiers 10Rows

○ The automated terminals such as ECT of Netherlands and the HHLA of Germany adopt the AGV-unmanned RMG system, and the PPT of Singapore and the Thamesport of Britain also plan to replace the existing Y/Ts with AGVs in the future. There are 2 kinds of yard operation types: the single yard type in which all functions are performed in a single yard and the multiple yard type in which multiple yards do different functions including buffer and storage separately.

- The operation systems of the 4 automated terminals analyzed in this

study were originally designed to have the standard AGV-unmanned RMG systems. The DSL and DDE terminals of the ECT and the CTA terminal of the HHLA have the single yard type in which a yard is laid out perpendicularly to the quay, and outbound and inbound containers are collectively stored. On the other hand, the Thamesport has the multiple yard type in which yards are laid out in parallel with the quay and containers are separately stored, and the Singapore's PPT also has the multiple yard type in which yards are laid out in parallel with the quay with the buffer yard behind the yard and containers are separately stored.

- In case of the terminal that is operated with multiple yards, the Thamesport in which multiple yards are laid out in parallel with the quay transports containers between yards with the RMG. In case of the PPT of Singapore in which yards are laid out perpendicularly to the quay, however, containers are designed to be transported with the AGV between yards.

○ It was found that the PPT of Singapore and Kawasaki terminals are operated differently in respect of the design for some reasons.

- In the case of the PPT of Singapore, the inland discharging system is designed for operation in a remote control way(semi-auto), but this is not used and gate operation is made with the RMGC because gate-in and gate-out traffic is not large and the semi-auto system requires huge investments.

  They were also found not using the AGV. They are said to have not adopted the AGV but are only studying it, because it requires a long period of time (8 years) to secure the target traffic to cover the costs required for adopting the AGV and the technical problems of the traj ectory

(navigation) system have not been completely solved.

- The Kawasaki terminal was found to adopt the conventional operation system in which external trucks directly gate in using the buffer yard as the marshalling yard because the traffic is quite less than expected. They also do not make tests in the yard with the AGV and rather plan to expand the conventional terminal in the future.

○ The HIT adopting automated system in yard operation concentrates on solving the problems that occur in the discharging operation in connection with its plan for automation, because containers are stacked closely and highly in the yard. Containers are discharged in full automation mode in the yard with the RMGC of one-over-five stacking and 12 rows.

3.6.2 Comparison of Automated Yard Equipment

○ The automated equipment which have been developed for stacking containers in the yard includes RMG, RTG and OHBC, of which most important automated terminals are adopting (or planning to adopt) RMG.

- Most automated terminals are adopting RMGs as stacking equipment in the yard, whose capacity is a little different from each other in terms of the number of stairs. In other words, ETC's DSL is operating (or planning to operate) RMG of one-over-two stacking, DDE of one-over-three stacking, Thamesport and HHLA of one-over-four stacking.
- But, the Singapore's PPT is adopting a mix of OHBC and RMG - OHBC for the yard storing on-board containers and RMG for the yard storing inland containers. The OHBC used in the PPT of Singapore

is designed to handle containers in one-over-eight stacking and 10 rows in the unmanned system and have 3 separate lanes for AGV operation in the center to be connected with the AGV.

The PPT of Singapore was found to be operated in full automation mode in the stacking area from the survey made in 1999, but is being adjusted to the remote-auto system in the control center for connection with the guide trucks in the yard center (3-truck lane). It was also found that truck drivers working in the OHBC block are trained and managed by the PSA.

○ Following is the comparison of characteristics of RMG and OHBC.

<Table 3-11> Comparison of Automated Yard Equipment

Item	RTG	RMG	OHBC
Possibility of Application to Conventional Terminal	Very Easy	Easy	Very Difficult
Precision of Job	Low	High	Very High
Initial Investment	Low	High	Very High
Technical Problem	- Engineering Facilities are necessary to prevent Settlement of Ground	- Engineering Facilities are necessary to prevent Settlement of Ground	- Engineering Facilities are necessary to prevent Settlement of Ground - Manufacturing steel boom with high intensity
Terminals Retaining The Equipment	-	ECT/DSL, Thamesport HHLA	Singapore (PPT)

- RMG can be partially automated. In case of designing the yard in one-over-four stacking, it is more economical than OHBC in terms of initial investments. But, in case the yard ground is soft and the

RMG system is adopted, efforts shall be made to prevent settlement of ground. For example, in case of HHLA and CTA terminals, experts advise that settlement of ground should be tackled to adopt the RMG system as their ground is soft.

- OHBC requires huge initial investments in erecting columns sustaining crane rail girds and ground breaking works. OHBC may also incur the matter of precision in connection with strength of the boom. To solve this matter, a steel boom requiring more investments shall be used.

3.6.3 Comparison of Yard Operation Types

1) Single Yard

○ This is the type in which yard is not divided by characteristics and purposes of operation but operated in a single yard. In other words, the yard is not divided into several zones for on-board and inland containers but used for storing on-board and inland containers in a single yard.

- It was found that DSL and DDE of ECT and HHLA of CTA do not separately operate yards for inland and on-board containers but operate single yards for storing both of them.

(1) ECT Type

○ Advantages:
  - AGV traveling distance is short.

○ Disadvantages:
  - Yard crane travel distance gets long.
  - High stacking is impossible.
  - Initial investments in a unit of yard crane are excessive.

- It is difficult to tackle operation due to troubles of yard crane.

(2) HHLA Type

○ Advantages:

- AGV travel distance is short.
- Relatively high stacking is possible in comparison with ECT type.
- Easy to tackle troubles of yard crane
- Yard crane travel distance is short.

○ Disadvantages:

- Initial investments requiring many yard cranes are excessive.
- Investments in ground breaking increase as the number of cranes increases.
- High technologies are required for operation of terminal

(3) 2-Yard Type

○ Terminal is classified into 2 types depending on operation type:

- First, the Thamesport type is operated with 2 separate yards - one for storing containers externally delivered and another for storing containers discharged from ships.
- Second, the type adopted in Singapore is operated with 2 separate yards
- one for storing on-board containers and another for storing inland containers, to effectively operate on-board and inland works.

○ Advantages and disadvantages of each yard operation type are as follow:

① Thamesport type

○ Advantages

- Not only container boxes can be assorted in night with idle yard equipment, but also containers to be loaded onto a ship can be

moved to the on-board yard at night for effective loading in day.

○ Disadvantages

- Excessive re-operation may occur.
- Land use rate can be reduced without high stacking equipment.
- Yard crane travel distance gets long.

② PSA(PPT) type

○ Advantages

- Easy transshipment
- Advantageous when transshipment traffic is larger than export-import traffic.

○ Disadvantages

- Skilled and precise terminal operation techniques are required as AGV is in charge of travel between inland and on-board yards.
- Despite high stacking stowage, actual land use rate is similar to that of a single yard. (High stacking equipment should be used for raising land use rate.)
- Initial investments in high stacking equipment are excessive.

3.6.4 Classification of Automated Container-Handling Systems

On automated container-handling systems, many consulting engineers and manufacturers of handling equipment have published their concepts and ideas. These concepts and ideas are classified into the following two categories.

1) Non-captive type

The automated container-handling will be performed by the equipment in terminals. No special attachments, fittings or structures will be required

on both of containers and ships. Therefore, usual containers and ships will be always possible to be handled in terminals of this type.

The automated container-handling systems of non-captive type are further sub-divided into two categories.

(1) Direct Stacking Type

Containers are placed directly on the ground, or stacked directly on top of the containers below.

○ Merits
- easily released, because of extension of existing system

○ Demerits
- selectivity when choosing certain container
- rehandling is necessary when accessing certain container

○ Selected Terminal
- most automated terminals that we looked into in this research choose non-captive type

(2) Rack Type (Pigeonhole Type)

Containers are individually stowed in each cell(pigeonhole) of rack structures. (Just like the rack system of an automatic warehouse).

○ Merits

selectivity of certain container is excellent

accessibility to certain container is excellent

high efficiency of container handling

○ Demerits

very large initial investment

(3) Comparison of Direct Stacking Type and Rack Type

In the direct stacking type, stacking tiers will be usually limited to four or five high because it will be very difficult and troublesome to retrieve

the designated containers from the lower tiers of multi-tier stacks.

On the other hand, in the rack type, the selectivity and accessibility will be excellent. But, as the utilization of land area will not always be good compared with the direct stacking type, very tall structures having 10 to 15 tiers will be necessary to compensate the wrong utilization of land area. This will also require very large-scale investments.

<Table 3-12> Classification of Automated Container-Handling Systems

	Non-captive type		Captive type
Classification	The automated container-handling to be performed by the equipment in terminals. Any attachment, fittings or structures not to be required on both of ships and containers.		The automated container-handling to be performed by not only the equipment in terminals, but special attachments, fittings or structures required for either containers or ships or both of them.
Division	Direct Stacking Type	Rack Type(Pigeonhole Type)	
	Containers to be placed directly on the ground of terminals and stacked directly on the top of containers below.	Containers to be individually stowed in each cell (pigeonhole) of rack structures.	
Merits	Easily released, because of extension of existing systems	Excellent selectivity and accessibility. High efficiency of handling	Excellent selectivity and accessibility High efficiency of handling Possibility to develop no-man handling system
Demerits	Less selectivity and accessibility	Large initial investments	Very large initial investments
Examples	Under Operations/Construction:~ Matson: Mousetrap system ECT/Sea-Land Terminal in Rotterdam La Spezia Container Terminal Thames/Kawasaki Container Terminals Pasir Panjang CT, Singapore	Under Plan:~ Kaiser Speed-Tainer System Auto-Lux Apiarium System HHLA, Terraced Conveyor System	Under Plan:~ vickers lautovick system Meeusen Containoveyer System MECO System

2) Captive Type

Although the automated container-handling will be performed by the equipment in terminals, special attachments, fittings or structures are required for either containers or ships, or both of them. Accordingly, usual ships stowing usual containers will not be able to call on terminals of this type.

3.6.5 Comparison of Productivity of C/C

○ Productivity of quay crane is only roughly compared because major automated terminals have greatly different levels of automation and it is impossible to compare their productivity on a single standard. The following is the productivity comparison of the single hoist container mostly used in conventional terminals and the double hoist second trolley crane proper for automated terminals.

- In general, the total hourly throughput of a quay crane is about 35 for the second trolley and about 25 for the conventional crane.
  - Single hoist quay crane: 20 25/h
  - Dual hoist quay crane: 30 35 (1999, ECT)
    38 40 (In future, ECT)
- Absolute comparison is difficult, but, in case yard operation system is properly established, the quay crane of automated terminal is more effective than the conventional crane in general.

3.6.6 Comparison of Yard Layout Type

○ Yard layout is divided into perpendicular and parallel types. Among major automated terminals, ECT DSL and DDE and HHLA CTA have perpendicular layouts, while Thamesport and Singapore's PPT have parallel layouts.

○ Advantages and disadvantages of each layout type are summarized below:

1) Perpendicular Layout

○ Advantages
- Yard storing effectiveness is high.
- Easy for automation of separate operate inland and on-board operations
- Easy for flow planning

○ Disadvantages
- Apron width shall be wider than in parallel layout.
- Unitary storing block is limited.
- Effectiveness is reduced when traffic is converging.
- High stacking is difficult as discharging equipment is required for rapid travel.
- Difficult to tackle troubles of equipment
- Difficult to adapt itself to enlargement of ships
- Low flexibility in using yard

2) Parallel Layout

○ Advantages
- Less limit in unitary storing block
- Transport efficiency is high as traffic is dispersed.
- Effectiveness of yard equipment increases (transport between blocks is possible)
- The number of required equipment is small.
- Easy to tackle troubles of equipment
- Easy to adapt itself to enlargement of ships
- High flexibility in use of yard

○ Disadvantages

- Traffic control is difficult because of heavy traffic and complicated flow planning.
- Construction of roads for transport equipment is relatively complicated.
- Automation of operation system connected with equipment is absolutely required..
  (Flow planning is complicated.)
- High stacking is difficult as discharging equipment is required to rapidly travel.

3.6.7 Comparison of Stacking Height and rows

- It was found that the PPT of Singapore has the storing system of one-over-eight stacking and 10 rows, the Thamesport one-over-four stacking and 9 rows, HHLA of CTA one-over-four stacking and 10 rows, and ECT's DSL and DDE one-over-two stacking and 6 rows and one-over-three stacking and 6 rows, respectively. The PPT of Singapore found that its land is used very efficiently since its stacking height is the largest.
- The Hong Kong's CT 6 and 7 terminals are automatically operated only in yards, in which RMG is operated in one-over-six stacking and 12 rows.

3.6.8 Comparison of Terminal Capacity in Terms of Quay Length and Area

- Criteria of comparison may depend on productivity of equipment and other terminal situations, but the results of comparison can be roughly summarized as follow:
  - The designed terminal capacity in terms of quay length in the PPT of Singapore is 1,513 TEUs/m. (The actual throughput based on

the traffic surveyed in 1999 was 946 TEUs/m.) The capacity of CTA's HHLA was surveyed to be 1,357 TEUs/m, ECT's DSL was 876 TEUs/m, and Thamesport was 636 TEUs/m. It shows that recently planned automated terminals are designed to have higher quay capacity. However, the finding that the PPT of Singapore has the highest capacity is because its transshipment traffic is much higher than that of any other port. The traffic of PPT of Singapore is about 1.42 million TEUs as of 1999, 63% of the planned 11.27 million TEUs, but the transshipment throughput is about 75% of the total throughput.

<Table 3-13> Unitary Capacity of Automated Terminal in Terms of Quay Iength and Area

Item	*ECT/DSL	*Singapore (PPT) (Phase 1-1)	*Thamesport	**HHLA(CTA)
Capacity (Designed Value)	500,000box	2,270,000 (Empirical Throughput in 1999 is 1,420,000TEU)	350,000	1,900,000
Quay Length	970m	1,500m	550m	1,400m
Water Depth	13.65m	15m	13.5 15m	16.5m
Total Area	60ha	65ha	40ha	79ha
Stack Height	3Tier 6Row	8Tier 10Row	4Tier 9Row	4Tier 10Row
Capacity per Meter	515box (876TEU)	1,513 (Empirical Throughput in 1999 is 946)	636	1,357
Capacity per Hectare	14,166	34,920 (Empirical Throughput in 1999 is 21,846)	8,750	24,048

Note 1) The ratio of box to TEU is 1.7(Empirical Value of Gamman Terminal of Pusan in 1998).
2) Capacity per hectare is calculated from annual capacity(TEU)÷total area(ha)
3) * : The data of 1996, ** : The data of 1999

- The designed terminal capacity of the Singapore's PPT in terms of

quay area was surveyed to be 34,920 TEUs/ha (the throughput based on the actual traffic surveyed in 1999 was 21,846 TEUs/ha,), HHLA 24,048 TEUs/ha, ECT DSL 14,166 TEUs/ha and Thamesport 8,750 TEUs/ha. The PPT of Singapore was surveyed to use land in the most effective way. In general, the terminal capacity in terms of area is related to the stacking height of the yard. The PPT of Singapore was analyzed to have the highest terminal capacity in terms of area as it is designed to store containers in one-over-eight stacking.

3.7 Selection of Recommended System

3.7.1 Superiority of Automated System

In general, the automated terminal is analyzed to be superior to conventional terminal in the following 3 aspects:

- Effectiveness of Handling

In preparation for traffic increase in the future, container terminals should achieve higher productivity than present. Productivity improvement will be achieved by increasing handling equipment and automation of terminals. However, it is technically impossible to increase equipment because interference of equipment may result in reduction of the entire productivity. As container carriers tend to be enlarged and so width of ship and freeboard increase, there will be limits in improving productivity through increasing equipment. In conclusion, the container handling equipment to be introduced in the 21st century should achieve higher efficiency. Automation will be a good alternative to achieve this goal.

- Effective land use

When traffic increases, the vast area of land on shore should be developed

in container terminals. However, it is very difficult to find proper land for use as a new terminal. As a result, container terminals should be constructed neighboring upon waters. In addition, larger budgets will be required for reclamation and dredging works. To save such construction costs, the existing container terminals will have to be remodelled for ensuring more effective use of land. To use land more effectively, the methods to store containers in higher stacking in the yard will have to be invented. Automated systems are thought to be the very solution to high stacking of containers in the yard.

○ Reduction of personnel and prevention of accidents through simplification of operations

Discharging works including container handling are considered as labor intensive industry. Accordingly, as traffic increases in the future, labor cost is expected to drastically increase and this will take a lion's share of total container handling cost. Also, the possibility of occurrence of accidents will also greatly increase. If operations are simplified through automation, labor cost will be reduced and many accidents will also be prevented.

3.7.2 Selection of Recommended Automated System

Based on the results of comparison and analyses on the currently automated systems, this study reviews recommendable automated terminals in Korea.

○ Types of automated system

The automated system widely introduced by major international ports is the AGV-RMG type. Its technologies are thought to be well proved. It is the most recommendable system to Korea, which is just in the

very beginning stage to design and operate automated terminals. It is also recommended in terms of management of investment risks.

○ Stacking height and rows

Most automated terminals, except for ECT's DSL and DDE, were surveyed to adopt one-over-four or higher stacking rules. Particularly, the yards of ECT's DSL and DDE, the terminals having first introduced automated systems (in July 1996), are designed to have one-over-two and one-over-three stacking rules. The yards of the automated terminals thereafter are designed to have one-over-four or higher stacking rules. It shows that stacking technologies have been advanced aiming at more effective land use in automated terminals. Accordingly, it is thought that, if ground conditions are satisfied, the stacking rule of at least one-over-four or up to one-over-five-to-six would be available.

In connection with the number of stacking height and rows in the yards of automated terminals, it was surveyed that HHLA has a 10-row rule and the Hong Kong's HIT operating automated system only in the yard has a stacking rule of one-over-six and 12 rows in case of RMG. Accordingly, Korea is also expected to possibly have 12 or more rows if yard conditions are allowed.

○ Yard operation type

Most international automated terminals were surveyed to adopt the single yard type in the perpendicular layout and the 2-yard type (including buffer area) in the parallel layout. It was surveyed that ECT's DSL and DDE and CTA's HHLA have the single yard type in the perpendicular layout, and PPT of Singapore and Thamesport have the 2-yard type having the buffer yard in the parallel layout.

Korea is also thought to select the 2-yard type in the parallel layout

or the single yard type in the perpendicular layout.

○ Yard layout type

In consideration of advantages and disadvantages of perpendicular and parallel layouts, it is thought that selection will have to be made considering terminal conditions through studies of technologies, productivity and land use efficiency concerning equipment control, interface of RMG and external trucks, interface of AGV and external trucks, etc.

3.8 Analysis of Causes for Failed Automation of Terminals

3.8.1 PSA, Pasir Panjang Terminal

Items	Causes for failure	Designing points
Layout (Discharging & transport routes)	Dedicated blocks for gate operation and discharging were laid out in parallel at the end of the terminal, and the 2-side cantilever type RMGC are used for discharging. As results, the AGV transport distance increases and productivity falls.	As the KMI layout terminal is not a transshipment terminal as the PSA, separate export/import blocks are not planned. So, it is designed to have a certain level of productivity.
Layout (Troubleshooting repair & maintenance)	In case problems occur in transport in the yard block due to the features inherent in the parallel layout, external personnel cannot easily enter the automated zone which may badly influence the entire AGV operation system.	Maintenance is considered in the KMI parallel layout. That is to say, the maintenance zone of 10m is designed on the AGV transport lane by adopting the cantilever type ATC. In case of the perpendicular layout, maintenance is designed to be done in the Kiosk zone.
Layout (Construction and technologies)	The PSA adopted the parallel layout enabling to stack containers in high stairs as it is the terminal focusing on the transshipment containers. It adopted overhead bridge cranes enabling to stack containers in 8 stairs instead of the RMGC. After the terminal was completed, however, it was found that the transport of many cranes at the same time cause some problems including vibration. Lots of time was required to stabilize the equipment.	Korea does not have as many transshipment containers as the PSA. The KMI's parallel layout is designed to use the ATC and have containers stacked in 5 tiers and 15 rows with about 40 bays and stores 600 TGS and 3,000 TEUs. The PSA is designed to use the OHBC and stores 380 TGS and 3,040 TEUs in 8 tiers and 10 rows at 38 bays. The ATC established is of the type used at conventional terminal. As utilizing both-side cantilever type of 12 rows and one-over-six stacking, it is operated unmannedly in Hong Kong, and can be immediately adopted.
Layout (AGV run design)	As 3 running lanes are set up in OHBC yard, much yard space is required.	KMI's both-end cantilever type ATC is designed to be shared by 2 blocks. Much space is not required.

Items	Causes for failure	Designing points
Layout (Infrastructure)	As rail is set up on reinforced concrete structure for OHBC, additional construction work is required.	KMI type requires construction of rail.
Economy of AGV	2.5-4 million TEUs should be secured based on 6 berths for economy of scale, but AGV is not required at present traffic. (containers handled in 1999: 1 million TEUs)	
Technical reliability of AGV	Adoption of navigation system of vision type causes exposure to damage from dust, rain, etc., and limited frame processing speed and S/W support makes commercial operation unavailable.	Navigation system using transponder
Layout (sensor, communica-tions system)	As parallel layout, it has many crosses as AGV travels inside bridge crane of one-over-eight stacking. Problems were found in technically settling real-time control of more than 50 AGVs throughout the terminal. High costs for settling such problems was one of major causes for failure.	Project team developed integrated controllable system.
Layout (Navigation System)	It was not perpendicular layout like ECT, but parallel layout. An expensive transponder was not used but a camera system was used that caused many disadvantages including limits on environment during AGV travel.	In both KMI's perpendicular and parallel layouts, transponder is used for navigation system without any technical problems.
System integration	Equipment developed by different developers causes problems in equipment interface and system integration.	Project team can establish integrated system.
Spreader Stacking Guide	As durability and anti-shock of stacking guide were not secured, it is not used at present.	Technologies of stacking guide were secured having stacking guide durability, anti-shock and accurate sensors were developed.

3.8.2 Kawasaki Terminal

Items	Causes for failure	Designing points
Operation system	Failure in setting up automated operation system by equipment maker ① Client/server design not considering characteristics of process - Overload of server processor in all process lowers performance and processing speed. - Efficiency of simulation process such as ship/yard planning worsened. - Operation application design and user interface flexibility lowers. ② Client server design not considering characteristics of data - As all data is stored in DBMS of data server, data is overloaded in network and performance lowers. - Display speed lowers. ③ Non-existence system development theories - Conventional system development method is used. (Connection of work is linear, and individual components are totaled.)	* Dispersed data processing system is set up according to process and data characteristics. * System is developed in consideration of characteristics of terminal operation. - Milestone-based approach - Object-oriented data modelling - Enterprise data modelling
Terminal Layout	As terminal layout is divided into stacking area and buffer area, container handling process is complicated and productivity lowers. * Flow of export container Gate → Kiosk → Stacking Area → RelayPoint → Buffer Area → YC * Flow of import container YC → Buffer Area → RelayPoint → Stacking Area → Kiosk → Gate ① Transfer should be made from stacking area to buffer area before ship arrives. - Dual operation of container causes unnecessary RMG work. - Container handling time from kiosk to YC is excessive (13-16 minutes per container) ② Too long block causes excessive equipment travel. - About 6 minutes are required to transport a container from kiosk to stacking area, causing waiting of gate-in and gate-out trucks and yard congestion. (A container should be handled in 1 minute and 30 seconds for meeting service level.) ③ As interface between RMG and YC is made at an end of buffer block in parallel with quay, YC path converges on a side causing increase of transport distance and buffer congestion.	* Simple container handling process * Increase of equipment transport speed * Storage block of proper length considering equipment transport speed * Storage block to minimize move of equipment * Estimation of accurate productivity depending on layout type (Actual productivity is nearly half theoretical productivity.)

Items	Causes for failure	Designing points
Terminal operation organization	As terminal operator was absent in terminal planning, goals are not concrete and specific features are not reflected.	Integration team including all following experts to be organized - Terminal operators - Operation and IT experts - Equipment experts - Distribution experts
Unreason-able yard layout	As transport process of Gate→Kiosk→Stacking Area→Buffer Area→Ship is complicated and long, and block is long, hourly productivity is low. (8 units/hr)	Minimization of transport process - Yard to be designed so that equipment flow line is simplified and minimized.
Unskilled operation layout	All operation systems software were made by equipment maker, and system lack of expertise concerning terminal operation was established. - As omitted subsystem was made by other firms, system integration is difficult.	* Realization of integrated operation system * To be realized by integration team, functioning equipment, operation system and yard layout
Layout (yard operation)	In parallel layout, equipment is installed at a run due to features of RMGC layout which causes a decrease of efficiency due to work load and interference between equipment, decrease of transport crosses, enlarging of crane travel distance, and deterioration of productivity.	KMI's parallel layout is of conventional terminal type, having 3 blocks in a run. AGV discharging and transport routes between blocks ensures no interference between cranes and increase of discharging crosses to cause no distant move of cranes.
Layout (Yard operation)	In layout, all containers on discharging and transport routes of export and import containers by AGV are designed to gate in and out in the eastern part of terminal. Accordingly, converging AGV deteriorates efficiency and discharging productivity. Now, it is changed to conventional RMG type layout. Automation of RMGC was achieved, but, due to some problems in development and application, it is not applied.	KMI layout enables travel of discharging routes of AGV between blocks causing running efficiency.
Unskilled computer system	- Client/server computerization concept was introduced, but data dispersing process was not realized, causing server overload and handling delay. - Operation related logic is not made in algorithm but processed in DB, causing failure in making system required for automation of equipment. - EDI system is not set up.	Dispersed data processing system complying with process and data characteristics is established.
Automated equipment	Untested dual trolley gantry is adopted. - 2 drivers are required. - Hourly productivity is as low as 20 lifts.	In selecting automated equipment, it is required to select equipment which can be tested and compared with current technical level and existing terminals.

4. The Handling Technology of ACT[8)]

4.1 Dual Hoist Systems

The demands being made of single-hoist cranes are stretching them to the very limits of their capability. It is estimated that if a single-hoist crane was to be fitted out with all the latest performance enhancing technologies, productivity would not exceed 50 moves an hour, compared with a theoretical estimated requirement of 60-70 moves per hour for the latest generation of ship-to shore cranes to work a 18+ container wide post-Panamax ship.

Although not a new concept by any means, the second trolley system is still seen as a viable option by some to improving the hourly move rate, most notably by VIT on its KoneCranes and Flanders Container Terminal (FCT). ECT installed a dual hoist system on its Nelcon cranes and, initially, claimed that it increased productivity by as much as 15% and brought about a smoother handling cycle. However, ECT has now removed or no longer uses the second trolley on its dual hoist cranes, citing reliability problems and a failure to increase productivity as the main reasons. Ansaldo, which has supplied dual hoist cranes to the Sea-Land terminal at Kaohsiung, points out that the real utilisation of the dual hoist is very rare. The most recent interest in the dual hoist system comes from HHLA, who have ordered three units for delivery in 1999 from Noell.

While there are benefits to a dual hoist system, it cannot, of course, increase

---

8) This chapter is based on the materials, "The Future of Container Handling Technology"(Cargo Systems, 1999), "Developments in container handling technology"(Cargo Systems, 1997), "Recent developments in information technology for container terminals"(Cargo Systems, 1999).

terminal throughput by itself. The real bottle neck in container terminals remains on the quay. Noell consider that the low level of demand for dual hoist systems is a result of this problem. There is no point speeding up quayside operations of yard systems cannot match their productivity.

Although there are variations in design, cranes with a dual hoist system normally have two extra features compared to standard single-hoist cranes: a moving platform and a hoist frame.

Using a rope pulley system the platform carries containers weighing as much as 55 tons over a distance of up to 35m, moving automatically between the manually operated main crane trolley at the quayside and a parking position below the telescopic spreader of the stationary hoist at the landside.

The hoist frame loads and unloads the platform and also lowers and hoists the containers, over a maximum distance of 5m, once the platform has moved off. All movements are controlled by an on-board PLC connecting the chassis loader to the chassis/trailer train.

In using semi-automation one operator is usually sufficient though sometimes two operators and two cabs are used. To protect the drivers from the impact of sudden acceleration and deceleration of the trolleys, the cabs are run on independent rails alongside the trolley runway. One problem with two trolleys running at the same time along the same runway is deflection in the boom. Dual hoist systems also increase the overall weight and the wheel loads of the crane. This means they are not suitable for many older terminals.

Noell has developed two dual hoist designs. The first, under construction for HHLA, uses a lasher platform to the ship to an area where they can work safely. The main trolley brings the container to the lasher platform where the twistlocks are removed. The second trolley is fully automated. It transports containers between the trailer and the platform. Noell designed this system to improve lasher security. However it claims that computer

simulation has demonstrated that it is 20% more productive than a standard, single trolley crane.

The other, patented Noell system involves two independent trolleys that can pass each other. Although there have been no orders, Noell claims that this design can increase productivity by 70% over a single trolley crane. It also offers lower wheel loads than other dual hoist designs.

VIT is another of the double-trolley or dual hoist system. VIT's dual hoist cranes were supplied by KoneCranes. Here, the platform is positioned vertically close to the level on the deck of the vessel where the containers are handled in order to reduce the longer ship cycle. Both the sea and the landside operations are under the automatic control of the PLC. VIT reports that its dual hoist cranes give an increase in productivity of 10 moves per hour. The disadvantage is that the maintenance costs double.

KoneCranes has manufactured dual hoist cranes with following specifications:

<Table 4-1> KoneCranes Double-trolley Specifications

Lifting capacity under spreader	40.6 tonnes
Out-reach from waterside rail	45.7m
Backreach from landside rail	22.9m
Lifting height above rails	33.3m
Rail span	15.2m
Hoist speed with full load	55m/min
Hoist speed without load	130m/minute
Ship trolley speed	180m/minute
Shore Trolley speed	75m/minute
Gantry speed	45m/minute
Boom hoisting time	5minutes

4.1.1 Paceco-Mitsui Supertainer

Although the Supertainer design concept has been around for several years, there have been no orders to date. However, Paceco-Mitsui continue to market the Supertainer concept considering it to be the only crane fast enough to handle the future mega-sized container ships. A mega ship is defined as 20-22 containers wide with a capacity of up to 15,000 TEUs.

In theory, the Supertainer is capable of handling 90 boxes an hour, which is three times faster than a new Portainer Crane. The operator's cab is attached to the waterside trolley and the chute operation's cab/checker's cab is at the container chute, but there is no operator cab on the landside trolley. A key development here is that the trolleys do not travel when hoisting. Instead, the horizontal movements are undertaken by the traverser which takes the containers from the waterside trolley to the landside trolley. The traverser runs along the outside rails of the girder while the trolleys are mounted on the inside. When the trolleys and the traverser overlap the hoisted container is transferred. Most of the operation is done automatically except for positioning on landside and waterside and trolley lowering motions.

The traverser platform can be raised and lowered to match the container height on the ship. This reduces hoisting and lowering time and, therefore, overall cycle time. This makes the Supertainer most suitable for a ship without hatch covers, but with extended guide rails above the deck. However, as present ships are all hatch cover design, the following elements are incorporated in the Supertainer design:

- Semi-automatic cone handling: The semi-automatic cone is attached to or detached from the bottom of the lifted container by the workers on the ground. Containers above hatch covers are handled between the ship and the ground with their semi-automatic - cones underneath the bottom of the container. The traverser is designed to receive containers

with cones attached.

- Shorter path handling: For a hatch cover ship, it is not necessary to lift each container up to the maximum height. The traverser can be lowered in three steps, to a total of approximately 8.7m. This reduces the cycle time for a container in the hold by five seconds.
- Hatch cover handling: When a hatch cover is handled, the traverser is moved to the quay side beyond the waterside trolley. The waterside trolley can pick up the hatch cover, transport it to the backreach and lower it to the ground. The landside trolley is moved to the end of the backreach to allow for this.

Both trolleys are MOT type to eliminate the complicated rope reeving that would be needed otherwise. The hoisting ropes are reeved down from the drums, through the sheaves of the headblock, back up to the trolley and connected to hydraulic cylinders installed in the trolley frame. Hydraulic cylinders operate the trim, list and skew of the spreader, for snag protection and absorption of rope slack.

The concept of the Supertainer has undergone some design alterations since it was first unveiled. The most recent specifications offered from Paceco Corp. include three different outreach options. These are listed below.

<Table 4-2> The Paceco Supertainer - Dimension Options

	18 row outreach	20 row outreach	22 row outreach
Backreach	50ft	75ft	75ft
Span	100ft	100ft or 150ft	100ft or 150ft
Lift height above rail	125ft	130ft	135ft
Lift height below rail	60ft	60ft	60ft
Total lift height	185ft	190ft	195ft
Traverser clear height	110ft	115ft	120ft
Leg clearance	60ft	60ft	60ft
Portal tie clear height	550ft	50ft	50ft

In addition to the different size options available, there are two different speed options.

<Table 4-3> The Paceco Supertainer - Speed Options

	Case 1	Case 1
Main Hoist(both trolleys) With Load		
Hoisting	99m/minute	137m/minute
Lowering	113m/minute	152m/minute
Without load		
Hoisting	198m/minute	274m/minute
Lowering	198m/minute	274m/minute
Trolley travel		
Waterside trolley	152m/minute	152m/minute
Landside trolley	76m/minute	76m/minute
Traverser travel	152m/minute	274m/minute
Chute travel	76m/minute	76m/minute
Gantry travel	46m/minute	46m/minute
Boom hoist time	3Min 45ₒ	3Min 45ₒ

The rated load of the waterside trolley, landside trolley and traverser is 65 LT each. Therefore, the total rated load for the cranes is 195 LT.

AC inverter control is planned to ease maintenance. However, it is intended to equip each main hoist with 2 X 750kw DC thyristor control. While total motor capacity is approximately 4,500kw, power consumption is far less. This is because the No.1 and No.2 converters are connected to a single large transformer so as re-use backpower from one side to the other without going through the transformer. On the Supertainer, when one hoist is raising the other is lowering.

The power source to the Supertainer is AC, three phase 60Hz, 11kV. DC power to the trolleys is through conductor bars and shoes. AC power for trolley travel and communication is provided through festoon cables. Because

of the high traverser speeds, AC power and communication to the traverser may be by contactless (inductive) power supply.

Inside the chute is a safety stopper to ensure protection should a driver walk underneath it when the landside hoist is lifting or lowering a container. To prevent injury there are hydraulically retractable stops inside the chute. The extension of the stopper the hoisted container or spreader stops automatically just before it. Once driver safety has been confirmed, the stopper is retracted.

In addition to faster handling speeds other estimated benefits include excellent cost performance, with initial cost per box lift being around 58% of a New Portaniner model, and running cost per box lift at 79% of a New Portainer crane.

It is also claimed that the ease of automatic operations confirms reliability and conversion to further automatic operation while a lack of sway and cyclical moves ensure operator comfort.

For the working of post-Panamax ships four standard post-Panamax quay cranes are used. Paceco suggests that the Supertainer is used in conjunction with two standard cranes, thereby reducing the number of cranes required to work a ship by one. The company claims that besides this advantage, which also brings about cost savings, the flow of quay-to-stack transfer vehicles is simplified and congestion reduced.

4.1.2 Elevating Girder

In July 1997 VIT put out to bid its elevating girder crane. This was the culmination of the 'Container Crane 2000' project VIT had been undertaking in conjunction with KoneCranes. The basic idea is that the crane operator can be positioned as close to the vessel being worked as possible. To achieve this, the design will feature a boom capable of being raised and lowered

horizontally over the container stack. Attached to the boom is a high speed trolley, weighing between 30 and 40 tonnes. Wheel loads are around 175 kipps/wheel with 5 foot spacing.

During operations, the boom is positioned as close as possible to the top of the current row of shipboard containers. Once a container is selected from the ship, the spreader is fully raised and locked into the trolley. Trolley speeds of 275m/minute are possible without load sway.

The crane has the option of being fitted with anti-sway, but really only to be used in certain spotting situations. The main specifications are that the boom mast must be able to elevate over a distance of 60ft at a speed of 20ft/minute. Although Virginia Port Authority(VPA) invited tenders for an elevation girder design in 1998 for the Hampton Roads terminal, VPA decided on a conventional A frame design. There were problems with the height of the elevating girder crane at this particular terminal.

The plan for an elevating girder crane has not been shelved indefinitely. The design will be considered again for future terminal up-grades.

4.1.3 Independent Double-Trolley Design

This is perhaps the most recent concept in twin trolley cranes. Flanders Container Terminals(FCT), a transhipment facility owned by Katoen Natie Terminals, aims to achieve a minimum average of 2 10 container moves per hour per vessel and become the first "fast terminal". FCT calculates that, to achieve this target with "conventional" post-Panamax cranes, at least 6 cranes working simultaneously are needed. However, this is very much dependent on having a stowage plan that enables 6 cranes to work simultaneously and yard logistics that can cope with the flow.

After a technical evaluation of the systems available, FCT put out a tender

for a double-trolley system in 1998. The difference between this and the other double-trolley designs outlined above is that there will be no moving platform, but neither will the trolleys pass each other. It is intended that both trolleys operate independently over the full range of a 52m outreach. Although the trolleys can operate within a distance of 8m of each other, it is intended that they will handle containers on their respective sides of the ship. Each trolley will fitted with a long twin spreader. FCT claim that simulations have shown an increase in production of between 45% and 78%, depending on the ship and loading plan.

Seven manufacturers came up with a design for this type of system and a shortlist of five was then compiled. FCT has recently made a decision on the final design and the supplier and a price has been agreed. However, FCT needs an increase in container traffic of around 100,000 TEUs before it can justify an extra crane, otherwise the design will have to wait until an existing model needs replacing.

FCT have adopted a straddle carrier direct yard system to support the planned increase in productivity. This involves straddle carriers fitted with twin-lift spreaders serving the quay cranes. A buffer zone is employed on the yard, rather than buffering under the quay.

4.2 Full Automation - (RMGs, ASCs, OHBCs)

4.2.1 Introduction

While RMGs have obviously become easier to automate than RTGs, driverless machines are still the exception rather than the rule. The prime examples of where they are used are at purpose built 'automated' terminals such as ECT Delta/Sea-Land, Thamesport and Pasir Panjang PSA.

While these terminals have successfully introduced fully automated RMGs,

¢¥3i

other terminals have not had as much success. NKK corporation experienced technical problems with fully automated RTGs at its Kawasaki terminal. Likewise, Samsung heavy industries did not have a favourable experience introducing semi-automated RMGs at PSA.

4.2.2 RMGs

At the Delta/Sea-Land terminal lightweight Nelcon Automated Stacking Cranes(ASC) are used in conjunction with AGVs. Following an original delivery of 26 quay cranes in 1989, another 28 upgraded models were installed in 1995 as part of the 2000-8 project, capable of stacking 1 over 3 high. The original deliveries have low stacking capabilities and as such only need simple mechanical load control mechanisms, while the more recent units, because they stack higher, have needed electronic anti-sway devices installed.

While most positioning systems for yard gantries use intermediate reference points, the ASCs at ECT use a Holes-devised magnetic system for continuous reference for movements over the stacks. Mounted on blocks beneath the crane rails are magnetic transponders, placed at 3m intervals. These generate magnetic fields which are picked up by sensors containing microprocessors, mounted on the underside of the ASCs. Accuracy can be obtained to 1cm.

At Thamesport the driverless RMGs travel along the rails and constantly check their own positions using a relatively simple technology. Reinforcing bars, 20cm long and welded onto plates, have been bolted onto the sleepers under the rails at known intervals. On the cranes are infra-red beacons. As a crane moves along the rails the infra-red beam is interrupted allowing the RMG to recalibrate itself, such as when the rails are wet or when position is lost due to power surges. Acceleration and deceleration are under the control of the on-board PLC, while the position of the cranes is reported

to the central by radio data transmission. The only part of the operation involving human input is the lowering of containers onto truck chassis, where an attendant controls the process using a remote control unit. This is simply because truck drivers tend not to park exactly under the line of the spreader.

HHLA had recently released information on the design of the new Altenwerder terminal, now under construction. The yard is to be fully automated, incorporating AGVs and ASCs. The AGVs will operate in a 100m wide area between the quay cranes and the ASCs. The yard storage area is to be divided into 22 storage blocks with a total capacity of 30,000 TEUs. While some blocks will be of a special design incorporating steel platforms to service reefer units, most will be ten rows wide, 37 long, with transfer areas at each end. Each block will be served by two ASCs. The unique feature of the ASCs is that they have been designed so that one larger crane can move freely over another smaller, inner crane. This gives each crane the ability to service the entire block simultaneously with all slots accessible at any time. Another advantage is that, should one ASC break down, the other can still operate the full length of the block.

As is with the driverless RMGs at Thamesport and the OHBCs at PSA, the transfer to and from road trucks will not be fully automated. Trucks will reverse into one of six handling lanes at the rear of the holding block, where the ASC will automatically position itself. The final approach and locking of the spreader into the corner castings will be remote controlled by a central supervisor using cameras that would need to be mounted on the ASC or the spreader. At the time of writing, HHLA was still in the tender process and no supplier had been decided on. However, it is understood that the concept of two ASCs passing each other was developed by Noell.

¢ÌÄv

4.2.3 Overhead Bridge Cranes

The latest development in unmanned yard cranes is the OHBC system at the Pasir Panjang Terminal at PSA. On April 3, 1997 the first two Keppel/Mitsui cranes were installed. Twenty two more followed over the course of 1997. Twelve more were supplied in 1998 and the final 12 will be installed over the course of 1999. These incorporate what PSA claims to be the latest technology, namely an automatic crane control system(ACCS) comprising an APIS, an automatic travel control system, a stack profile scanning system and an automatic fine alignment system. The prime reason for PSA investing in the OHBC system is that both land and labour costs in Singapore are very high. The result of this is that the cranes, which run on girders mounted on 28ft tall concrete pillars, are high enough to be able to stack containers one over eight high and up to 10 wide plus three truck lanes. This is a big advance when compared with the one over six high stacks attainable by the MHI RTGs at Modern Terminals at Hong Kong and also by PSA's own Keppel Mitsui RTGs. The lifting mechanism, which has a capacity of 40tons, is comprised of a winch hoist and a spreader, suspended at the headblock which attached by ropes to the trolley. The drives are powered by AC motors and except for hoisting, DC drives are used, achieving horizontal travel speeds of 90m/minute when loaded, 120m/minute when unladen and a trolley speed of 70m/minute. Laden hoisting speeds average 53m/minute, the fastest attainable by any yard crane in service, well over twice the rate for most RTGs in operation. Unladen, a maximum of 130m/minute is possible.

The initial plan at PSA was to use the OHBCs in conjunction with AGVs. This plan is now on indefinite hold. The ABB-supplied ACCS

was to be used for picking up containers from AGVs, and using the ABB CPC electronic anti-sway and load position control unit. Used in conjunction with a Target Positioning Sensor(TPS), it facilitates the automatic pick-up and landing of containers in the stack or on vehicles. The TPS is a piece of laser-based equipment which is used for fine alignment of the stack and profile scanning.

However, currently precise remote positioning is only possible with PSA's own prime movers and not with vehicles arriving from outside the port. This is because there is no uniformity in their dimensions. Consequently, the OHBCs used for interfacing with external vehicles are manually operated. They are controlled two at a time by operators situated in the terminal control room. As with other advanced crane systems the OHBCs operating status and diagnostics can be monitored from the central control via a computerised crane management package.

4.3 Automated Guidance Vehicles AGVs

4.3.1 Introduction

As with other technologies recently taken up by the container handling sector such as bridge cranes, AGVs themselves were not a new concept when ECT and PSA initially began testing them in a container terminal application. However, the container terminal creates different technological requirements. The earlier versions were designed to work in enclosed environments and as such were battery-powered surfaces. Moreover they did not require non-stop, round-the-clock operating. Unlike other yard container handling machinery which the large suppliers can manufacture to a standard in bulk at relatively low cost, AGV suppliers do not manufacture heavy-load versions unless there is a definite buyer.

The prime reasons for ECT opting for AGVs are the same as for automation of other terminal equipment: to save on long term high labour costs and human error or motivational problems and to achieve round-the-clock productivity.

For outdoor operations AGVs need to be considerably more robust than an indoor type of vehicle capable of withstanding repetitive shocks as containers land on the chassis at the shore-side and travelling 24hours a day over uneven surfaces in all kinds of weather. Such specifications clearly add to R & D costs, making this type of system only a viable option where cost benefits will outweigh alternative labour costs in the long term.

To date, MDGottwald is the only large scale manufacturer of AGVs for container handling, supplying ECT. Kamag and MES have tested their designs in Singapore during PSA's AGV trial. Several other suppliers have prototype designs including: MHI, Liftech Oy and Huisman-Itres.

The key to an effective multi-AGV operation lies in the traffic control system. Essentially there are two types of traffic control. The first, central traffic(CT) control is where there is no information processing 'intelligence' either built into the AGVs or installed at specific zones within the infrastructure. Zones are those areas bordered by track interactions. Here all vehicle movements are directly controlled by the systems central traffic controller via a system of mutual exclusion. Distributed traffic(DT) control is where the AGVs and possibly the critical zones have some form of 'built-in intelligence' implying that overall 'control' is replaced by 'coordination'.

As ECT was the pioneer in the use of the trailer-train concept so it has also been at the forefront in implementing AGV technology. Currently, ECT is the only operator actively using AGVs, though PSA has been carrying out extensive trials for several years and Thamesport has postponed the idea after successful tests with its Terberg/Firefly prototype. NKK also considered

using AGVs within a totally automated terminal at Kawasaki.

4.3.2 AGVs at ECT

ECT now around operates 150 AGVs at the Delta/Sea-Land terminal(DSL) and the Delta Dedicated East(DDE) terminal, manufactured by MDGottwald. Since their introduction, the vehicles have undergone around 70 modifications. At the time of writing Hutchinson Port Holdings are seeking EU approval to purchase ECT. This cast some doubt as to whether the AGV development would continue. However, at the Container Handling Conference in London in 1999, the Director of ECT confirmed that Hutchinson was committed to maintaining AGV development at ECT.

ECT's AGVs, purpose-built for use at DSL, are two-axled, four-wheeled chassis, capable of carrying either a 20ft, 40ft or 45ft container of up to 40tons. Powered by a DAF diesel engine, they can run 24hours a day for several days without refueling. Transmission is automatic with a specially designed torque converter built in. Both axles are steerable, but only one is driven, allowing for a high degree of manoeuvrability including crabbing. Maximum speed fully laden is around 18kms/h. AGVs are capable of climbing a one in twenty gradient.

In late 1998, ECT asked MDGottwald to develop a new AGV model with an increased capacity of 60 tonnes, configured to allow one 45ft, one 45ft or two 20ft boxes to be carried, rather than just one container as at present. The development and testing programme of the new model, the CT60, has now been completed. The CT60 incorporates an onboard MDGottward computerised navigation system (Navimatic) with data input from fleet control as to the desired path, to constantly compare and monitor position and heading (every 20 milliseconds) with the subterranean transponders. If there is any track deviation it will make the necessary speed and

positioning adjustments to bring the AGV back onto the programmed path.

Navimatic features a positioning accuracy of less than 20mm, a repeating accuracy of less than 1°, cycle time for serious tasks of one millisecond and cycle time for navigation purposes of 20 milliseconds. It has smooth steering algorithms, smooth driving and positioning algorithms, slip error detection and detailed maintenance interface.

For the new CT60 models, operating speed is normally between 12km/hr. The speed can be set to 25km/hr but any faster is not recommended because of the possibility of containers overbalancing on the track curves and the speed over the transponder would be too fast for adequate readings and responses of the fleet control programme. The first deliveries were made in June 1999 and 41 of the new vehicles will be in operation by 2000.

At present, navigation is based on a combination of grid technology and FROG (Free arranging on grid), developed by Industrial Contractors Holland. The system is based upon position estimation with odometry, combined with position calibration on a point grid made up from passive transponders buried beneath the terminal surface. This allows AGVs to roam freely, rather than along fixed axes. When an AGV passes over a transponder, this is activated by an antenna under the AGV determining the absolute position on the grid. An on-board micro-processor controls the steering via an RDT link to the Traffic Control System. The mechanical and electrical functions are controlled by a Siemens Simatic 55 programmable logic controller which also acts as a diagnostic system, detecting fuel and oil levels, faulty components and so on.

While the DSL terminal has been specifically designed to be 'unmanned', each AGV is fitted with infra-red sensors at the front and rear which can locate objects within a 10-12m range at optimum speed. AGVs move by

'claiming' 10m areas ahead ('claiming areas'), using the RDT-central control link. In short, these 'areas' ahead of the vehicles are sensed out to check that there are no obstacles in their path. Should there be, the AGVs stop and only move once the obstacle has quit the 'claiming area'.

The AGVs shuttle between the area beneath the quay cranes to the Automated Stacking Cranes(ASC) at the stack. The interchange between the AGVs and the ASCs is controlled centrally. AGVs are part of the overall logistics system.

4.3.3 PSA's AGV Trial

While ECT has years of experience testing and actually operating AGVs, PSA has yet to settle on any system, having been carrying out tests with both MES and Kamag AGVs. Field trials beginning in 1994 involved using three Kamag and two MES machines at the Brani terminal. Tests involved working a single berth using five quay cranes in conjunction with five AGVs.

In the same way ECT's MDGottwald-built vehicles use the FROG system to control navigation, so the Kamag/MES chassis that were tested were fitted with Tadiran Telematic's AMOS navigational system (AGV Management and Operation System). At ECT transponders are used in a freeroaming grid format. But this has only been possible because DSL is a purpose-built automated terminal. PSA, which is hampered by lack land availability, has had to go down a different route.

The PSA prototype tender specified load travel speeds of 7m/second with cornering speeds and crabbing speeds of 4m/second which require 350HP engines. The AGVs themselves were fitted with an obstacle detection system consisting of two radar points at opposing diagonals which sweep through 270 ° to gain 360 ° range of visibility over a distance of 40m. As with the FROG system, AMOS detects the safety zone, the parameters of which are determined by speed and direction of travel. When an obstacle is sensed,

AMOS gives a command for the hydrostatic drive unit to slow down. Should an object appear within a smaller 'ahead' area, the obstacle detector gives a command to the navigation system. The Kamag versions have on-board diagnostic systems which were built into the electronic controller responsible for monitoring and controlling the hydraulic and electrical systems, engine parameters, drive and steering systems, signaling and warning lights and other components. Normal maintenance data is transmitted between the onboard communications system and the computer controlling the whole AGV operation. Once the AGV is sidelined to the maintenance area, a laptop computer could be used to receive a readout of the AGVs status including data on what work needs to be done. Work on all the main mechanical systems is made easy by mounting them in a self-contained Power Pack, located in the middle of the vehicle, which could be removed as a whole from the quick-disconnect couplings.

Tadiran claim that AMOS demonstrated a straight ahead drive at a speed of 6.5m/second, with an accuracy of +/-10cm along the lane, the abilities to change lanes to parallel, u-turn to a parallel lane at 20m distance and turn to perpendicular lanes at speeds of up to 3m/second with loads of up to 50 tons. However, Tadiran is currently undertaking further research and development to improve the system's performance to achieve higher driving and docking accuracy, faster reactions to commands, faster and easier adaptation to various types of AGV and more autonomous control of the AGV.

PSA and other companies involved in the project spent considerable time and effort developing AGVs for the Pasir Panjang terminal(PPT). To date, no AGVs have been put into use at PSA. The initial trials conducted with Kamag and MES AGVs and the AMOS navigation system were completed in 1997. The latest available information is that PSA intends to start replacing its current prime movers with AGVs beginning in December 2002 at PPT

Berth 6. The operational system will be tested in 2003. When this is successful, the intention is to extend the AGV system to other PPT berths. PSA calculates that AGV's will permit each berth to handle a minimum of 750,000 TEUs.

Despite PSA regarding the initial trials as commendable, it is understood that the initial results did not meet the demands of PSA's complex operational requirements. In May, 1998, it was announced that, for the final phase of development, agreements had been signed between PSA DSO National Laboratories and CET Technologies Pte Ltd. This next phase of development seeks to improve further the vehicle control, navigation sensors, algorithms and wireless communications. DSO will design and develop the Navigation Systems and handle the design integration of the entire AGV system based on PSA's specifications and requirements while ECT will supply and integrate the components used in the Navigation System. PSA will provide the terminal operations knowledge for the project and also develop the AGV Deployment System(ADS).

4.3.4 The HHLA Altenwerder Terminal

HHLA and its container handling subsidiary Container Terminal Altenwerder GmbH announced a decision on the technology for the new Altenwerder terminal in Hamburg. This terminal is planned for completion in 2003. The terminal will use the double trolley crane design developed for HHLA by Noell and the ASCs. The quay to stack transfer will be by AGV. All that is known about the AGV's design is that they are to be a diesel electric, rubber tyred vehicle capable of carrying up to two standard containers at a speed of 6m/second. The planned navigation system consists of 'electronic markers' (transponders) set in the ground that the AGV reads when passing. The first stage of the terminal is

planned for completion at the end of 2001. This will see two berths designed to handle 1. 1 million TEUs a year in operation.

4.3.5 Other AGV Prototypes

Several manufacturers have developed AGV prototypes on the scale necessary for automating quay to stack transfer.

1) Huisman-Itrec AGV

Huisman Special Lifting Equipment BV, part of Huisman-Itrec of the Netherlands, have designed an AGV for use in heavy industry. The design originated in the MA thesis of Marco Broer, a student of Delft University in the Netherlands. Called the Self Propelled Modular Transporter (SPMT), a vehicle is in use in Huisman's own factory.

The SPMT is a modular design vehicle consisting of two independent halves split longitudinally. Depending on the application, different size and shaped middle sections can be coupled between the halves or they can be coupled together. Multiple SPMTs can also be coupled together lengthwise. Each half is identical with its own diesel hydraulic drive powered by a DAF diesel engine, electronic unit, braking unit and hydraulic lifting unit. Speed is controlled by a digital electronic control system, controlling the engine speed, displacement of the drive and the drive motors. A configuration of transporters can operate either with traction control or with speed control.

Unlike other AGV designs, the SPMT lifts a load by driving underneath a raised platform and then lifting the platform, and the container placed on it. A hydraulic lifting system is employed to raise the load. Each lifting cylinder can be allocated to a specific lifting by means of ball valves. For container handling, the SPMT would lift containers from a raised platform.

The containers would be placed on steel frames supported by the raised platform. The SPMT would then lift the container and the frame from under the platform. Unloading would be the same process in reverse.

The vehicle has crabbing steering and can turn at 90°. Navigation is achieved by DGPS. The SMPT offers considerable saving on vehicle turning space in the yard. Huisman-Itrec calculate that the SMPT could operate in a yard with 60m between the quay crane and the stack buffer.

2) Kamag AGV

The Kamag AGV itself is of welded steel, two-axle construction and is capable of carrying a 20, 40 or 45ft container. Both axles are designed as steering axles with brakes. Only one axle is driven. The drive system consists of Mercedez Benz OM 401 LA watercooled diesel engine producing 302HP at 1.900rpm linked to a hydraulic motor, driving a gear on the axle differential, which itself drives the outside planetary gears connected to the wheels. The drive is hydrostatic to provide smooth acceleration over a wide range of operating conditions. Braking is regulated by opposing the direction of travel, thus reducing wear on the normal braking components.

Both wheels on an axle are connected by tie rods. They are steered by two steering cylinders acting independently on each wheel. Drive and steering encoders are integrated on the axle. To ensure optimum traction and steering on uneven ground or roadways, the non-drive axle is mounted with pendulum bearings. The drive axle is rigidly mounted to the frame structure. The electronic steering system is equipped with four different steering programmes:

- MODE 1 - Normal Drive with all-wheel steering(+/-40°)
- MODE 2 - Front Wheel Steering
- MODE 3 - Rear Wheel Steering

- MODE 4 - Parallel Steering

Kamag offers three different safety systems. The first is the Obstacle Detection System(ODS), free of contracts. This involves sensors looking for movement in safety zones straight ahead and sideways. The sensors have a range of 30m front and back and 5m sideways. Two zones are monitored: The Emergency Stop Zone and the Deceleration Zone. Deceleration zone distances are reduced with speed. The second safety system is a front and rear ultrasonic system. The third is a mechanical emergency stop system.

<Table 4-4> Kamag AGV Specifications

Payload	40,000kg
Vehicle deadweight	18,000kg
Tyres	8X 13.00R 25 Twin
Axle loads	2X 29,000kg
Max traction	Approx 5,300 daN
Max gradient ability loaded	6.5%
Maximum loaded speed (flat ground)	20km/h
Acceleration to full speed	20 seconds
Turning radius (all wheel steer mode)	11.5m

3) The MES AGV

The MES AGV tested at PSA featured several key differences from the Kamag model:

- Whereas the Kamag AGV's featured an ultrasonic back-up electronic bumper, the MES version used a less costly but larger mechanical bumper.
- The Kamag AGVs had independent steering mechanisms while the MES machines used intermediate tie rods.
- By using an extra sensor at the wheel measuring time against distance

covered, the Kamag units were able to accelerate over the same distance whether laden or not. The MES AGVs did not have this feature and were reported as accelerating faster when empty, but slower when laden.

4.3.6 Merits and Potential of AGVs

There are varying opinions of the merits of AGVs in container terminals. Their greatest benefits are a potential reduction in labour costs and an increase in safety. Speaking at the 1999 Container Handling Technology conference in London, Rob van Eijndoven, Director of ECT, argued that AGVs are definitely economically viable. Without providing a numerical comparison, Eijndoven estimated that AGVs, in combination with ASCs, had reduced the number of people needed in a crane team from seven or eight down to three.

When they were introduced at ECT, AGVs were intended to be capable of supporting high speed cranes operating at 50 moves per hour. As with any new technology, there were obviously problems implementing AGVs. It is understood that productivity at ECT was around the level of 25 moves per hour, later moving to 30 moves per hour. ECT now plans to increase its productivity from 30 moves per hour to 35 moves per hour by further enhancements to the AGV operation. The new MDGottwald AGVs that can carry two twenty foot containers at a time offer considerable potential to achieve this by allowing twin-lift operations.

Noticeably, the plan for the new North-West terminal on the Maasvlakte includes AGVs, reflecting the belief of the research and design team that they can achieve the kind of productivity levels estimated as necessary to service vessels of 8,000 TEUs in 24 hours. As far as AGVs themselves are concerned, it is worth noting that the Smagic project involves giving them more 'intelligence' to improve their operational flexibility.

Although ECT remains committed to AGVs, the position of PSA is less certain. AGV implementation at PSA seems a long way off and is still subject to satisfactory further development.

As discussed above, HHLA recently announced its decision to implement AGVs as part of a new automated terminal at Alternwerder. The first two berths of the automated facility are expected to be operational by the end of 2001, representing a major breakthrough in terminal automation. While the tender process is not expected to be completed until the end of 1999, this is the first time since ECT implemented AGVs that another terminal made a concrete decision to follow its lead. HHLA expects that the total investment in the four-berth terminal will be in the region of DM $670 million. This includes seven quay cranes and 60 AGVs. It is not known what the cost of the AGVs themselves was.

As far as Thamesport is concerned, while no firm commitment has yet been made, it seems clear that it intends to introduce AGVs in the near future. AGVs were part of the initial plan when Thamesport was constructed, but lack of development funds forced the idea to be shelved. Thamesport still plans to use the radar navigation system that it tested in 1993. This technology is now being developed for straddle carrier automation in Patrick terminals in Australia.

For an established terminal with a large investment in infrastructure, switching to an AGV operation is still very high. AGVs may be a considerably more attractive investment for a green field terminal. However, despite many new terminals carefully considering the idea, as yet only HHLA at Alternwerder has opted for AGVs. Another of the latest terminals, Ceres in Amsterdam, will be a straddle carrier direct operation. However, MDGottwald considers that AGVs are gaining in an acceptance momentum, but because of the initial capital cost outlay, AGVs are really only feasible

where there are high labour costs. In terminals where labour costs are lower, a labour intensive operation is more economical at present.

MDGottwald is currently engaged in extensive negotiations with a number of major ports throughout the world. Negotiations involve the vehicle and the layout and systemic planning of the terminal. MDGottwald expects that within three years, at least one more port will be in operation with its AGVs. Other manufactures, such as Huisman-Itrec, have been involved in discussions with container terminals, but have not yet secured any firm commitments.

4.4 Terminal Operating Systems

4.4.1 Introduction

Historically, terminal operations have centered on cranes and yard vehicles carrying out their tasks virtually in isolation. However, as typified by advanced operators such as PSA, ECT and Thamesport the trend is towards wholly integrated systems whereby each component in the terminal set-up dovetails with another, so minimizing equipment non-productive time. Many aspects of terminal equipment operations are already semi-automated but the focus has been on automated vehicle steering/guidance and positioning systems as exemplified by the AGVs at ECT, the unmanned overhead bridge cranes at PSA and the driverless RMGs at numerous other ports.

While labour cost reduction has been a prime motivation to automate, often accompanied by skills shortages, the main motivating factor has been improved productivity. This is in part achieved through faster and more efficient equipment performance.

Perhaps more important has been the linking up of all the logistics parameters to the central control system. Full control of terminal equipment

is achieved by being able to marry the physical flow of goods to the information flow. This section looks at the components that go into making up the overall terminal management system: container/terminal vehicle tracking and the planning/management systems they interface with.

Efficient terminal operation is to integrate all activities within the terminal area into a seamless whole. A number of terminal operators have or are developing their own software for integrated management systems which bring together planning packages designed for stowage, yard, traffic, EDI and berth control. At Bremen, for instance, BLG claims that its most state-of-the art technology is its in-house developed Van Carrier Operating System(VCOS). Felixstowe, Southampton, PSA and Hong Kong International Terminals are among others which have in-house management and planning systems. Others like Hessenatie, the Port of Hamburg and the Port of Genoa have set up software companies to develop proprietary systems made available for use by other operators. The Hessenatie Group includes Cosmos NV which is well known for its yard planning system SPACE, vessel planning system SHIPS, transporter control system TRAFIC, EDI messages monitor SIGNAL and the Container Terminal Control System(CTCS) which communicates with these modules.

The vast majority of available software systems are PC-based. Recently, the market leader, the Navis' SPARCS system formerly Apple Macintosh-based, running off the Apple system 7 operating system, is now Windows '95 compatible. Most other operating systems are either DOS, UNIX or Windows. The latter is used with Cosmos' SHIPS, SPACE and TRAFIC packages.

Packages are available either as integrated modules or as separate applications, covering all or most aspects of modern container terminal operations including stowage, berth, yard and rail planning, gate processing, customs, payment control, EDI interfacing etc. Most systems are also

compatible with radio data terminals and the Internet while some can be interfaced with (D)GPS systems.

4.4.2 Typical Structure of Terminal Operating Systems

On an elementary level, terminal operating systems have a three layered structure. The bottom layer is the database used for receiving and storing information about the containers themselves, including weight, destination, shipper number and so on. The medium layer is the planning module which plans the movements of containers through the yard and the loading/unloading sequences from vessels. The top layer is the control module which sends instructions to the crane and truck drivers and ensures all of the movements are made accurately.

1) Database

The database module stores, manages and communicates information about the containers in the terminal. This includes the name and contact details of the shipper, the destination address, the container number, its size, route, shipping line, haulier, contents, dangerous goods information, customs information and anything else which may be required.

This data is provided to the terminal on the Bill of Lading, a legal document which the shipper is obliged to provide to accompany the shipment. The Bill of Lading can either be faxed to the terminal and typed into the system manually, or it can be transmitted by EDI as an electronic document and input into the database automatically.

The database holds a record of the position of containers in the terminal at any time. It is updated whenever a container arrives through the terminal gate or on a vessel, or whenever a container is moved in the terminal. The

information in the database is used to plan terminal movements.

The database will keep records of all the container movements through the terminal, which can be referred to at any stage. The information can be used to print out reports and lists, such as a list of containers on a particular vessel, a list of containers carried by a specific haulier or a report about terminal performance. If the terminal system uses digital photographs or a driver identity scheme, this information is stored on the database. The database can be used to store billing information, prepare invoices and keep accounts.

Many terminal operating systems opt to use general database software which is not specific to the container industry, such as Oracle. They then use a database interface module, such as Navis EXPRESS, as an interface between the database and the rest of the system. The interface module performs all the tasks which are specific to a container terminal, such as preparing job data for the planning system, handling EDI and internet communications and distributing data around the terminal.

2) The Planning System

This can include a container yard planning system, a vessel planning system and sometimes a rail planning system.

The container yard planning system works out the optimum way to move the containers through the yard. The first containers to be moved are always placed on the top of a pile. Containers might be placed near to the vessel they are to be loaded onto or placed near the gate if they are to be driven out of the terminal. Straddle carrier and terminal tractor movements through the terminal are minimized.

The vessel planning system determines the optimum way to unload and load containers from the vessel so that crane and truck movements through

the terminal are minimized. When loading the vessel, containers are carefully placed so that the first containers to be removed at the next port of call of the vessel are placed at the top of a stack. All regulations covering segregation of hazardous goods on a vessel must be adhered to.

Similarly, the rail planning module determines how containers should be loaded or unloaded onto a train. This can get complex if there are a number of different trains in the yard going to different destinations being loaded simultaneously.

3) The Control System

This module issues detailed instructions to crane and truck drivers about the container movements which must be made through the terminal and the order in which they must be made. The instructions are transmitted to the trucks and cranes by radio data networks and displayed on mobile computers in the cab.

Many terminals use positioning systems to ensure that all the movements have been made accurately. The use of satellite positioning systems, to ensure that the crane is in the correct location, is gaining ground. Other options are radio tag systems which send a signal to the central computer when a straddle carrier passes a certain point. The computer system is also informed when the containers are moved up and sown or released, so it can ensure the containers are put down in the correct spot.

4.4.3 Inputs and Outputs to a Terminal Operating System

There are many forms of data input and output to a terminal operating system. Input includes notification from a shipping line about the cargo on board a vessel, notification from a haulier or rail company about the containers

to be brought into the terminal by road or rail, and notification from the gate system that a container has been brought into the terminal. Output includes notification to a shipping line about containers loaded onto a vessel and their position, notification to a haulier about a container awaiting collection and notification from the gate system that a container has left the terminal.

At present, most ports, terminals and shipping lines are using their own proprietary messaging format for this messaging. However, the use of the international UN-standard messaging format is gaining ground. These messages are developed by a number of organizations around the world, overseen by the United Nations, to ensure every company uses the same standard format. The format was originally developed to replace paper documents. For example, the BAPLIE message is sent from a shipping line to a container terminal to list the containers on board a ship and their position on the ship. This message replaces the bay plan paper document.

In the future, communication between computer systems is likely to move beyond transmission of batch data in standard formats towards constant communication. That means that rather than the shipping line sending the container terminal one single BAPLIE message describing the contents of a container vessel, the shipping line and container terminal will be in constant communication, The container terminal will have access to all the shipping line's data about vessels coming into the terminal and the shipping line will have access to data about all the containers coming through the terminal which are of concern to the shipping line.

This type of continual communication is made possible by the advance of the internet. The speed and reliability of the internet is increasing all the time as developments are made so that more information can be carried along a wire.

4.5 Communications Technology

4.5.1 Introduction

Communication within the terminal is just as important as equipment in the productivity equation. Misplaced containers and stacking errors are just as bad for terminal productivity, if not worse, than slow machinery systems. To achieve effective terminal control, it is necessary to have a realtime continuous communication link between the various components within the system which in turn leads to a highly efficient monitoring of container positions and equipment within the terminal. Modern terminal systems need to be seen as more than a way to achieve a greater level of automation. Traditional solutions, using a combination of paper or data-inputting based systems and a telephone or other 'wire/cable' - based communications, are relatively ineffective. As well as problems with time lapses between messages simply reducing efficiency, there is a lack of continuous monitoring. Often the location of a container is simply not known until it reaches a point where its position is checked or entered into a system. The chance of a misplaced container is greatly increased. Incorrectly received or transmitted messages can compound the problem.

The modern solution to such problems lies in wireless communications technology capable of transmitting and receiving signals in real-time. This section focuses on two such technologies. The first is focused on communications within the terminal environment. Radio Frequency Data Communication (RFDC) is the current standard for real-time communications between central control and terminal equipment. The second is that of electronic data information(EDI) which is the system of choice for real-time communication between the terminal and external parties.

4.5.2 Radio Frequency Data Communication

Some terminals, and the number is decreasing, still use voice radio systems, whether VHF or UHF, for communications between the central control and the manned yard equipment. Here, the operators are required to report their positions and job status to the control centre and to record their movements manually. In the control hub the controller has to key in the received information or write it down for a data entry clerk. This approach is subject to a relatively high level of error.

When tied in to an integrated terminal system. RFDC has, for those operators using it, proved invaluable in the scheduling of the most appropriate vehicles for particular jobs with a minimum of machine inactivity. For efficient scheduling it is necessary to have up-to-the-minute information detailing vehicle job status. Feedback on parameters, such as delays and estimated times for job completion, allows for flexibility in scheduling, thereby dispensing with having to dedicate vehicles for specific tasks. For instance, by dedicating straddle carriers to particular quay cranes time is wasted when a straddle carrier is required to wait in queue, when in fact there might be a container waiting underneath another crane at the other end of the dock. RFDC allows vehicles to interact directly with the central computer wherever they are in the terminal, either providing feedback or getting new work orders. This may involve considerable change for terminal staff used to a greater degree of independent decision making in their daily duties. However, experience has shown that productivity can be increased.

The key performance indicators for an RFDC system are response time, range and data throughput. For RFDC systems to work effectively, all the components must have the same processing power, otherwise the whole system will only process at the rate of the slowest constituent.

Most RFDC systems are supported by 32-bit processing power. The trend throughout those industries using RFDC is towards customized systems. This is because of the widely varying needs of the user and the characteristics of the working environment.

While there are bound to be slight variations in the set-up of RFDC systems, there are common features. In the cab there is either a mounted mobile data terminal or one that is hand held. The real-time communication link is made via the location of radio base stations around the terminal, thus creating a wireless local area network(LAN).

Each vehicle move or change in status is picked up by the mobile data terminal which transmits the data via the nearest base station to the host computer, which in turn verifies the accuracy of this information and updates that on the database, thus providing a real-time inventory of yard activities.

RFDC terminals need not just be mounted inside a vehicle cab but are also portable and in this instance are particularly useful in trucking yard management. Should a truck be directed to a specific location only to find it occupied, it can be re-directed by a person on the ground with a handset, which in turn updates the yard co-ordinator and the host computer. The yard co-ordinator first fixes a slot location system in order to maximize the yard trailer capacity and arrange the trailers. This is a diagram of the yard divided into zones which in turn are sub-divided into numbered trailer slots which act as reference points for the locating and organizing of trailers, thus doing away with the need for yard checks.

While there are RFDC systems available from LXE Inc. Teklogix Inc. and Morris among others, some of the larger terminal operators such PSA and ECT have designed their own applications. This is in part due to the fact that certain important criteria vary from port to port. This is the data capacity of radio frequency channels, the roaming effect and variation in

the times of transit.

1) Comparison of RFDC Systems

There are two systems currently used for RFDC application: narrow band and spread spectrum.

Narrow band systems operate in the 70cm band at around 400 and 512 Mhz. They transmit data up to 10,000 bits per second(bps). This equates to an average transmission rate in the vicinity of 75,000 characters per RF terminal per second. Narrow band systems are capable of transmitting data over a wide area of over 1000m, minimizing the number of antennas required.

Spread spectrum signals are transmitted over a wideband frequency, 2.4GHz or 900Mhz, using either Direct Sequence (DS) or Frequency Hopping (FH). With DS a continuous signal is transmitted over a very wide part of the overall available bandwidth. This allows for greater data throughput but power and range are compromised. Continuity is achieved via redundancy. This term is applied to the alternative transmission of binary-based digital data, where the '0' is converted into one long bit-stream and the '1' is inverted. This means that there could be up to 1,000 bits representing each individual bit. Even if the signal breaks up during a DS type transmission, the data can be statistically recovered using redundancy.

The approach using FH involves the sending of information by 'hopping' from one frequency to another with terminals and transmitters in synchronization. Normally, the number of frequencies 'hopped' is about fifty with the overall band remaining on each for less than one second. The advantage of FH is that usable power is more tightly concentrated, thus greater ranges can be obtained at only marginally lower data rates. On the negative side, because redundancy is not available, broken signals have to be sent again.

Both DS and FH occur in the 2.4-2.4835 GHz range, which is just beneath microwave levels, and the 90918MHz range. Maximum power output is dependent on the country of use, but almost always gives a lower range and propagation characteristics than narrow band. Because of the propagation properties of these very high frequencies and the low power output, spread spectrum transmission ranges are shorter than those of narrow band systems, but the volume of data is considerably higher at above 2 Mbits/second. Put another way, Spread Spectrum systems are better for transmitting more data faster over shorter ranges. They have a much faster band rate than narrow band. Therefore, they can transmit much more data: up to 200,000 characters per second. Coverage is spread spectrum's main disadvantage. It is dependent on the frequency and the power level allocated. There is a major difference in this area between Europe and the USA. In Europe spread the spectrum is allocated the 2.4-2.84GHz range and power is a limited to just 0.1W. There are some differences within Europe. Germany, for instance, has the 1.3 - 1.5GHz range available. In the USA the system is much more powerful, operating at 900MHz and 2W. Although opinions vary, when the difference in coverage is translated into the container terminal environment, a spread spectrum access point has, in the past. obtained 10-30% of the coverage of a narrow band access point. This means that much more infrastructure is required for a spread spectrum system.

According to UK-based National Semiconductor, as FH systems use a pseudo-random sequence to control the profile of 'hops' it is unlikely that they could be subjected to interference from DS or narrow band systems. Should a 'hop' cause interference, the 'packet' is regained in the subsequent 'packet' with only a 5% degradation in throughput. Where there are several DS and FH systems in the same location, the DS devices tend to show extensive 'jamming', but the FH systems tend to remain largely unaffected.

In June 1999 LXE introduced a new spread spectrum system claimed to be a major step in reducing the number of access points required for a spread spectrum system. Using the Spire antenna, developed by LXE's parent company EMS, LXE claims it is now possible to reduce the number of access points required for online and real-time data communications down to almost the same number as needed with a narrow band system. The Spire antenna can be placed between container stacks without suffering from significant interference in transmission.

The system was tested in Singapore, Hong Kong and Hamburg. Some vast improvements in coverage were recorded, including coverage from an access point in a four high reefer stack of up to 250m. Overall, LXE considers that it can now offer a spread spectrum system with coverage from each access point of 200m. This is a significant improvement on the previous 50m. In one test, better coverage was recorded with DS than FH, although both still met the needs of the particular terminal.

2) The Problem Interference

While spread spectrum technology is less prone to interference than narrow band, there can be a problem if the bandwidth becomes saturated by the proliferation of other wireless equipment such as RFID vehicle location devices. Cold or humid atmospheres also affect performance.

Interference in the radio frequency spectrum can be controlled by the regulated placement of narrow band frequencies in clearly defined non-overlapping frequency bands. Narrow band signals can compress large amounts of data into very narrow spaces so that radio frequency power is tightly concentrated into a signal that takes up a mere 'slice' of the frequency range. Two of the main approaches to controlling RFDC systems are

outlined below. The data presented here is UK-specific and is merely provided as an example.

One approach involves the use of approved equipment which can be used in the telemetry band, which uses frequencies in the 458.5-458.8 MHz range and a maximum power output of 0.5 watts. The equipment must have government approval, but the use of the Telemetry band is otherwise un-regulated and as such no transmission license is needed. Using 32-bit based technology data rates of up to 9600 bands are allowed, though this still provides sub-second response times. The problem is that with un-regulated frequencies there is, in theory, no ceiling on the number of radio station set-ups. The only solution to the likely resulting interference is to find an unoccupied frequency. It is considered advisable to obtain a full spectrum analysis of the area to be covered in order to identify existing current signals before investing in an RFDC system.

In the UK, for example, potential buyers of narrow band systems can buy a license to operate, using frequencies in either the 430-450 MHz (UHF 1) or 450-470 MHz (UHF 2) ranges. Power output of up to 2 watts can be used, thus enabling greater transmission ranges, but speed is compromised where transmission rates of 4800 band are the maximum, in accordance with UK government regulations. A licensed system is protected from interference from unlicensed users.

A similar problem to interference is absorption. Higher frequencies, such as those used with spread spectrum, are more easily absorbed by dense cargo, such as paper and wood. Because narrow band operates at a much lower frequency, it is prone to this problem.

3) Choosing a System

There are a number of key factors to consider when making a decision on whether to use a narrow band of a spread spectrum system. In terms of price, narrow band systems are cheaper in the main. This is because spread spectrum systems have in the past required somewhere between 2-8 times more access points than a narrow band system. For LXE, this equation may change significantly with its new spread spectrum system based on the Spire antenna. Narrow band systems have been favoured because most terminals can easily operate with them. Therefore, the extra cost of spread spectrum is not justified. This is reflected in the most recent deliveries of Teklogix and LXE. Of Teklogix's seven major installations in 1998, six were for narrow band. Of LXE's recent installations, only one has been a spread spectrum system.

The recent increase in the use DGPS technology for yard vehicle positioning and tracking is likely to lead to a greater use of spread spectrum systems. The greater information carrying capacity of spread spectrum means that it is possible to put more devices on the system backbone. Spread spectrum, while more expensive, enables a terminal to put both voice and data on the same band. For a terminal that requires this, only one frequency is needed. This makes the two systems more comparable in terms of cost. Spread spectrum coverage is also beneficial to a terminal that has in operation a RFDC system in client/server mode and/or using a graphical user interface.

The following comparison is provided by LXE.

<Table 4-5> Narrow Band/Spread Spectrum Comparison

	NARROW BAND SYSTEM	SPREAD SPECTRUM SYSTEM
Coverage	XX	
Throughput	X	XX
Material Penetration	XX	X
Speed	X	XX
RF Power	XX	X
Regulated license available	X	
Unlicensed usage		X
Interference sensitivity	XX	X

A further option is to combine the two systems. Teklogix offers base stations that support both spread spectrum and narrow band radio bands. One such system was recently installed at Shanghai Container Terminals Limited. Narrow band was used for the main terminal management system, with spread spectrum being employed for the gate operations where the small area and high data throughput made it more effective.

Which system is the most appropriate very much depends on the characteristics of the particular terminal, and perhaps more importantly, the country it is in. The technology has now reached a level where it may be appropriate to invest in hardware that is capable of supporting more data transmission than is currently required. Taking this long term approach allows for future growth.

4.6 Gate Operations - Personnel Identification Systems

With the exception of the Maher Terminal Logistics system, the OCR system described above do not identify truck drivers. While Maher has Perceptics cameras and computer software for this purpose, another approach is unique

identifier cards at entry and exit gates. These are common in other industries.

With respect to container terminals, the removal of standard checking-in procedures at the gate also reduces queuing at the gate, facilitates the transfer and exchange of information and hence speeds up the whole container handling process.

It is estimated that an undetected human input error occurs one in three hundred characters typed in. Automatic data capture technologies can reduce this error rate by a factor of at least 10,000. Such an improvement produces economic benefits, not only from faster input and hence greater levels of output, but also because they allow for unlimited data amendments. A particular benefit for intermodal operators is that data can be read at high speeds in a fraction of a second when using RFID systems.

The collected data is made immediately available to the central computer system, thereby saving someone having to read, check and take the document to the central control. However, it appears from research for this report that there are a number of larger terminal operators which still require drivers to leave their trucks and go into the gate office in order to get the necessary paperwork processed.

4.6.1 Machine-Readable Card Systems

Several terminals are now operating card-based Automatic Data Capture (ADC) systems. Many have developed their own in conjunction with an in-house community/EDI system.

The less common of the two main available formats is the magnetic stripe, the other being the 'smart card', though in the wider field, the former has the larger number of applications.

The magnetic stripe works on exactly the same principles as cash cards and transit tickets, whereby data is encoded onto material on the card, and

on coming into contact with a magnetic reading/encoding head the binary data bits are picked up and encoded into digital signals. The reader then transforms these back into data bits.

A much newer concept in ADC at container terminals in that of the Smart card, a credit card-sized piece of plastic, in which information is downloaded onto an embedded microchip. The advantage of these over magnetic stripe cards is that they can store considerably more data and can also embody minute processors, capable of adding, deleting and modifying data, manage transactions and control access to data. They are read from and written to either through contact points embedded on the card or through inductive coupling. The latter types can be read by bringing the card close to a reading surface without having to swipe.

At those terminals with smart/swipe card systems, the arriving truck driver swipes or inserts his card into the reader at the gate entrance. Contained on the chip are details related to: the driver and his haulage firm and the consignment to be picked up. Once this information has been retrieved and transmitted to the central computer, a first message is sent to a yard vehicle to the appropriate location in the stack to pick up the assigned container. A second message is relayed to the truck driver, informing him where to collect it.

Southampton Container Terminal has recently introduced its Advantage swipe card system. Trucks can be processed through the terminal gate by the driver entering an electronic PIN number. The system operates in tandem with manual gates. At present around 30% of haulers have opted for the Advantage system.

4.6.2 Biometric Identification

Of the available ADC technologies, biometric identification is the most

complex and expensive and as such it is not surprising that few of the survey respondents have even considered carrying out trials. One major North European operator has recently begun trials with its own in-house system.

The technology is most befitting in high security establishments where restricted access to unauthorised personnel is paramount and cost considerations are secondary. Container terminals do not quite fall into this category, though in those more high-technology operations which own equipment worth hundreds of millions of dollars, there probably is reason enough to install the most advanced security systems available.

As with other ADC technologies the purpose of biometris ID is to crate a unique pattern by encoding personal characteristics. Using some physiological feature, most appropriately a hand in the case of truck drivers, information is digitised and stored in the central computer's memory. ECT is a pioneer in using biometrics for driver identity verification. The procedure requires the trucking company to transmit the pre-information via EDI to the terminal. The information detailing the job in question is sent to the gate where the driver dismounts from his cab and checks in, using his swipe/smart card and left hand for biometric identification. Only when both sets of information have been verified as corresponding correctly is he given notification to proceed. The Cargo Card can be used to identify the driver, and hence the container being carried, at every stage through the terminal. ECT switched over to the Cargo Card system in May 1988 and other terminals are expected to follow.

ECT is currently working on increasing driver throughput before embarking on the next stage which will involve the driver not having to leave his cab.

PART II
A Study on the Operational Control and Layout Design of the ACT

5. Operational Control of an ACT

6. Design and Evaluation of an ACT

7. Economic Feasibility Study

8. Conclusion

5. Operational Control of an ACT

5.1 Port Resource Assignment

5.1.1 Equipment Assignment

1) Outline

Port resource assignment is to plan how much and when to allocate port resources including facilities, equipment and manpower and further to make decisions on how to dispatch port operation resources according to the plan. The main purpose of port resource assignment is to enhance the productivity of a terminal by efficient distribution of port resources and identification of system bottlenecks. The equipment assignment described in this section is to allocate container handling equipment for each operation and assign operations and tasks to each equipment. Quayside container crane closely related to ship berth planning is described in more details in 5.1.2 titled 'Berth Assignment'. Planning is described first of all, and then equipment dispatching for operations is discussed. This study is roughly divided into two parts in terms of the type of equipment - an ATC (Automated Transfer Crane) as a yard crane and an AGV (Automated Guided Vehicle) as a transporter. The study of Lai and Lam[9] shows that throughput, efficiency and waiting time in a container terminal depend on combination of various workload and equipment (i.e., how many yard cranes and yard tractors to be allocated to a C/C).

---

9) Lai, K. K., and Lam, K., "A Study of Container Yard Equipment Allocation Strategy in Hong Kong", *International Journal of Modeling and Simulation,* Vol.14, 1994, pp.134 138.

2) Assignment Using a Negotiation Based Bidding

(1) Outline

In an ACT, a large part of operation systems are unmannedly operated. With the centralized architecture of operation systems in the conventional terminal, it is difficult to cope with a variety of requirements in an ACT. Therefore, the distributed architecture of an operation system is suggested as an alternative.[10] In general, the distributed architecture is favorable in making rapid responses to changes in the system and preventing interruption of the entire system even in case a problem occurs, but unfavorable in developing and using effective relevant decision making procedures. Accordingly, this study intends to review the applicability of distributed architecture to the ACT and present the algorithm or methodology for equipment allocation. This study also describes the negotiation based bidding as the proper decision making procedures in order to construct the distributed architecture of operation system in an ACT. The negotiation based bidding is similar to commercial transactions in which demanders and suppliers negotiate prices. In this study, the negotiation is represented as the relationship between the operation agent requiring resources and the resource agent enabling to allocate resources, where agent, as the unit independently making decision, means the software controlling and managing an individual task, equipment, operation or groups of equipment.

The operation agent can be catagorized into the loading/discharging operation agent and the receiving/delivery operation agent according to the kinds of operation. The loading/discharging operation agent manages

---

10) Lin, G. Y., *A Distributed Production for Intelligent Manufacturing Systems* (Ph. D. Thesis), Purdue University, 1993.

the process of loading operations and discharging operations related to containerships. The receiving/delivery operation agent manages the process of receiving operations and delivery operations related to outside trucks.

First of all, the events triggering decision making in the negotiation based bidding will be described. The loading/discharging operation agent will request equipment when the actual work process is delayed comparing with the planned schedule, when interference between the ATCs occurs, or when the travel distance of equipment is extended. When the travel distance of the ATC is enlarged and work is delayed, it will be requested to add more ATCs. The receiving/delivery operation agent will request equipment when the waiting time of an outside truck exceeds the target waiting time. The resource agent, which manages ATCs or AGVs, requests new allocation of a operation when they complete the performing operation or become idle.

(2) Procedures

In order to apply the distributed operation system to equipment allocation, the information system identifying the terminal conditions on real time is required. The information system continues to monitor terminal conditions and detects requests of equipment allocation. When the operation agent requests equipment, it requests the resource agent to estimate the effect of allocation. The resource agent, which receives the request, submits the effect of re-allocation to other operation agents as well as the corresponding operation agent. Allocation of new equipment and re-allocation are decided in consideration of the effect of allocation and the location and condition of equipment.

The operation agent initiated negotiation refers to the negotiation occurring when the operation agent requests equipment due to the beginning of a new operation, delay of operations, trouble of equipment, etc. The

resource agent initiated negotiation refers to the negotiation occurring when equipment finishes an allocated work becomes idle and requests a new work.

① Operation agent initiated negotiation

[Stage 1] Request equipment and submit bid

When the operation agent requests the resource agent to allocate equipment additionally, the effect of allocating equipment is estimated. Using the estimated effect, the price bid is derived from the following formula:

$$P = \frac{E_i}{T_i} \text{ (or, } E_i = P \times T_i) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(2-1)}$$

$$E_i = \Delta M_i \times P_u \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(2-2)}$$

$$T_i = Q_i \times t \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(2-3)}$$

Where,

E_i : effect during the expected operation time when a unit of equipment i is added

T_i : expected operation time of equipment i (time interval required for completing the remainder of operations assigned to equipment i)

P : bid price

ⓐ In case of loading/discharging operations

P_u : amount of cost saved when the processing time of performing operations is reduced by a unit time.

ΔM_i : processing time reduced by adding a unit of equipment i required.

ⓑ In case of receiving/delivery operations

P_u : amount of cost saved when the waiting time of an outside truck is reduced by a unit time.

ΔM_i: average waiting time reduced for outside trucks by adding a unit of equipment i required.

In addition to the bid price estimated above, all other factors including kinds of work, kinds of equipment required, operation time, location of equipment request, etc. are combined for giving a bid to the resource agent.

[Stage 2] Request for revised agreement for allocated equipment

The resource agent being given a request for equipment from the operation agent identifies whether its bid price exceeds the minimum level and available equipment exists. When both conditions are satisfied, it allocates the equipment whose travel cost is the lowest.

When the bid price exceeds the minimum level but there is no available equipment, it requests other operation agents to revise the agreement. In this case, it should describe the kind of equipment required.

[Stage 3] Submission of revised conditions on revised agreement

The operation agent being given a request for revised agreement re-estimates allocation effect of the available equipment and makes a proposal reflecting expected operation time and current location for submitting to the resource agent. The estimation is made in the same manner as in requesting allocation of equipment.

[Stage 4] Evaluation of conditions on revised agreement

After collecting proposals for agreement from the operation agents, the optimal equipment allocation plan is drafted in consideration of bid prices, locations of work, current locations of equipment requested, etc. Estimation for selecting optimal equipment is derived from the following formula. Equation (2-4) is to estimate profit from allocation of equipment j to work k. Equipment j making the estimated value highest is allocated

to work k, where opportunity cost of equipment refers to its minimum bid price.

$$R_{jk} = P_k \times t_k - c_{jk} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}4)$$

$$c_{jk} = a_j \times t_k + s_j + d_{jk} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}5)$$

where,

R_{jk} : profit when equipment j is assigned to operation agent k

P_k : bid price of operation agent k

t_k : expected time of equipment allocation to operation agent k

c_{jk} : cost of allocation of equipment j to operation agent k

a_j : opportunity cost of equipment j

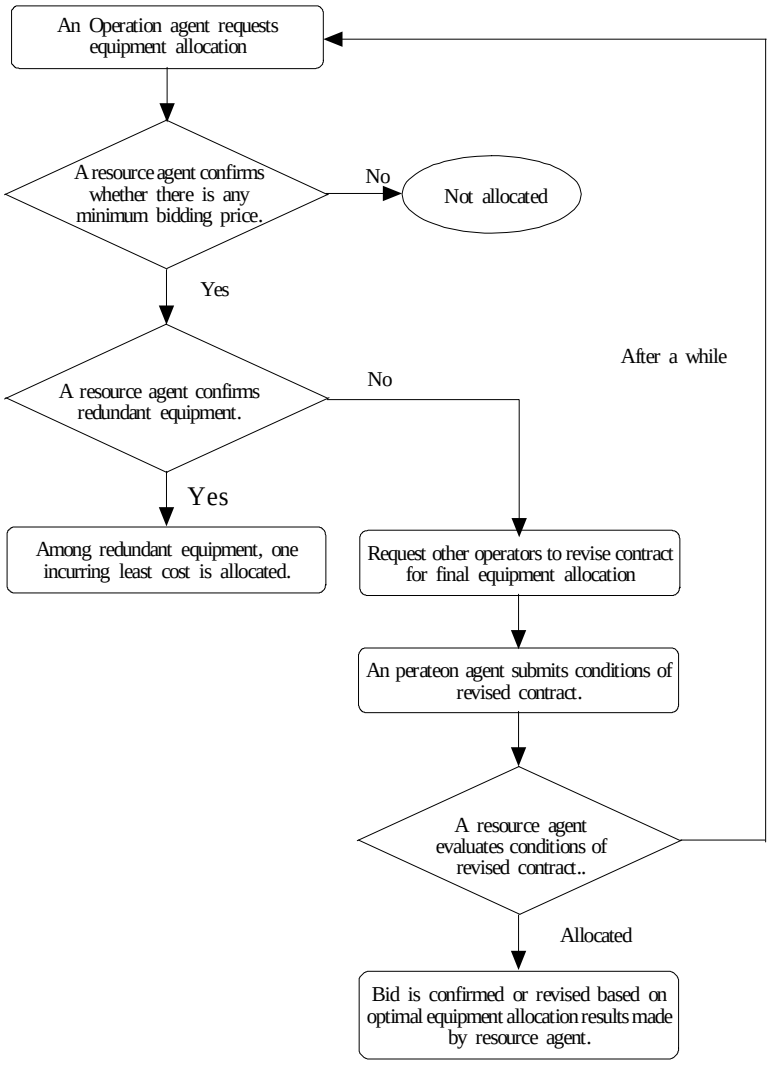
s_j : setup cost of equipment j

d_{jk} : travel cost of equipment j for operation agent k

[Stage 5] Signing and revision of agreement

Agreement is newly signed or renewed depending on the estimation results for optimal allocation of equipment made by the resource agent. Then, all the data is renewed and operation begins. In some cases, equipment is not additionally allocated but the current situation may continue. After an elapse of a certain period of time, this procedure is iterated, or another request for re-allocation is given to the resource agent. <Figure 5-1> shows the procedure of the operation agent initiated negotiation.

<Figure 5-1> Procedure of an Operation Agent Initiated Negotiation



② Resource Agent Initiated Negotiation

[Stage 1] Announcement of available equipment

When equipment becomes idle, it is classified as available equipment. The resource agent managing the available equipment notifies each

operation agent that the equipment is ready to be assigned, including its kind and location.

[Stage 2] Submission of bid

The operation agent that receives the announcement from the resource agent estimates the effect of additional allocation of the concerned equipment and the bid price. The estimation is made in the same formula as in the operation agent initiated negotiation. Then, the operation agent prepares a proposal in consideration of bid price, location of work and period of use time to submit it to the resource agent.

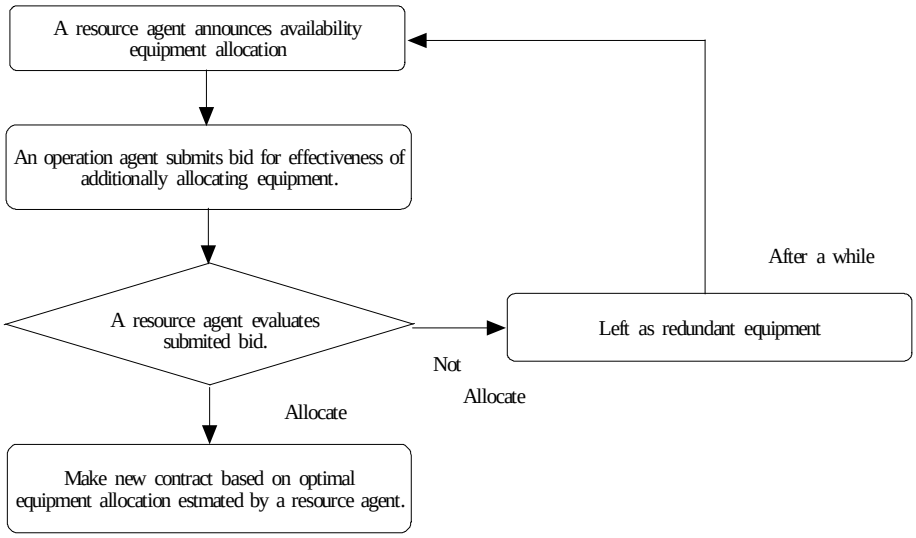
[Stage 3] Evaluation of proposal

The bids received from operation agents are evaluated in terms of bid price, location of work, location of equipment, operation time, etc. in order to make an optimal equipment allocation plan. Bids are evaluated in the same way as in the operation agent initiated negotiation.

[Stage 4] Signing of agreement

New agreements are signed according to the optimal equipment allocation plan prepared by the resource agent. When the effect of expected allocation is not satisfactory, agreement is not signed with the concerned equipment remaining available. When equipment is not allocated to remain available for a certain period even after the operation agent initiated negotiation, the negotiation procedures are taken again. <Figure 5-2> shows the procedure of the resource agent initiated negotiation.

<Figure 5-2> Procedure of a Resource Agent Initiated Negotiation



The most important estimator used in computation of expected cost and effect is the lifts per hour of a C/C in case of loading/discharging operation and the turnaround time of outside truck in case of receiving/delivery operations (to be easily computed from the waiting time of a truck). This estimator is evaluated through the stochastic model.

(3) Estimation of the Throughput Rate and the Number of Equipment Required for Loading/discharging Operations

① Definition of stochastic model and estimation of throughput capacity

The discharging operation among the loading/discharging operations is summarized herein. The analysis results may be used for the loading operation by simply replacing roles of a C/C with that of an ATC.

[Stage 1] Define states of each handling equipment.

<Table 5-1> describes states of each handling equipment required for loading/discharging operations.

<Table 5-1> Description of States of Each Handling Equipment

equipment	state	description
C/C	Blocked(B)	Operation is delayed because of no waiting AGV.
	Working(W)	Containers are discharged from a ship.
ATC	Idle(I)	Waiting the AGV to arrive
	Working(W)	Discharged containers are stacked in the yard.
AGV	Idle(I)	Waiting at the C/C to take over containers
	Blocked(B)	Waiting at the ATC to be served with containers loaded
	Loaded travel(L)	Traveling with containers loaded
	Empty travel(E)	Traveling without a container to the next location of operation

Handling equipment is systematically connected to with each other and treated as a gang of resources serving containers. Their states are expressed as providing service or waiting.

[Stage 2] Define of system state

System state is defined with the following notations :

X : State of a system

$S_{C/C}$: State of a C/C

S_{ATC} : State of an ATC

N_I : Number of AGVs waiting in front of a C/C

N_L : Number of loaded AGVs traveling to an ATC

N_B : Number of AGVs waiting in front of an ATC

N_E : Number of empty AGVs traveling to a C/C

N : Total number of AGVs

As shown in equation 2-6, system state is defined by combining states of all handling equipment.

$$X = (S_{C/C}, S_{ATC}, N_l, N_L, N_B, N_E) \cdots\cdots\cdots\cdots\cdots\cdots (2\text{-}6)$$

where, $N = N_l + N_L + N_B + N_E$

[Stage 3] System state as a whole defined by combining states of all handling equipment

The operation process can be defined in Continuous-Time Markov Chain on the assumption that the service times of handling equipment are distributed exponentially. Completion of service by equipment is defined as an event. When an event is completed, state is changed. The transition rate describing change between states is decided by multiplying the service rate of handling equipment by the number of handling equipment, on the assumption that service time is distributed exponentially. More than one state of equipment is related to the states of the system, in which state of the following equipment is decided by the state of the preceding equipment. The transition rate can be defined by the connecting state of each equipment.

<Figure 5-3> shows the relationship between states in case there is only one AGV.

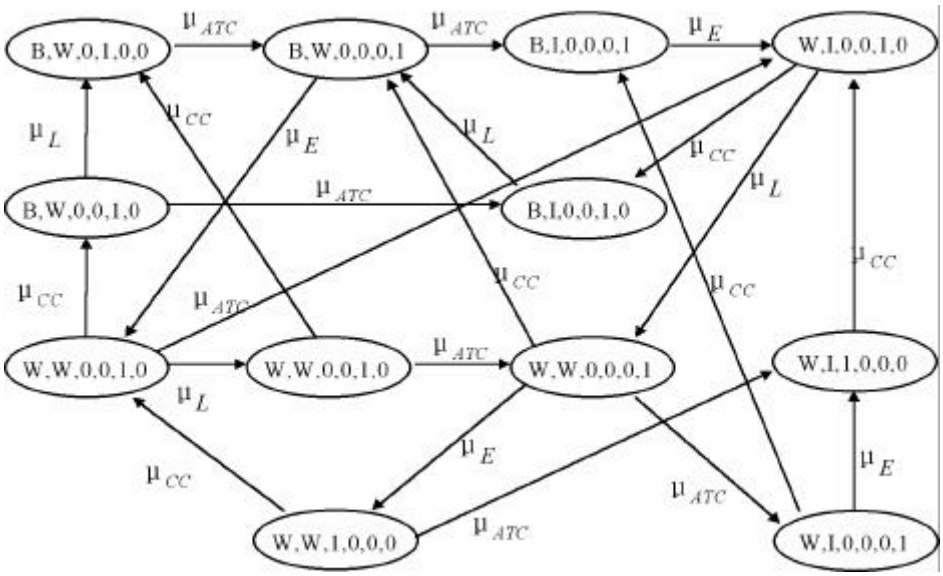
$\mu_{C/C}$: Service rate of a C/C

μ_{ATC} : Service rate of an ATC

μ_L : Service rate of a loaded AGV

μ_E : Service rate of an empty AGV

<Figure 5-3> State Diagram in Case of One AGV



[Stage 4] Estimation of steady-state probability for each state

As time passes, each state comes to have one steady-state probability. Steady-state means that the total transition rate within a state excluded equals to the total transition rate within a state included. Equation 2-7 shows transition between states at steady-state.

$$\sum_{i=1}^{m} P(i) y_{ij} \mu_{ij} = \sum_{k=1}^{m} P(j) y_{jk} \mu_{jk} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}7)$$

Where,

$X(i)$: State of equipment i

m : Number of states

$P(i)$: Steady-state probability of $X(i)$

y_{ij} : If $X(i)$ can be changed to $X(j)$, $y_{ij} = 1$. Otherwise, $y_{ij} = 0$.

μ_{ij} : it refers to transition rate from $X(i)$ to $X(j)$.

Formula 2-8 means that the sum of all steady-state probability is 1.

$$\sum_{i=1}^{m} P(i) = 1 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}8)$$

When Equations 2-7 and 2-8 are simultaneously solved, steady-state probability of each state can be obtained.

[Stage 5] Evaluation of loading/discharging operation's throughput with steady-state probabilities.

ⓐ C/C utilization ($U_{C/C}$)

$$U_{C/C} = \sum_{i=1}^{m} P(i) \cdot GW_i \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}9)$$

GW_i : If $S_{C/C} = W$ for $X(i)$, $GW_i = 1$

ⓑ ATC utilization (U_{ATC})

$$U_{C/C} = \sum_{i=1}^{m} P(i) \cdot TW_i \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}10)$$

TW_i : If $S_{ATC} = W$ for $X(i)$, $TW_i = 1$

ⓒ AGV utilization (U_{AGV})

$$U_{AGV} = \frac{\sum_{i=1}^{m} P(i) \cdot (N_L + N_E)}{N} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}11)$$

ⓓ AGV queue length in front of C/C ($L_{C/C}$)

$$L_{C/C} = \sum_{i=1}^{m} P(i) \cdot I_i \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}12)$$

I_i : N_i of $X(i)$

ⓔ AGV queue length in front of ATC (L_{ATC})

$$L_{ATC} = \sum_{i=1}^{m} P(i) \cdot B_i \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}13)$$

B_i : N_B of $X(i)$

ⓕ Throughput rate of loading/discharging operation (C_{sys})

$$C_{sys} = \mu_{C/C} \times U_{C/C} \quad \cdots\cdots \quad (2\text{-}14)$$

With Equation 2-14, we can cope with operations of a terminal in dynamic environment.

② Evaluation of the stochastic model through simulation

In order to evaluate validity of the stochastic model, the simulation was compared with the stochastic model. The service rates of C/Cs and ATCs were estimated with the actual data for application to the stochastic model, and the service rate of AGVs was estimated with the distance from the berth to the container yard and the speed of AGV. <Table 5-2> shows the results of the experiment made by setting the distance from the berth to the container yard at 65m, 400m and 750m, and the number of AGVs from 1 to 6.

<Table 5-2> Comparison of Stochastic Model and Simulation Model

Unit : container count per hour

Distance / No.of AGVs	65m		400m		750m	
	Stochastic Model	Simulation	Stochastic Model	Simulation	Stochastic Model	Simulation
1	25.6	31.6	11.4	10.3	6.6	4.6
2	28.6	32.0	19.2	17.8	12.4	9.1
3	29.9	32.0	24.2	22.8	17.3	13.2
4	30.6	32.0	27.3	28.0	21.3	17.3
5	31.1	32.0	29.1	31.2	24.5	21.3
6	31.4	32.0	30.1	32.0	26.8	24.9

The experiment results show that there is not so much difference between the stochastic model, in which service time is exponential distribution, and the simulation with actual data. <Table 5-2> shows that the results of stochastic

model is less than those of simulation value in case the distance is shorter, and vice versa in case the distance is longer. Considering convenience of the mathematical model, it is thought that the stochastic model is useful in spite of the possibility of a little error.

(4) Estimation of Waiting Time and Equipment Required for Receiving Delivery Operations

① Allocation of ATCs for receiving/delivery operations

In allocation of ATCs, the analysis of work factors at ATC is very important. Ryu[11] provided the basic data of standards and estimated operation rates of individual equipment and the entire system used at the terminal with that basic data. The basic data of standards was suggested by classifying work factors of transfer cranes and that equipment operated at the container terminal and then measuring that data. The processing times were analyzed again in terms of mean and variance for each work factor, and then the simple regression equation was drawn out. The equation, after goodness-of-fit, was finally used for analyzing standard time for each operation.

In receiving/delivery operation, ATCs will be allocated on the basis of the bidding procedure and its stages are same as the procedures described above. The queueing model described below will be used for allocating equipment at the beginning stage of receiving/delivery operation at operator's request. (For example, when the waiting time of a vehicle exceed the target waiting time)

If the ATC is working when an outside truck is in queue, then the outside truck shall wait. In this case, the queueing model is used for analyzing the

11) Ryu, M., *A Study on the Container Handling Time in Port Container Terminals* (Master Thesis), Pusan National University, 1998.

waiting time of the outside truck.

As arrivals occur at rate λ, the service time per ATC follows a general distribution, and only one ATC serves outside trucks, the M/G/1 queueing model can be used. <Table 5-3> shows the formula for the queueing model.

<Table 5-3> Basic Measures of Performance for M/G/1 (Receiving operation)

Item	Notation	Description
arrival rate	λ	Arrival of loaded outside truck
service time	$1/\mu$	Mean handling time + Mean travel time
congestion rate	$\rho=\lambda/\mu$	Utilization of an ATC
variance of service time	V	Variance of handling time + Variance of travel time variance
expected number of customers in system	$L_s = \rho + \frac{\lambda^2 V + \rho^2}{2(1-\rho)}$	
expected number of customers in queue	$L_q = \frac{\lambda^2 V + \rho^2}{2(1-\rho)}$	Mean length of waiting vehicles in block
expected waiting time in system	$W_s = \frac{L_s}{\lambda}$	Waiting time of arrival vehicles in block
expected waiting time in queue	$W_q = \frac{L_q}{\lambda}$	Waiting time of waiting vehicles in block

In case delivery operation is to be done with the ATC, it is not known when the ATC can serve the arriving external truck. So, analysis was made with the given arrival rate of outside trucks and the mean and variance of ATC's operation factors in the queueing model as follows.

Mean and variance of handling time ($\mu_{T_w}, \sigma^2_{T_w}$)

Mean and variance of travel time ($\mu_{T_m}, \sigma^2_{T_m}$)

Mean and variance of rehandling time($\mu_{T_r}, \sigma^2_{T_r}$)

In using the queueing model of M/G/1, the travel time was estimated on the basis of first-in-first-out (FIFO; in case of one block).

As means and variances of each operation factor are mutually exclusive, the mean and variance of service time can be derived as follow:

$$\mu\,(\text{mean}) = \frac{1}{\mu_{T_w} + \mu_{T_m} + \mu_{T_r}}$$

$$V(\text{variance}) = \sigma^2_{T_w} + \sigma^2_{T_m} + \sigma^2_{T_r}$$

② Determination of the number of ATCs for receiving/delivery operations

In the parallel layout, we studied operation with the division of import and export yards. Travel of ATCs may cause delay of operations in case of export, while, in case of import, ATCs do not have the work load and may be installed at the block relatively far away. In case there is possibility of dual cycle, however, it is thought to be effective to classify them differently. And, it is also more effective than not to classify them in terms of workload balancing.

3) ATC Allocation

Only the number of ATCs required is decided in loading/discharging operations, while the working region of ATC should also be decided in receiving/delivery operations. In general, determination of the number of ATCs is relatively simple in loading/discharging operation because the determination of the number of ATCs depends on the number of C/Cs, and ATC allocation depends on the working schedule of C/Cs. In receiving/delivery operation, however, decision making is more difficult because arrival of external trucks is not expected and service level also should be considered.

It is desirable to allocate ATCs to more urgent work according to the effect the effects of allocating an extra unit of equipment to various alternatives of work. It is not easy, however, to decide priority because various operational

conditions have different performance measures.

(1) Parallel Terminal Layout

In general, allocation of equipment by the loading/discharging operation agent depends upon the working region of the equipment because there are many cases in which only one ATC is allocated to a C/C. In this case, there may be no complicated theory of allocating equipment. Even though more than one ATC serve a unit of C/C, ATC allocation is not difficult because the loading plan is determined by of the working region and sequence for the C/C. But, there is possibility in which the loading plan gets complicated. In case of parallel layout, there is a probability in which a certain ATC is generally allocated to a certain C/C for exclusive and intensive operation, because it intends to minimize ATC travel. In receiving/delivery operation however, there are a number of points to be considered, and service level for external truck may heavily depend on decision making. In addition, scope and contents of strategies depend on the kinds of ATC - RTG or RMG.

It is important to allocate working region aiming to achieve service balancing for external trucks. In the discharging/loading operation, allocation of equipment by the loading/discharging operation agent equals determining the working region of the equipment because ATC is exclusively allocated to a certain C/C. In receiving/delivery operation, however, there should be a certain operation theory to properly allocate working region to each ATC because only the list of equipment is delivered to the receiving/delivery operation agent. When the receiving/delivery operation agent is given to one more ATC or hands over its allocated equipment to another operation agent, it is required to adjust working region of the equipment allocated to receiving/delivery operation agents.

Allocation of working region for receiving/delivery operation aims to

balance service rate. Working region is allocated to each ATC in consideration of the number of external trucks and the type of block. Allocation of working region refers to the coverage of block. In case the number of blocks where receiving operations occur is four and 2 ATCs are allocated to receiving operation, the block equal to half the whole operation volume will be allocated.

There are some points to be noted in allocating block in consideration of features of block layout and ATC in container terminal. Allocation balancing is not easy because the block layout of container terminal consists of run and section. In addition, ATC can easily travel along the run in block layout, but face difficulties in traveling along the section.

(2) Perpendicular Terminal Layout

The fact that working region of an ATC is fixed should be considered in yard planning for load balancing. Accordingly, the matter of ATC dispatching is an important issue in the perpendicular layout.

4) AGV Allocation

For this matter, other decision making procedures are required depending on which strategy is applied to AGV dispatching, such as dedicated dispatching, pooled dispatching. In case of pooled dispatching, a particular algorithm is not required. Accordingly, loading/discharging operation for allocation strategy will be described in assumption of dedicated dispatching hereinbelow.

5) ATC Dispatching

"Dispatching" is to assign specific works to certain equipment. It aims to maximize utilization of equipment and minimize operation delay or

waiting time. Whenever a C/C completes a operation, it notifies the corresponding ATC of the next work.

(1) Loading/Discharging Operation in a Parallel Terminal Layout

As C/C always announces work to be done, ATC comes to have several jobs. When AGV is dispatched, ATC is decided also. As loading/discharging operation is performed in orders listed up in the sequence list, specific theories of allocating jobs are not required.

(2) Receiving/Delivery Operation in a Parallel Terminal Layout

In conventional terminals, receiving/delivery operations are recorded in the operation system when vehicles pass the gate. In an automated terminal, delivery operation is same as the conventional terminal, but receiving operation is triggered when entrance instruction is given from the operation system. Lai and Lam[12] developed a new type of yard crane operation in order to reduce waiting time of container trucks and improve service level. First of all, they tested 4 strategies (FCFS, ODM, NT and SST) for scheduling of the yard crane with the simulation model. The test continued for more than 2 cranes. Finally, they suggested improved ways in consideration of effectiveness of the new layout strategy. Results indicated they learned that the nearest strategy is more excellent than the one-direction movement comprising all strategies. They also learned in the test of multiple yard cranes that the home area zone strategy (having its own region to provide service) is more excellent than the full stack zone strategy (providing service considering waiting trucks throughout the region).

The study of Lee[13] focused on reducing waiting time of trucks in

12) Lai, K. K., and Lam, K., "A Study of Container Yard Equipment Allocation Strategy in Hong Kong", *International Journal of Modeling and Simulation*, Vol.14, 1994, pp.134 138.

13) Lee, K. M., *Sequencing Delivery and Receiving Operations for Transfer Cranes*

order to improve service level in receiving/delivery operations. The study suggested using the reinforcement learning method for ATC dispatching. The test was made for the situation in which a transfer crane serves trucks arriving at various locations because the method of allocating working region to equipment for operation is improving efficiency of the entire system and demonstrating more excellent functions by preventing interference between equipments and allocating its own working region.

On the assumption that delay cost occurs when the operation is delayed over the limit of waiting time, the dynamic programming model was suggested to optimize static problems under the dynamic situation in which jobs continuously occurs to when deciding operation orders to minimize the total of such delay costs. And the reinforcement learning method was also suggested to compare it with other methods. In addition, comparative analysis was performed between the reinforcement method and other methods.

FCFS (First-Come-First-Served) : First coming trucks are served first.
UT (Unidirectional Travel) : Trucks are served in a direction, and if there is no truck in the direction, direction is changed.
NT (Nearest Truck First Served) : The truck nearest the crane is first served.
SPT (Shortest Processing Time Rule) : The truck whose service time(container handling time + travel time) is the shortest is first served.

(3) Loading/Discharging Operation in Perpendicular Layout

When a C/C completes a work, it notifies the corresponding ATC of the following operation. However, assignment is made when the concerned AGV

(Master Thesis), Pusan National University, 2000.

passes the relevant decision point on the route making a notification. At this moment, the concerned operation either belongs to the queueing model or is allocated to an ATC. Of course, the decision point may differ between loading and discharging (because of different required time). In the perpendicular layout, receiving/delivery and loading/discharging operations are performed by an ATC in a block, in which loading/discharging operation has always higher priority.

6) AGV Dispatching

In this chapter of AGV dispatching, only the loading/discharging operation is described. It is why receiving/delivery operation is performed either by the buffer yard or directly the external truck. In this connection, Bose et al.[14] studied the carrier-direct system operated with straddle carrier between quay and yard. Studies were focused on how to allocate transport works to straddle carriers in order to maximize productivity of container crane and reduce lay time of ships. Two alternatives were studied: dedicated dispatching of a carrier to a crane and pooled dispatching of a carrier to several cranes.

(1) Dedicated Dispatching

In dedicated dispatching, jobs of a C/C are allocated to an AGV one by one. Remaining jobs to be done by C/C are allocated in order.

(2) Pooled Dispatching

In pooled dispatching, C/Cs and AGVs are pooled for allocation. In the existing dispatching algorithm, dispatching is generally made at the rate of 1:N when vehicles become idle and operations are announced.

14) Bose, J. et al., "Vehicle Dispatching at Seaport Container Terminals Using Evolutionary Algorithms", *Working Paper*, Germany : Technical University Braunschweig, 1999.

Such a dispatching can be made in a simple rule, but its performance is said to be not so good. Accordingly, the centralized heuristic algorithm for pooled dispatching and the distributed AGV dispatching algorithm through negotiations are described below:

(3) Centralized AGV Dispatching

Kim and Bae[15] suggested the heuristic of AGV dispatching for loading/discharging operation of automated container terminals.

The purpose of AGV dispatching was set to minimize operation delay in comparison with the original C/C operation plan. In this case, performance of the AGV depends on the kinds of operation on ship - transport of containers from the yard to the C/C in case of loading, and transport of containers from the C/C to the yard in case of discharging. In this course, there is a point of time when operations are synchronized between a C/C and an AGV, which is called the event occurrence time. In case travel times of AGVs are not considered, the minimum event occurrence time and the interval of time which do not cause any delay can be estimated through analyses. In case the AGV travel distance increases during operations, however, the event occurrence time shall be inevitably enlarged. And such a delay is applied to all operations following the delayed work. In addition, various features of a container terminal and operation effect of AGV shall also be considered.

(4) Distributed AGV Dispatching

This section describes the distributed dispatching to minimize empty travel times of AGVs and delay times of operations.

---

15) Kim, K. H. and Bae, J. W., "A Dispatching Method for Automated Guided Vehicles to Minimize Delays of Containership Operation", *International Journal of Management Science*, Vol.5, 1999, pp.1 25.

¢7Ø x

The concept of distributed dispatching is based on the negotiation described above. For example, in case of vehicle, bid is given to the most profitable work after estimation of profit with handling charges and costs of each operation. The difference between alternatives bringing about the first and the second largest profit is also suggested. The operation having received more than 2 bids is degraded in attraction through lowering handling charges, while the operation having received no bid is upgraded in attraction through raising handling charges. A solution is sought for within the allowed limit in the course of adjusting handling charges in the first and the second best alternatives.

The handling charge of each operation is same at the initial stage, but may increase or decrease as assignment problems are solved. Cost depends on operation, transport equipment, travel distance and delay penalty. Travel distance refers from the point completing the present operation to the place of another container to be handled. Delay penalty is estimated in comparison of due-time with the expected time of work completion estimated with expected time of travel and operation. Deducted costs from the handling charge estimated in such a manner is the profit of a vehicle.

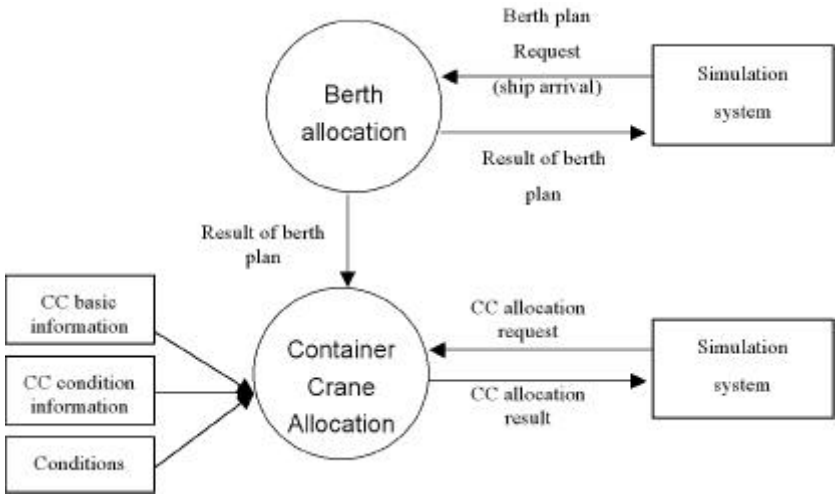
5.1.2 Berth Assignment

1) Outline

The objective of berth assignment is to decide the berthing times and locations for ships entering the container terminal and the number of C/Cs to perform loading/discharging operation. Therefore, berthing place shall be so decided that ships may berth at the most desirable place. Berthing time shall be so decided that ships can be most satisfied with

time of arrival and departure at the terminal. In addition, the number of C/Cs to perform operations shall be decided. In berth assignment, there will not be a great difference with the conventional terminal because the automation of loading/discharging operation is still difficult and there are a number of situations and requirements beyond control. Therefore, this section describes basic concepts and studies on the theoretical trends concerning berth assignment.

<Figure 5-4> System Diagram of Berth Assignment and C/C Assignment



2) Analysis of Existing Studies

○ Study of berth assignment with heuristic algorithm[16)]

This study described assignment problems on the assumption that berth is discretely located. In berth plan, the 0-1 integer programming model

16) Lee, H. G. and Lee, C. Y., "A Heuristic Algorithm of Berth Assignment Planning in a Container Terminal", *Journal of the Korea Institute of Port Research*, Vol. 8, 1995, pp.1 8.

was suggested to minimize total lay time of ships at terminal, total lay time at berth and maximum lay time at berth. It also suggested the method to establish berth plan in consideration of orders of ship arrival and operation of terminal by using the concept of MPS (Maximum Position Shift) showing the maximum tolerable allowance in orders of arrival and berth of ships. To solve realistic problems, this study performed numerical experiments suggesting heuristic algorithm with simple rules related to objective functions.

○ Study of container berth assignment[17)]

For the berth assignment strategies currently used in a container terminal, 3 new berth assignment strategies were suggested, and their effectiveness was compared and tested through computer simulation. This study also considered berth as discrete resources, one of several berths to be allocated to a ship. Simulations were performed to compare and analyze mean waiting time, mean system lay time, occupancy, etc. for the following 4 policies: **i**) Each firm has its own berths, but, in case of no available berth among its own berths, another available berth is immediately allocated (Policy A), **ii**) Berths are so allocated that ships can complete works and depart the system at earliest (Policy B), **iii**) An available berth is immediately allocated, and, in case of no available berth, ships are given weighted priority depending on large, medium and small size (Policy C), and **iv**) Ships are classified into 2 kinds, L and M class ships are given the earliest departure criteria, and S class ships are given berth on the FIFO basis in case of no L or M class ship (Policy D). As results, Policy B and Policy D were found to be better berth assignment strategies.

---

17) Lai, K. K. and Shih, K., "A Study of Container Berth Allocation.", *Journal of Advanced Transportation,* Vol.26, 1992, pp.45 60.

○ Study of berth planning problems[18)]

This study is related to the decision making of berth location of ships by describing it on a continuous line considering ship length, berth time, required operation time, minimum ship-to-ship distance and minimum distance from the end of berth are given. As the first trial to define berth in a continuous line, it is meaningful in the aspect that berth planning was studied in 2-dimension packing. It is studied to minimize the total berth length used at a certain time when berth time is fixed. It expressed its studies in graphics and decided berth place of a ship by using heuristic algorithm. Experiments were performed on the basis of actual date from Singapore.

○ Study of scheduling with multiple-job-on-one-processor pattern[19)]

This study defined berth assignment problems as scheduling problems in which several vessels are assigned to single process (berth). It approached the scheduling problems to minimize operation time by classifying the case of completing operation at an apron and another case of moving the operation place of a ship. It assumed that operation time is given, all ships have already arrived and width of a ship is large comparing with operation time. Experiments were made by applying first-fit decreasing heuristic on the ground of Bin packing problems and similarity. Analyses and experiments were made by applying heuristic algorithm both in case of inability to move a ship with transformed FFD heuristic and in case of enabling to move a ship by minimizing setup time.

---

18) Lim, A., "The berth planning problem", *Operation Research Letters*, Vol.22, 1988, pp.105 110.

19) Li, C. et al., "Scheduling with Multiple-job-on-one processor Pattern", *IIE Transactions*, Vol.30, 1998, pp.433 445.

○ Study of crane scheduling problems[20)]

This study suggested heuristic methods to decide the number of C/Cs to be allocated to each time zone by ship and by bay on the basis of the number of containers allocated to bays from a ship. It studied both the static case in which several ships have arrived and the dynamic case in which other ships arrive in the middle. In case ships have arrived, modelling was made in integer programming. Together with several useful allocation rules, heuristic methods were suggested as solutions.

The study of maximizing reduction of costs through earlier departure of ships and minimizing crane allocation costs have been done. One weak point is that it has neither solved interference between cranes nor studied crane allocation schedule in details. However, it is considered to be meaningful in the aspect that it first studied discharging crane scheduling.

○ Study of a branch and bound solution method for crane scheduling problem[21)]

Assuming that a ship has several holds required for discharging in the situation in which several ships are waiting, this study examined when to allocate a certain holder to a certain crane in order to minimize the total weighted berthing time with multiple cranes. The 0-1 integer programming model, and the branch and bound method through the optimization method have been suggested. In suggesting solutions, the 2-stage approach in which cranes are allocated aiming to satisfy departure time after finding the best departure schedule for each ship is used.

---

20) Daganzo, C. F., "The Crane Scheduling Problem", *Transportation Research-B*, Vol.24B, 1989, pp.159 172.

21) Peterkofsky, R. I. and Daganzo, C. F., "A Branch and Bound Solution Method for the Crane Scheduling Problem", *Transportation Research-B*, Vol.24B, 1990, pp.159 172.

Seeing that interference between cranes was not considered, it is thought that this study's main target was not the container terminal. Another weak point is that the study focused on a static case.

(1) Berth Assignment

① Decision of berthing time and place of ships arriving at a container terminal

② Features of berth assignment

- ○ To decide berthing place so that a ship can berth at its favorite place
- ○ To satisfy desired calling and departing time of a ship
- ○ To require safety distance between ships for berthing and departing convenience
- ○ To prepare berth planning in compliance with characteristics and operation strategies of terminal

Ships to be served in the same time zone should be given a certain space. And, ships to be served at the same berth should be given a certain interval of time. Operation commencement and completion times of each C/C shall be decided in consideration of available operation zone of the C/C so that loading/discharging operation can be completed within the planned berthing time.

(2) C/C Assignment

- ○ To allocate C/Cs so that loading/discharging operation can be completed within the planned berthing time
- ○ To decide starting and completion times of each C/C
- ○ To establish plans by classifying operational and supportive C/Cs at each berth and checking possibility to utilize supportive C/Cs

(3) C/C Re-Scheduling

- ○ To frequently check operations for ships and make C/C and berth

re-scheduling in case berth schedule is expected to be delayed due to delay in operations of ships

5.1.3 Gate Lane Assignment

1) Outline

Gate lane assignment is related to decision of entrance lane among several lanes in case external trucks arrive at the gate of the container terminal. This matter can be studied in 2 aspects. First the operational policies are studied to decide entrance lanes for a certain number of trucks expected to arrive for a certain planning period. Second the decision to use assigned gate lanes for arriving trucks during operation of terminal.

The first method is to establish a plan to allocate lanes for trucks expected to arrive by using such information as expected time of arrival, kinds of containers, utilization of EDI, operation time of each gate, etc. when information is available. In this case, plans can be made with the mathematical model of resource assignment problems. The second method is to allocate lanes for arriving trucks at a certain time of arrival in the course of actual operation of container terminal because information of future events including kinds of containers, EDI utilization, expected time of arrival of trucks, etc. may change from time to time. This section describes operations of gate lanes applicable to ATC.

2) Dedicated Lane Assignment

(1) Pusan Port

In Pusan and Kwangyang ports, container terminals are currently being operated with dedicated lanes for some containers. Each of them is allocating a dedicated lane at gate for on-dock firms because those gate lanes are separately equipped with inspection facilities for on-dock empty

containers. Of course, those dedicated lanes can be used for container trucks of other firms than on-dock firms. In Korea, there is no container terminal operating dedicated lanes to be allocated depending on kinds of container and EDI utilization. In addition, entrance and exit of special containers are operated at the rightmost lane of the gate where roof is not given as the lane should be large for entrance and exit of special containers. In Korea, there is no container terminal being operated with dedicated lanes for special containers.

(2) Pusan New Port

For gate lane assignment problems, the KPC made many simulations with 8 employees for 10 entrance lanes and 5 exit lanes at the gate which are closed during meal and shift times, in which 2-3 dedicated lanes were allocated for both the EDI utilizing trucks carrying red containers or empty caches and the trucks not utilizing EDI and carrying empty containers. But, the simulation results advanced from the basic scenario were not found. This means that service time for trucks at the gate is not closely related to the operation of dedicated lanes. Therefore, the KPC did not recommend operation of dedicated lanes.

5.1.4 Summary

In terms of allocating port resources, this section discussed operational strategies, such as equipment assignment, berth assignment and gate assignment, in an ACT. The characteristics and requirements of an ACT can be summarized as follows.

- More efficient information system
- Real time control of container handling equipment
- Flexible and rapid response for the changes of terminal
- Decision making without interference of operators

An ACT requires new approaches to the operation system because the operation system applied to conventional terminals cannot cope with a variety of requirements of ACTs. In this study, the procedure of negotiation based bidding is suggested to adopt the distributed architecture of operation system as a new approach.

The operation methods for ATCs, AGVs, and storage space are presented to increase the productivity of a terminal considering the characteristics and constraints of ACTs. Also, this study proposed mathematical models to secure reliability and efficiency of decision making.

Operational strategies for berth assignment and gate assignment in ACTs are expected to be similar to those in conventional terminals. So, the study on these operations focuses on the literature review of previous studies and the survey of cases used in current terminal.

5.2 Yard Operation Strategy

5.2.1 Outline

The throughput rate and the productivity of a terminal depend on size of a yard, yard layout, and fleet size of equipment etc. Therefore, to analyze and evaluate these in designing a container terminal, yard operational strategies should be reasonably studied.

Yard operation means decision making of container storage in consideration of yard conditions in terminal operation. Yard operation is closely related to not only yard storage conditions but also transporter travel and distribution of workload in a yard. Therefore, experts of yard planning and control dynamically operate container terminals analyzing and considering operation information case by case. Yard operation, aiming to distribute workload to maximize equipment operation efficiency within

certain yard capacity, plays an important role in an operation system to maximize productivity of the terminal.

The objective of this study is not to develope optimal strategies for yard operation but to suggest the ways to realization of an automated container terminal.

Decision making of yard operation consisted hierarchically of the planning stage to allocate storage space in the yard to specific containers and the operation stage to decide a specific storage place when gate-in discharging containers arrive at the storage space. Yard storage planning is the stage to allocate storage space in advance before individual containers arrive in consideration of stevedoring volume from a ship and expected time of operation, while the decision of storage place is to decide the planned storage space on real time basis in consideration of characteristics of containers and current conditions of yard when containers actually arrive at the yard. The study of Kim[22] who developed yard operation decision support system in analysis of operations in the Pusan container terminal, also set up a decision making structure for yard operation with the hierarchical structure of planning and control focusing on planning functions.

Yard operation strategies are suggested for perpendicular and parallel layouts of the yard block in consideration of the designed capacity of the crane, travel conditions of transporter, container flow and the difference in productivity therefrom.

First of all, generally applicable strategies and theoretical developments for yard operation are suggested in 5.2.2 by reviewing important goals of yard operational strategies. And then, theories of storage planning

---

22) Kim, K. H. et al., "Development of Decision Support System for the Yard Assignment Planning of the Import and Export Containers", *Korean Management Science Review*, Vol.12, 1995, pp.1-12.

are described in 5.2.3, and decision of storage place in 5.2.4. Last 5.2.5 summarizes the contents and results of 5.2, yard operational strategies.

5.2.2 Purposes of Yard Operation

1) Reduction of Operation Time

Time required for stevedoring operation largely consists of discharging time of C/C, discharging time of ATC and transport time of AGV. The way to reduce operation cycle time in yard operation is to allocate storage space enabling to reduce transport time of AGV and allocate equipment enabling to reduce discharging time of ATC.

In other words, in order to reduce transport time of AGV, containers shall be stored near the stevedoring place in consideration of not only transport route of AGV but also to limit the operation space between AGV and crane. ATC operation time is influenced much more by variable factors such as ATC travel distance resulting from dispersion of operation places and the number of rehandling depending on conditions of storage space than by relatively invariable factors including hoisting, travel, loading and discharging. Accordingly, the way to reduce ATC operation time is to store containers enabling continuous operation of ATC in compliance with the pattern of stevedoring operation.

However, the target of service depends on operation contents, and operation time also differs accordingly. In general, stevedoring operation focuses on reduction of service time for ships, in which discharging work is operated in a relatively simple flow, while loading work takes preference in yard operations as loading work is complicated and requires satisfaction of a number of conditions. Meanwhile, in gate operation, reduction of service time for external trucks is important. In this case, service time of delivery

operation shall be intensively managed because rehandling in the ATC operation occurs more frequently in delivery operations than in receiving operations. Accordingly, for achieving service goals, it is desirable to use storage space near the quay for loading operation and make gate-out operation occur at the yard near the gate.

2) Increase of Utilization of Storage Capacity

Utilization of storage capacity is closely related to yard operation strategies for reducing above-mentioned operation time. In general, containers are classified in groups and separately stored according to various characteristics including stevedoring ships, destination, size, weight, etc. This results in not only reduction of operation time but also reduction of broken space enabling to secure much storage space at the time of completing operations for each group and more effectively utilize available storage space for containers to be stored later.

Broken space refers to the space which cannot be used for collectively storing containers belonging to same groups in a certain storage space due to inability to store containers belonging to other groups despite existence of empty storage space. In conclusion, broken space results in reduction of yard utilization, and unreasonable utilization of storage space results in drastic increase of operation time due to increased rehandling, reduction of productivity and deterioration of service level.

3) Dispersion of Operation Load

In case stevedoring and gate operations converge on a certain zone of yard at a time, work load comes to exceed handling capacity of ATC, which generally results in increase of gantry time of ATC and accordingly results in increase of operation cycle time of ATC and waiting time

of transporter. These problems may be mitigated depending on how to allocate equipment properly to each zone considering changing operation load to control handling capacity in operation space and how to allocate operation requests effectively to individual equipment in compliance with dynamic situations. However, it is impossible to allocate ATCs or distribute containers additionally in the perpendicular layout, and operation space of ATC is also limited in the parallel layout. In conclusion, allocation of equipment cannot solely determine the results of yard operation.

Proper dispersion of operation load without reducing operation of ATC is to keep the efficiency of equipment operation. This means that it is closely related to not only the operation scope of ATC but also the number of C/Cs allocated to ships.

5.2.3 Yard Space Planning

1) Outline

Planning for allocation of storage space to a ship does not refer to the decision of specific stacking position for each container of a ship, but refers to distribution of storage capacity of the yard to storage spaces in compliance with the above-mentioned purposes of yard operation. Space planning is not used for deciding stacking order and number of stacking containers, but only used for reference at the initial stage of deciding stacking position. Allocation of storage space to a ship is closely related to berth planning for the ship. Berthing position of a ship expected to enter a berth is closely related to proper decision of storage space in consideration of travel of AGV. The number of C/Cs to be allocated is one of factors to be considered in deciding how much storage space should be secured and dispersed because the discharging operation is performed in relation to ATC operation in yard.

Taleb-Ibrahimi et al.[23] first studied theories of allocating storage space of container terminal, introducing various concepts to explain space allocation of yard including space booking, storage space, new available space, etc. They also analyzed dynamic strategies to utilize a temporary yard to store on random basis the containers arrival before space allocation, in which they also studied additionally required containers. Kim and Kim[24] modelled dynamic space allocation with mixed integer problem in consideration of both acquisition of additional space due to departure of other ships and requirement for additional space for gate-in containers. Park[25] solved problems with heuristic methods based on Sequencial Decision Making (SDM) and the heuristic method based on Lagrangean Relaxation. These methods approached problem solutions with search methods utilizing limited conditions by classifying requirements into ones to be necessarily satisfied and ones to be kept. It used beam search method as the search algorithm. Kim[26] studied space allocation of an import container yard to minimize rehandling for each case in which import container arrival rate is constant, cyclic and dynamic.

Due to uncertain future situations and changing forecast storage planning it is difficult to decide an actual operation system and is required to be re-planned, corrected and supplemented from time to time. It is difficult

---

23) Taleb-Ibrahimi, M., De Castilho, B., and Daganzo, C. F., "Storage Space vs. Handling Work in Container Terminals", *Transportation Research-B*, Vol. 27B, 1993, pp.13 32.

24) Kim, K. H. and Kim, D. Y., "Group Storage Methods at Container Port Terminals", *The Material Handling Engineering Division 75th Anniversary Commemorative Volume ASME 1994*, MH-Vol.2, 1994.

25) Park, K. T., *A Space Allocation Method for Export Containers in Port Container Terminals Considering Liability to Model Change*(Master Thesis), Pusan National University, 1997.

26) Kim, H. B., *Operational Policies for Import Container Yard in the Port Container Terminal*(Ph. D. Thesis), Pusan National University, 1999.

to apply most of the existing mathematical models to actual situations because it requires lots of time for making analyses and finding solutions. Accordingly, the algorithm accepting intelligent search methods centering on practical knowledge and experience is recommended.

2) Parallel Layout Yard

Whenever a ship departs, storage space is allocated to the ship requiring it. The basic strategies applicable to the parallel layout yard are: (1) Install a yard block for either discharging/gate-out containers or loading/gate-out containers, and (2) Divide the block into sections perpendicularly from the quay. Following are the details.

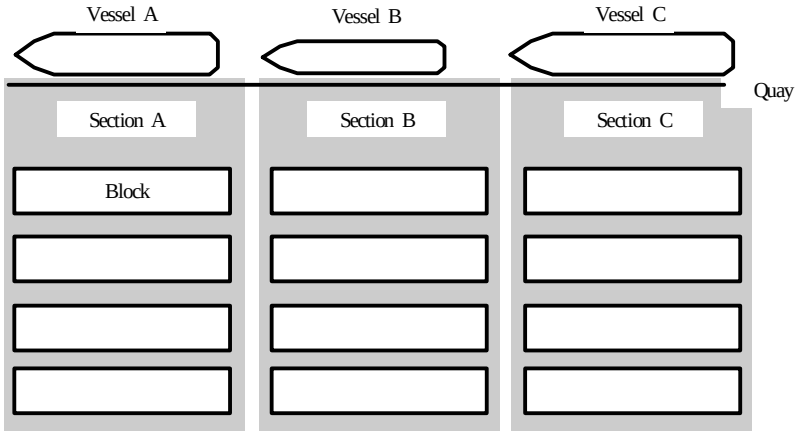
(1) Sectional Division of Export/Import Container

In perpendicular layout, it is desirable to make operation continuously performed in a block minimizing travel of ATC in the marshalling yard. Accordingly, it is desirable to divide storage space into loading/gate-in container block and discharging/gate-out container block.

(2) Division of Equipment Block into Sections by Berth Position

In general, a block is laid out perpendicularly to the quay along the path of AGV of uniform size in the parallel layout. If blocks laid out on the same perpendicular line are divided in sections as shown in next figure, they come to have similar AGV routes in operation positions connected to the quay. When the AGV is to travel to other operation positions than a block in a certain section of the quay, its frequency of transport over crossings and transport distance increase. Accordingly, unless there are inevitable situations, a ship's containers shall be stored in the block of a given section near the berth.

<Figure 5-5> Allocation of Section in Yard in Parallel Layout



In general, import containers have simple operation flows and do not have so much points to be noted, and storage planning for them does not have much influence on productivity. As a matter of fact, the storage space is planned after arrival of a ship in most operation systems. Meanwhile, export containers gate in before arrival of a ship and also have influence on the loading operation. Accordingly, this section describes only the storage space for export containers.

In the parallel layout yard, there may or may not exist buffer blocks between external trucks and internal automated zones. In case there is no buffer block, arriving export containers are either immediately stored in the marshalling yard or re-marshalled to the marshalling yard at a proper time after temporary storage in the random stock block. The buffer yard operation will be described at the end of this section.

3) Perpendicular Layout Yard

This is the type in which the yard block is laid out perpendicularly to quay, and the yard crane also travels in the perpendicular direction to

quay. The contact point of transporter and ATC is separated into berth operation and gate operation points, and the transport route in quay between C/C and berth operation point of a block is more flexibly operated than in the parallel layout. Accordingly, in the perpendicular layout, it is desirable to allocate storage space as shown in next figure in consideration of the shortest transport time of AGV rather than with the concept of a section in yard block for berth position described in the parallel layout.

The perpendicular layout assumes that ATC is operated between the operation position of transporter and the equipment position in block. Accordingly, the influence of dispersed equipment position on operational cycle time of ATC is less than in the parallel layout. In addition, as the number of ATCs allocated to a block is limited, interference between equipment does reduce productivity even though various kinds of operation are performed in a block. Accordingly, in the perpendicular layout, it is more effective to prevent waiting time of transporter by balancing work load of ATC.

In the perpendicular layout, unlike in the parallel layout, export and import containers are not classified in a block. And, the stevedoring operation takes precedence over the gate operation in operation the of ATC in yard to ensure operational productivity.

Gate-in containers are stored in the block within a certain distance from the berth, in which the distance is decided depending on the expected berth position of a ship and the number of C/Cs to be allocated. In case gate-in containers arrive after decision of block, selection is made among blocks not busy with operations in the direction of balancing storage. In other words, block decision is always so made that the values from dividing total containers of a ship or group by the number of blocks are similar to each other.

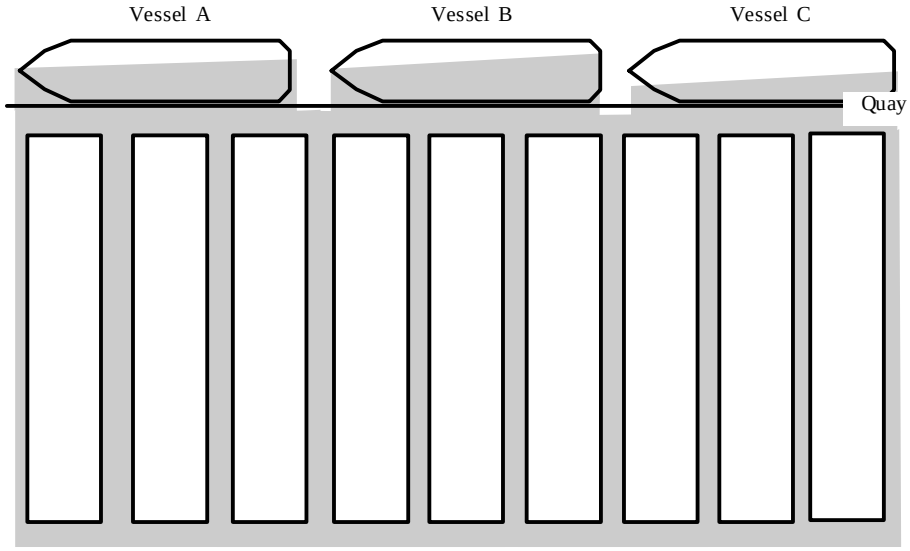
Discharging containers, like gate-in containers, are stored in the block which

is located near the berth and has enough storage space (a proper ratio of gate-in and gate-out containers should be decided in advance) and does not have excessive ATC operation load. In this case, the key is load balancing of operation type.

For loading, like discharging, selection is given to the block which stores containers of the same group and has the lowest work load (least waiting operation).

Export containers are stored in the bay near the berth, and import containers nearest on the opposite side. Bay is not so divided in advance, but divided only if possible.

<Figure 5-6> Storage Space by Ship in Perpendicular Layout



5.2.4 Decision of Stacking Position

1) Outline

In this section storage planning as a planning function and operational strategies for preparing specific operation instruction will be described. In fact, in case of adopting storage planning, the plan is adjusted through rescheduling because of a number of variable factors.

As stacking position is decided on the assumption that ATC, AGV and external truck are related to each other, it is closely related to allocation of equipment, and their situations are required to be fully considered for decision making. As the factors to be considered are different depending on the kinds of layout and container, stacking position strategies should be suggested after first confirming whether layout is perpendicular or parallel and then checking whether they are export or import containers as briefly discussed in the last section.

2) Export Containers in Parallel Layout

Storage position is decided when export containers arrive. Decision making is performed for two matters: one for deciding bay and another for storage position in bay. A primary bay is given to a group. In other words, a primary bay is once allocated when containers arrive, and when the primary bay is full, another primary bay is allocated. Primary bay refers to the bay for storing containers belonging to a group. Accordingly, in case the primary bay has further storage space when containers arrive, only stacking position in the bay is decided. In case the allocated primary bay does not have storage space, it is required to decide upon another new primary bay.

○ Bay decision strategies

This is related to planning a specific stacking position for export containers. To ensure rapid loading on board, containers of similar characteristics are required to be stored in a space or spaces located near each other where, if possible, little ATC travel is required and continuous operation in available. This refers to stacking bay planning, deciding the bay to stack containers group by group. There will be many alternatives, but it is the most realistic method at present to use the rules which storage planners have considering in the type of constraints identified through experiences.

Another point to be considered here is that arrival time of containers is uncertain. Accordingly, the volume of arriving containers are uncertain, and containers of various groups are stored in mixture. This results in reduction of loading efficiency.

But the problem is that the space allocated to a ship is limited and the number of arriving containers of a group is uncertain. Accordingly, the stacking bay should be decided in an adaptive manner. Therefore, for decision making, it is desirable to adopt flexible methods including constraint satisfaction programming.

3) Decision of Stacking Position in Bay

Stacking position should be decided when containers are to be stored in a bay by ATC after the external truck loading gate-in containers arrives ATC. When loading planning is set up for a ship according to bay profile, it should be ensured in general that heavy containers be put on the ship bottom in the concerned storage space in consideration of stability of ship. Accordingly, when heavy containers are stored on the bottom of the yard stack, possibility of rehandling becomes high in loading operation. To do this, containers are divided into groups depending on weight, and existing

groups into sub-groups. However, if grouping is made more deeply, required space tends to increase as broken space increases. Accordingly, this chapter suggests bases required for deciding stacking positions in the allocated bay in yard operation, and also suggests the algorithm to minimize rehandling for the container groups separated only by destination to analyze influence of rehandling during operation time.

The study of Kim and Park[27] described cases in which composite factors including destination, gate-out date, weight, etc. are applied to stacking operation. It centers on system realization method and coding strategies in consideration of composite factors including gate-out time, weight and destination influencing decision of stacking position. It also describes methods of information input for planning and internal structure of the decision making system utilizing them. It also describes establishment of theories for not only decision of stacking position for containers but also rehandling. The study of Kim, et al.[28] suggested methods to decide optimal stacking position to minimize rehandling by using the dynamic programming expressed in network model covering from the initial type of storage in bay to the final empty bay without a container stored. But, it was found as a result of the study of performance of the following heuristic methods that dynamic programming that requires too much computation is not only simple but also effective in performance.

<Table 5-4> explaining the results of the test, shows that decision of stacking position with heuristic method is not greatly different from

---

27) Kim, D. J. and Park, Y. T., "A Planning Based Slot Assignment System for Containers", *Journal of the Korean Institute of Intelligent Information Systems,* Vol.5, 1996, pp.145 166.

28) Kim, K. H., Park, Y. M., and Ryu, K. R., "Deriving Decision Rules to Locate Export Containers in Container Yard", *European Journal of Operational Research,* Vol.124, 2000, pp.89 101.

the optimal stacking position decision method in the terms of the total number of expected rehandling. Those two methods can remarkably reduce the number of rehandling in comparsion with the random stacking position decision method.

<Table 5-4> Comparison of Total Number of Expected Rehandling (In Case of One-over-four and 6-row Stacking)

Decision Method	Total expected rehandling number
random stacking	8.222
heuristic procedure	0.395
dynamic programming	0.286

Source: K. H. Kim, Y. M. Park and K. R. Ryu, "Deriving Decision Rules to Locate Export Containers in Container Yard", *European Journal of Operational Research* 124, 2000, pp.89 101.

4) Import Container in Parallel Layout

Primary bay is decided when the first discharging container is dispatched and when the primary bay is full. As rapid stevedoring in very important in terminal operations, decision of storing position is a key to rapid discharging operation. Accordingly, the proper method is to decide the primary bay by C/C and store continuously containers coming from a specific C/C in the concerned primary bay is used. In the case the primary bay becomes full, select the next primary bay on real time basis.

5) Export containers in perpendicular layout

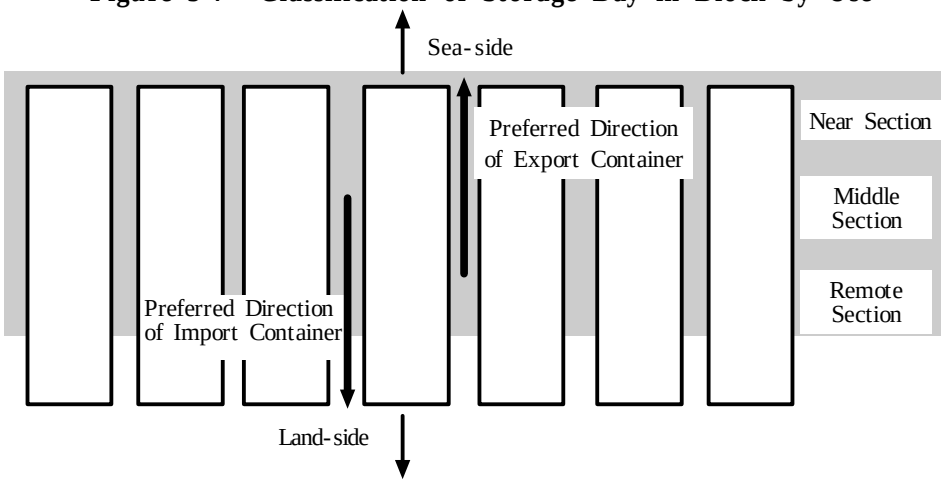
Storage block is determined whenever containers arrive at the gate. Storage position in the block is determined when gate-in truck arrives at inland operation position in the block for storage.

The number of storage blocks and scope of block are decided on the basis

of the number of C/Cs expected to be allocated and berthing position of ship, and the storage block for gate-in containers is selected to ensure equal distribution of them. By doing so, storage space and equipment load are equally distributed.

The number of storage blocks may be more than that of previously selected storage blocks, but should not be less than previously selected ones. However, too rapid increase in number may influence gate operation of other ships and should be prohibited. Therefore, it is desirable to adopt shared storage policy based on DOS (Duration-Of-Stay) for deciding storage position in a block. For example, if required space rate of gate-in is 60%, the portion equivalent to 60% of bay adjacent to operation position toward berth is divided into 3 sections, near, middle and remote. The containers of fast class of the least DOS value among gate-in containers are stored in the near section, containers of middle class in the middle section and containers of slow class in the remote section. In consideration of the entire arrival distribution and ship departure time, gate-in containers are classified into 3 classes, fast, middle and slow. This refers to the in terms of remaining time before departure time for utilization for decision making. Containers of same group are stored in the same stack to reduce rehandling. In case of grouping containers in the perpendicular yard layout, weight also should be considered. <Figure 5-7> shows preferred stacking position of gate-in and discharging containers in the perpendicular yard layout. And, the storage space of gate-in containers consists of 3 sections, (near, middle and remote) in terms of distance from a ship.

<Figure 5-7> Classification of Storage Bay in Block by Use



6) Import Containers in Perpendicular Layout

Storage block is decided when C/C discharges containers from a ship to load them to AGV for transport to yard and then AGV travels to yard, and the stacking position in the block is decided with AGV arrival at block.

It is very important to operate on-board loading rapidly in terminal. Accordingly, in decision making of stacking position with discharging operation, rapidness is the key to operation. Among blocks, such a block as work load is least and the number of containers discharged from a ship does not exceed the limit should be selected.

Storage space should be located on the opposite of berth to ensure easy gate-out operation, but in consideration of rescheduling, it is recommended to discharge more containers in the same bay. Discharged containers and loaded containers should be stored in different bays to prepare for probable rehandling. Not stacking containers discharged from other ships in the same stack reduces probability of rehandling. In the bay where a certain time has passed after discharging operation, assortment work is performed as its

stacking height is lowered.

7) Buffer Yard

The stacking operation is considered in the following 3 cases:

① When gate-in trucks pass the gate,
② When gate-out trucks pass the gate, and
③ When operation system instructs move of gate-in containers to marshalling yard.

It is assumed that operations made by crane in buffer yard have priority as follow:

① Gate-out operation which AGV with container is waiting (on FIFO basis)
② Gate-in operation of the largest waiting (FIFO)

For gate-out operation, both AGV and external trucks should wait below crane to which precedence is given. In case of gate-out operation, loading is performed from AGV directly to external truck in principle, unless there is no external truck with arrival of AGV.

(1) Gate-in Truck

As gate-in containers are stored group by group in the marshalling yard, it is desirable to make a ship use the same bay or make a group use the same bay in order to minimize handling cost for transport to the marshalling yard.

However, as it may be assumed that service for gate-in trucks is important and move of stacking will be performed at an idle time, it can be enough to pay attention only to prevention of stacking containers from other ships in the same stack. As a whole, focus is set on storage in the space nearest to berth and reducing waiting time in gate-in operation.

The evaluation value of the buffer crane is computed. In computing evaluation

value, distance from berth position of gate-in container ship and the number of waiting trucks are considered. Arriving trucks are allocated to buffer yard crane having the highest evaluation value. It should be noted that it is only for the stacks in a certain range causing no interference to a neighboring crane.

(2) Gate-Out Truck

As service time for external trucks is the most important performance criterion, the distance from stacking position of gate-out containers to buffer yard crane and the number of trucks waiting are computed as evaluation criteria. Crane should travel the least distance if possible and be operated on FIFO basis, whose procedures are summarized as follow:

Evaluation value of buffer crane is computed. In evaluation, the distance from stacking position of concerned containers and the number of waiting trucks are considered. Arriving trucks are allocated to the buffer yard crane with the highest evaluation value.

(3) Re-Marshalling

Gate-in trucks stored in buffer yard are moved to the marshalling yard when traffic of external trucks is not heavy. In this case, the buffer yard plays the role as a random stock pile. Random stock pile refers to the place where arriving containers from a ship are temporarily stored until they have space to be stored in the marshalling yard. The timing of loading to the marshalling yard depends on size of space to be allocated for the random stock pile. It is the space to be first excluded from the entire buffer space and the space for storing containers of a ship, to which yard is allocated, for a day and the space for storing temporarily some gate-out containers. The remainder of the space is used for random stock pile. It is difficult to decide to move all containers at a time several hours before closing time because it is related to berth planning.

Re-marshaling of gate-in containers is advantageous in terms of removing broken space at a proper time to secure available storage space. The clearing strategies to secure empty bay by moving containers staying in a bay at a proper time to another bay were analyzed by Castilho and Daganzo.[29] In addition, in connection with specific operation plans for that purpose, Kim and Bae[30] studied how to re-marshal export containers from container terminal. The 2-stage approach of task sequencing was suggested as a solution. The first stage is to solve bay matching and move planning problems, and the second stage is to minimize total travel time of transfer crane. Bay matching and task sequencing problems were modelled with dynamic programming, and move planning problems with transportation decision making. Points to be considered closely are summarized as follow:

- To improve efficiency of AGV and buffer yard crane and reduce influence on service for external trucks by transferring containers when gate operation load is low.
- To reduce mixture of container groups in a bay through transfer from the group because of too much handling
- To secure more buffer yard space by balancing transfer (based on lift) for containers loaded from 40 ft container
- To minimize transport of buffer yard crane and marshalling yard ATC
- To minimize AGV travel

5.2.5 Summary

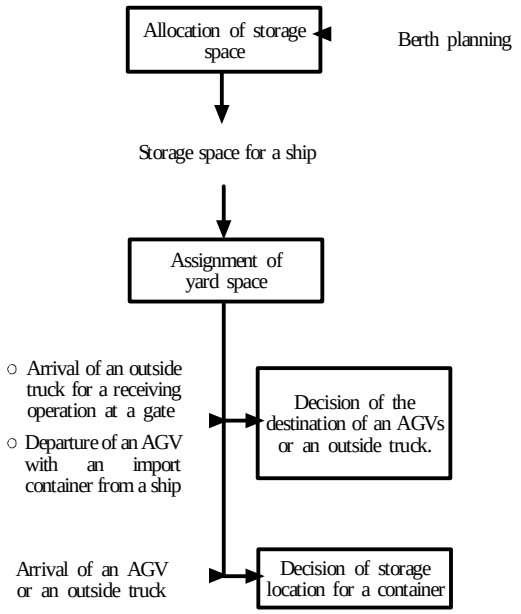
To design a terminal, yard operation strategy is absolutely required for

29) De Castilho, B. and Daganzo, C. F., "Handling Strategies for Import Containers at Marine Terminals", *Transportation Research-A*, Vol.27B, 1993, pp.151 166.
30) Kim, K. H. and Bae, J. W., "Remarshaling Export Containers in Port Container Terminals", *Computers and Industrial Engineering*, Vol.35, 1998, pp.655 658.

decision making reflecting actual situations. To suggest ways to develope future operation plans with the theories induced from actual experiences, knowledge and theoretical studies, the hierarchial decision making structure consisting of the plan for yard space allocation and decision of yard storage position is essential.

Goals and strategies concerning the time of implementing yard operation strategy, yard layout type and operational logistics were analyzed. <Figure 5-8> shows the implementation flow of yard operation strategy.

<Figure 5-8> Flow of Yard Operation Strategy



5.3 Basic Plan for Operations & Logistics of a Terminal

5.3.1 Outline

There are three issues described in this section. 1) General functions and

operations of a terminal, 2) Developments of automated container handling systems having concentrating on container handling equipment and terminal layouts applied to automated container terminals, 3) Basic plans for operations and logistics systems of a terminal by reviewing facilities required for each zone (quay, yard, rail and service area) in a terminal for effective operations.

5.3.2 General Functions and Operations of a Terminal

The quay of a terminal is equipped with container cranes. The yard behind the quay is used as storage for containers. Containers are transferred either between the quay and the yard, or between the yard and the gate.

The kinds of container in a terminal are as follows:

- Regular containers (20', 40', 45') and special containers (45' or larger)
- Full and empty container
- Reefer container and tank container
- IMO container (for dangerous matter)
- Bulk cargo

Special containers are stored in separate spaces, and yards for reefer and empty containers are operated in separation from general yards. Reefer containers in a reefer container yard are connected to electronic facilities, and a yard for empty containers provides cleaning, repairing and maintenance service. Inland terminal is connected to rails and roads. Rail cranes load and discharge containers to and from rail carriage at a rail terminal. Each terminal is equipped with proper container handling equipment for loading and discharging containers to and from outside trucks.

5.3.3 Container Handling Equipment in an Automated Container Terminal

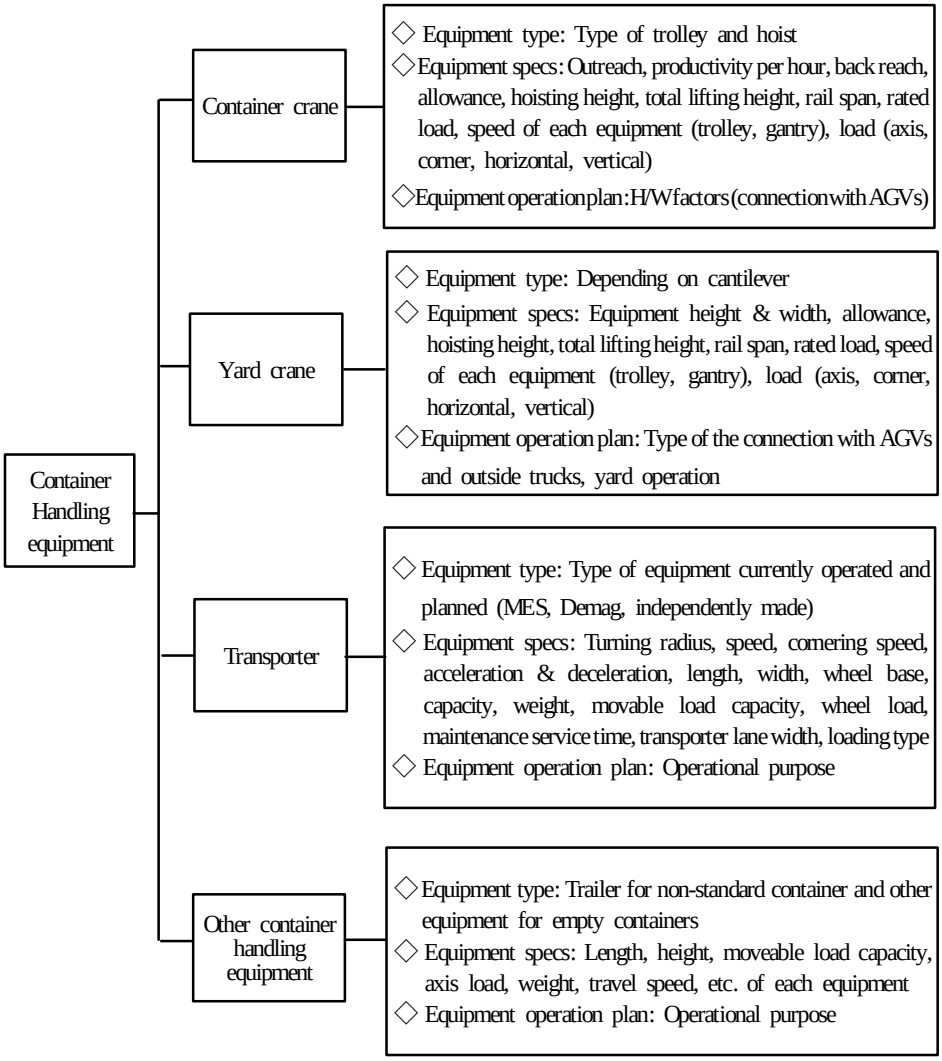
1) Outline

To establish a master plan for an operating system and logistics of an automated container terminal, it is required to analyze equipment used in automated container terminal in respect of types, characteristics, specifications, etc.

In this section, equipment used in the existing automated container terminals and equipment to be constructed by manufacturers are described. Some specifications and characteristics of equipment may be changed according to requirements from users, circumstances of ports to be developed and types of operation systems.

<Figure 5-9> shows the factors to be considered when selecting kinds of equipment to be used in container terminals. Equipment applicable to the basic plan for an automated container terminal will be studied in terms of these factors.

<Figure 5-9> Analysis of Factors Related to Container Handling Equipment



2) Container Handling Equipment for Quay Operations[31]

(1) Classification in Terms of Operation Method

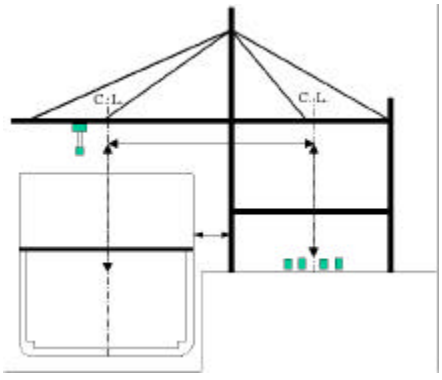
Quayside container handling equipment is called a container crane, a gantry crane or a quay crane, and performs loading and discharging operations. Their weights are about 40 tons and height about 40m.

Container cranes can be classified into three types: single trolley, double trolley, and dual hoist, in terms of operation methods of its trolley. Most conventional terminals adopt single trolley type, but automated terminals including ECT (Europe Combined Terminal) of the Netherlands and HHLA CTA of Germany mostly adopt the dual hoist type. Operation methods of trolley are described as follows:

① Single trolley

- ○ As the standard operation method used most widely at present, most conventional ports use this system.
- ○ A trolley picks up a container from a ship and transferes it to an inland transporter.

<Figure 5-10> Single Trolley System

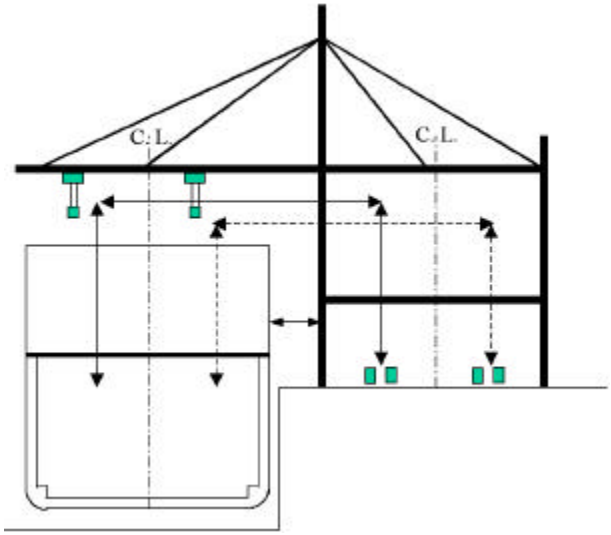


31) This subsection is summarized based on several articles of TOC 97, TOC 98, TOC 99.

② Double trolley

- 2 trolleys running on a rail
- Sea-Land Terminal in Kaosiung also adopted Ansaldo crane.
- If it is applied to an automated container terminal, it can be handled by one operator.
- Basically, 2 cabs and 2 operators are required.
- Operator cab is located on another rail which is separated from the lane of a trolley.
- It can be successfully used for dual hoist cranes in VIT (Virginia International Terminal).

<Figure 5-11> Double Trolley System



- The waterside trolley covers half of the width of a ship, the trolley covers another half.
- There may be a case in which, while a trolley travels, another trolley

interferes. To solve this problem, each trolley is required to have very precise load control system.

○ Installation of elevator rail is considered in order to reduce the waiting time of a transporter while the landside trolley passes.

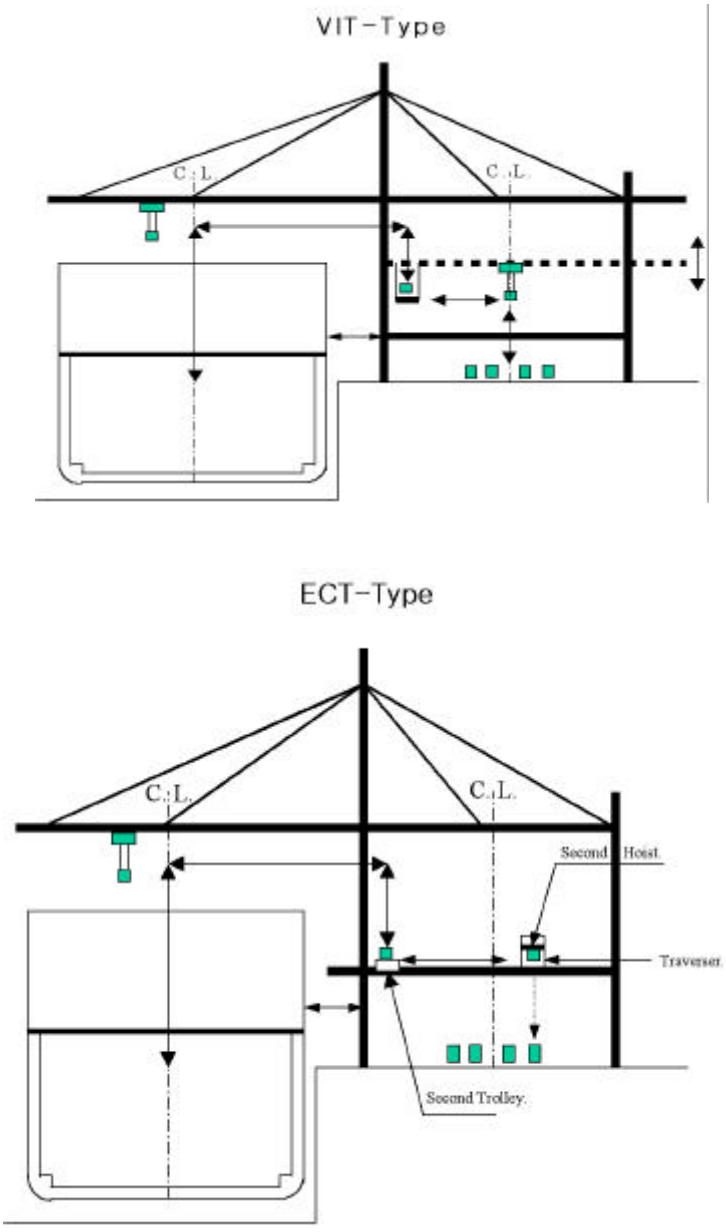
③ Dual hoist

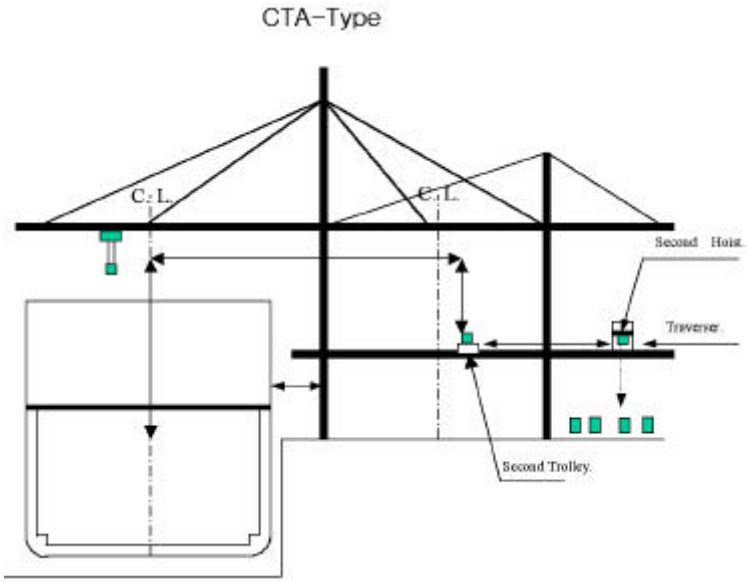
○ The platform of VIT to the land has the elevated mid-platform type. Dual hoist of VIT are located near the deck to minimize the travel time of a waterside trolley.

○ ECT is operating the "ship system" which transfers containers between a platform and a ship and the "dock system" which transfers containers between a platform and a transporter. This system is a fixed platform equipped with a traverser between 2 operation systems. This type is equipped with 2 trolleys and 2 hoists. At the same time as the trolley loads containers onto the second trolley to the land, it travels to a ship again and the second trolley transports containers to the adjusted position to load them to transporters. The advantages of this type include easy automation and easy connection to transporters because the waterside trolley performs only operations for a ship. The second trolley horizontally transports the hoist to the land operation on ground.

○ CTA type is similar to ECT type in terms of the travel of a trolley and the transport of containers, but its features exist in the structure ensuring easy transport of containers between a transporter and a yard by a installing route for dangerous cargo and a hatch cover in rail span and allowing transporter to position at back reach zone.

<Figure 5-12> Dual Hoist System





④ Supertainer system

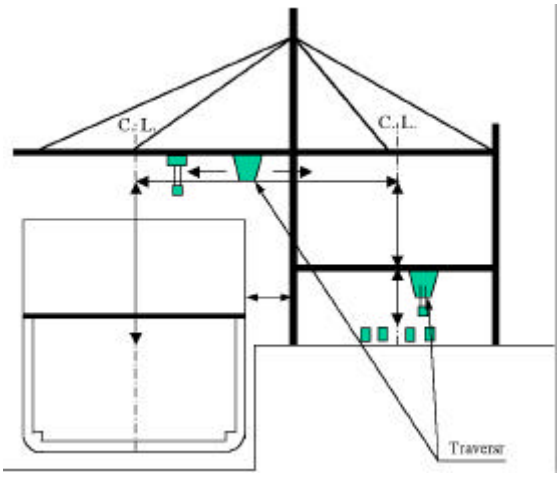
○ An operator cab is installed at the waterside trolley and a checker cab is installed at a container lift device. The trolley does not have a cab.

○ A trolley does not move during hoisting, and horizontal transport of containers from the waterside trolley to the landside trolley is performed by a traverser. A container is transported by traverser when a trolley enters into traverser.

○ Unless when waterside and landside trolleys are setting position for a target container, it is mainly operated automatically. It is designed to adjust the height of a traverser to improve the cycle time by reducing hoisting distance, irrespective of ship size.

○ A traverser is operated at the speed of 270m/min, and hoisting 135-150m/min, 270m/min in case of no-load.

<Figure 5-13> Supertainer System



(2) Specifications of Quayside Container Handling Equipment

Specifications of container cranes described above are summarized as follows:

<Table 5-5> Specifications of Quayside Container Handling Equipment

Operation Type		Single Trolley Double Trolley	Dual Hoist (Supertainer)
Tonnage		40 T	40 T
Outreach		56.5 m	50 m(18Rows) 65.5m(22Rows)
Backreach		15 m	15m 23m
Rail Span		30.5 m	30.5m 45.7m
Drive Speed		45 m/min	46 m/min
Trolley Speed	Seaside	180 m/min	152m/min
	Landside		76m/min
Traverse Speed			152 274m/min
Hositing Up/Down Speed	Loaded	60	137 / 152m/min
	Empty	135 220 m/min	274m/min
Upper Rail Span		34.0m	38.1m 41.1m
Lower Rail Span		14.5m	16.0m
move/hr		40 55	90
Provider		Noell, ZPMC etc.	Paceco-Mitsui
Applicable Port		General Port	

Source : TOC 97, 99 Conference, Cargo Systems

Note : Supertainer is designed conceptually and not commercialized yet.

<Table 5-6> Illustrations of a Dual Hoist System

Operation Type		Dual Hoist Type		
		ECT	VIT	CTA
Tonnage		40.6 T	40.6 T	40.6 T
Outreach		56.5 m	45.7 m	53.0 61.0 m
Backreach		15 m	22.9 m	16.5 m
Rail Span		30.5 m	15.2 m	35.0 m
Drive Speed		45 m/min	45 m/min	32 m/min
Trolley Speed	Seaside		180 m/min	220 m/min
	Landside		75 m/min	240 m/min
Traverse Speed		120 m/min		
Seaside Hoisting Up/Down Speed	Loaded	80 m/min	55 m/min	80 m/min
	Empty	170 m/min	130 m/min	180 m/min
Landside Hoisting Up/Down Speed	Loaded	50 m/min	55 m/min	75 m/min
	Empty	120 m/min	130 m/min	120 m/min
Upper Rail Span		36.0m	33.3m	37.0 41.0m
Lower Rail Span		16.0m	16.0m	23.0m
move/hr		60	60	60
Provier		Nelcon	KoneCranes	Noell

Source : TOC 97, 99 Conference Cargo Systems

3) Yard Crane

Yard cranes are used for transferring and storing containers in a yard.

(1) Yard Cranes

① ASC (Automated Stacking Crane)

○ Automatic loading and unloading operations for AGVs and remote control of operations for outside trucks

○ Currently used in ECT of Netherlands

○ An ASC is used for handling containers in ASC yard and should satisfy the following conditions:

• To be controlled by an AGV and a straddle carrier

- To be controlled by fixed flipper
- Maximum lifting weight is 350kN or less

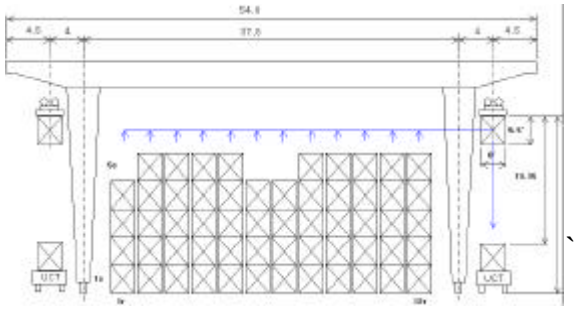
○ ASCs have height to lift 1 x 9'6″ or 2 × 9'6″ container
○ A trolley operates spreader at the highest position.
○ An ASC stores containers in a yard in 3.25m in direction of crane travel and 2.8m in direction of trolley travel. In a position setting system, reefer containers should be located uniformly away from platform.

② CATC (Cantilever Automated Transfer Crane)

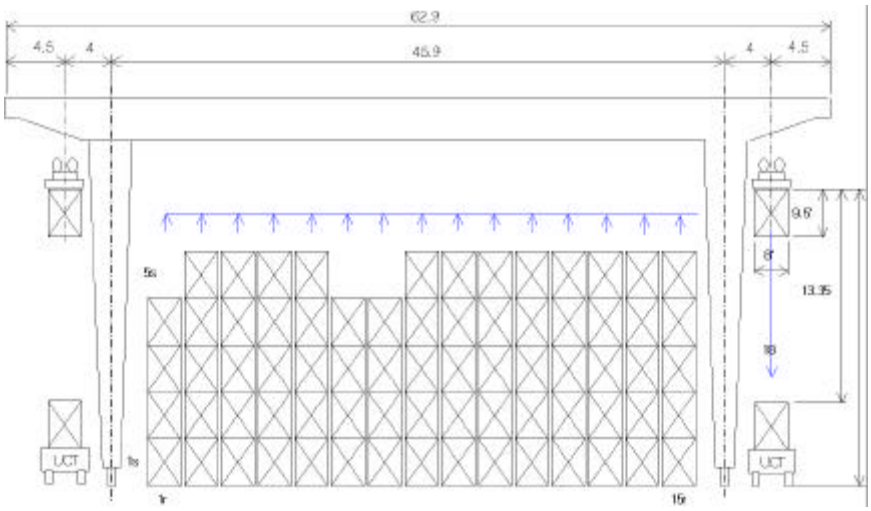
○ Automatically operated at both sides
○ Container blocks are in parallel with quay
○ Automated operation for AGVs and remote control for trailers/chassises
○ Referred to as CATC (Cantilever Automated Transfer Crane) in this study
○ Width and height of a CATC can be changed at request of user.
○ An automatic CATC performs operation
○ Gantry travel speed is 240 m/min(4.0 m/s)
○ A CATC is so high as to lift 9'6″-high container
○ A trolley operates a spreader at the highest position

<Figure 5-14> CATC Drawing(1)

① One-over-five and 12-row stacking CATC



② One-over-five and 15-row stacking CATC



<Table 5-7> Specifications of CATCs

Item		5Tiers 9Rows (Both Cant.)	5Tiers 10Rows (Both Cant.)	5Tiers 12Rows (Both Cant.)	5Tiers 15Rows (Both Cant.)
Trolley Span(m)		28.64	31.5	37.2	45.94
Hoist Height(m)		18.0	18.0	24.6	24.6
Gantry Speed(m/min)		150	150	150	150
Hoisting Speed (m/min)	Loaded	35	35	35	35
	Empty	70	70	70	70
Trolley Speed (m/min)	Loaded	120	120	120	120
	Empty	120	120	120	120

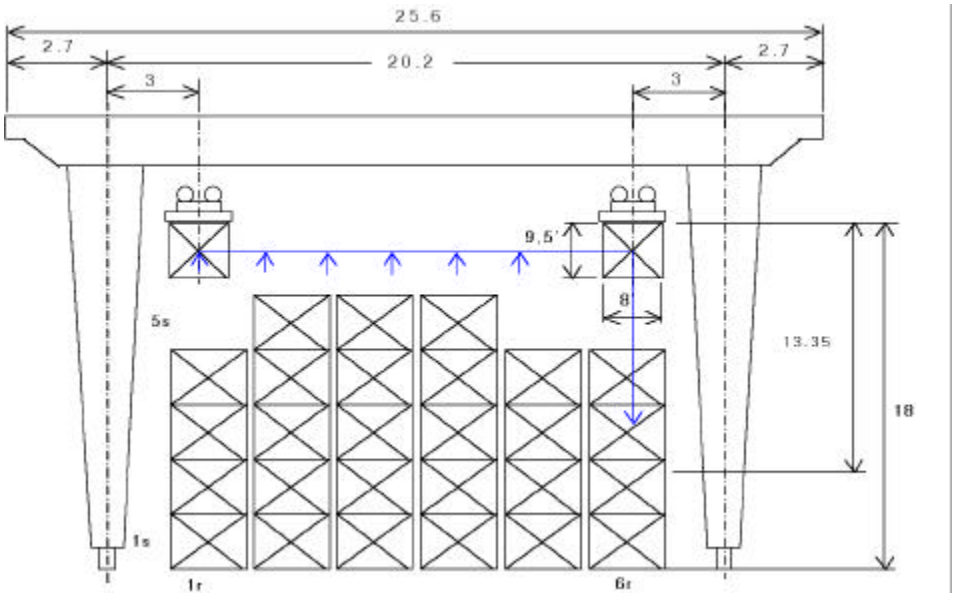
Source : Hyundai Heavy Industries Co.,Ltd.

③ Overhead Bridge Crane (OHBC)

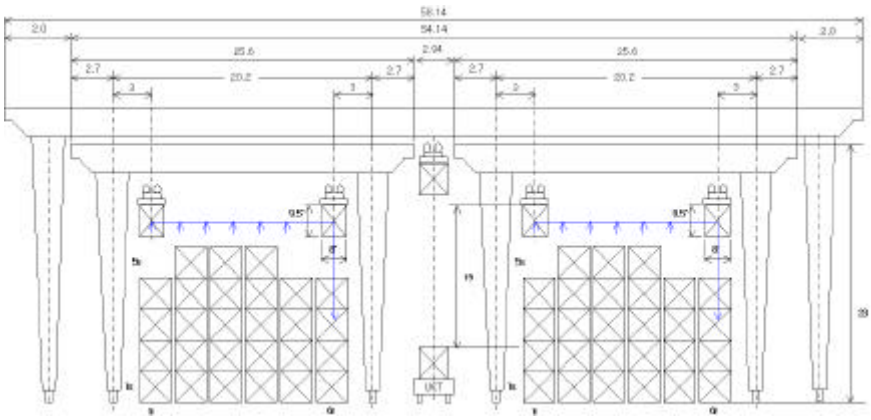
- ○ An automatic bridge crane is operated in yard
- ○ Working with an AGV for loading/discharging operations, transferring directly to trucks

<Figure 5-15> CATC Drawing (2)

① Inner ATC of 5 Tiers 6 Rows



② Outer ATC



④ Rubber Tyered Gantry Crane (RTGC)

- ○ Manually travel
- ○ Storage of containers in parallel with quay
- ○ Manual operation directly for outside trucks

<Table 5-8> Specification of an OHBC

Item		OHBC
Tonnage		40
Gantry Speed	Loaded(m/min)	90
	Empty(m/min)	120
Trolley Speed(m/min)		70
Hoisting Speed	Loaded(m/min)	60
	Empty(m/min)	120

(2) Characteristics of Yard Cranes

Selection of which kind of a yard crane depends on operational strategy for newly developed terminals as follows: (It also can be changed depending on the type of yard layout.)

- Automatic - Mostly using container handling equipment of rail type, such as CATC, ATC, ASC, OHBC.
- Semi-automatic - Mostly using CATC, ATC, OHBC
- Conventional - Mostly using container handling equipment of RTGC type

Travel speed is 90 240m/min, vertical transport 70 150m/min, hauling speed 20 65m/min with load, 40 135m/min without load depending on size of equipment. Speed of equipment can be modified by manufacturer at request of user.

<Table 5-9> Specifications of Yard Cranes

Item		Maximum speed (m/min)			Turning Radius (m)	Driving Type
Type	Equpment	Gantry	Trolley	Hoist		
Transport + Stevedoring	Straddle Carrier	-	-	-	-	Manned
Stevedoring	RTGC	134	70	20/50	15	Manned
	ASC	240	50	20/40	-	Unmanned
	ATC (Non-Cantilever)	-	-	-	-	Unmanned
						Unmanned
	CATC (Cantilever)	120	150	65/135	-	Manned (Semi-Auto)
						Unmanned
	OHBC	90/120	70	53/130	-	Unmanned

4) Transporter

Transporters[32] are used for either transporting containers from a ship to a yard or transporting containers from a yard to a ship. As transporters, AGVs(Automated Guided Vehicle) are used in automated terminals and yard truck in conventional terminals.

(1) Transporters

① AGV

- Transporting containers between a ship and a yard, and adopting automated travel system based on centralized control system
- Twin-lift loading available
- Driving speed 4 5m/s
- Navigation system: Control system for unmanned transporter AGV, and deciding direction and position with transponder/magnetic and

32) Cargo Systems, *Developments in Container Handling Technology*, 1997. Cargo Systems, *The Future of Container Handling Technology*, 1999.

dead reckoning

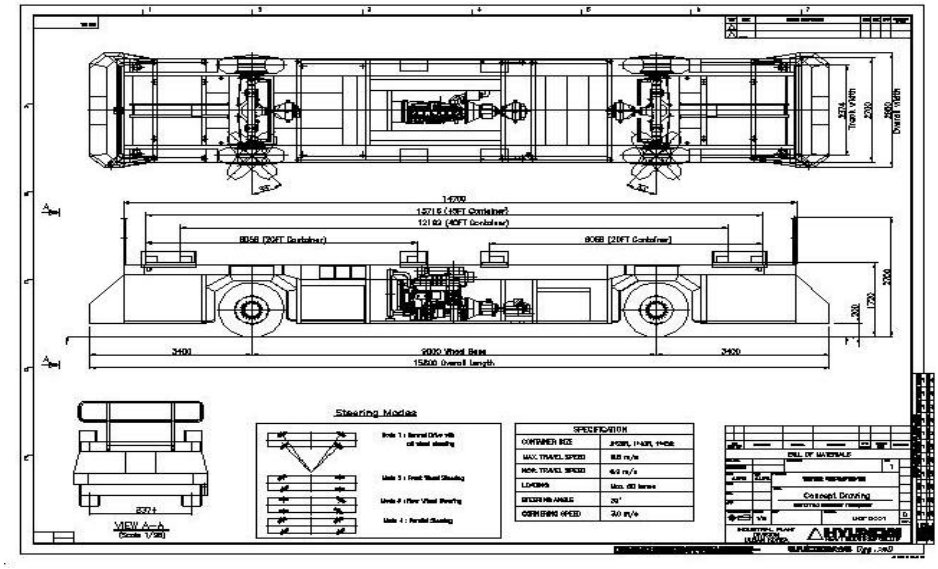
- Positioning precision: 20mm or more
- Loading and discharging containers in a certain kiosk zone to the waters and the land through transfer points with a yard crane in the case of perpendicular layout, and loading and discharging containers together with CATC or ATC directly using transfer point on transporter path in yard in case of parallel layout
- Control for prevention of collision through supervisor and operation of guide system
- To sense and control probable collision through laser or RF sensor

AGV is principally an unmanned operation, but remotely controlled in case of special situations including repair and maintenance work. In contrast, a yard tractor is used in a conventional terminal and operated by man. AGV has the maximum travelling speed of 300m/min and a turning radius of 9m while yard tractor has the travelling maximum speed of 750m/min and a turning radius of 7m.

<Table 5-10> Transporter Dimension (By Manufacturer)

UCT Maker / Description	KAMAG		GOTTWALD	MES	HHI
	ECT	PSA			
Delivery Destination	-	PSA	ECT	PSA	-
Deliverling Qty	-	3	110	2	-
Tonnage	40 Tonne	50 Tonne	40 Tonne	50 Tonne	60 Tonne
Load Capacity of Container	1×20ft 1×40ft 1×45ft	2×20ft 1×40ft 1×45ft	1×20ft 1×40ft 1×45ft	2×20ft 1×40ft 1×45ft	1×20ft 1×40ft 1×45ft
Max. Speed	4.5m/s (16.3 Km/h)	5m/s (18 Km/h)	Standard : 4.5m/s (16.2Km/h) ECT : 3m/s (10.8 Km/h)	6.9m/s (25 Km/h)	6.5m/s (23.4 Km/h)
Drive Speed	4.0 m/s (14.4 Km/h)	5 m/s (18 Km/h)	Standard : 4.0m/s (14.4Km/h) ECT : 3m/s (10.8 Km/h)	5 m/s (18 Km/h)	5 m/s (18 Km/h)
Axle Qty/ Tire Qty	2/4	2/8	2/4	2/4	2/4
Steering Mode	4	4	4	4	4
Length (mm)	17,200	(17,200)	17,200	16,720	15,800
Wheel Base(mm)	9,000	10,000	9,000	9,000	9,000
Cornering Radius	13,500	(13,500)	13,500	(13,300)	13,000 (8,000)
Navigation System	Inductive Wire or Transponder	Image Processing	Inductive Wire or Transponder	Image Processing	Trasponder
Obstacle Detection System	Laser	Milli-Wave Radar	UltraSonic or Laser	Laser	Laser
Positioning Accuracy (mm)	30	30	30	(20)	20

<Figure 5-16> AGV Drawing



② Terminal tractor

This equipment transports containers not to be transported by AGVs in a terminal and should be equipped with wireless communication devices.

<Table 5-11> Specification of a Terminal Tractor

Factor	Content
▪ Size - Length - Width - Wheel base - Width of Track - Turning Radius	 5.026m 2.45m 2.80m 1.96m 6.5m
▪ Speed	38km/h
▪ Axle Load	250kN (Max)

(2) Characteristics of Transporter

In general, an AGV used in an automated terminal is an unmanned transporter. In conventional terminals, terminal tractors (yard trucks) are used. In automated terminals, containers which cannot be transported with an AGV are transported by a terminal truck. S/Cs(Straddle Carriers) can be used either to transport or to handle containers and widely used in Europe.

<Table 5-12> Transporter Dimension (By Equipment)

Item		Max Speed (m/min)	Turning Radius(m)	Driving Type
Type	Equipment	Travel		
Transport	Terminal Tractor	600 750	7	Manned
	AGV	300	9	Unmanned
Transport + Stevedoring	Straddle Carrier	-	-	Manned

5.3.4 Automated Container Handling Systems

1) Outline

The container handling system of an automated container terminal can consist of various combination of automatic container handling equipment. Among automatic equipment developed until now, a transporter includes an AGV, and a yard crane includes ASC, ATC, CATC, OHBC, etc. This section describes automated container handling systems to be combined centering on these equipment.

2) AGV-ASC System

AGV-ASC system is an automated container handling system commercialized and having been used by ECT of the Netherlands. In a

parallel layout, this system shows such weak points as problems in AGV transport route and operation and limited stacking height and rows of ASC. This system is used only for yards in perpendicular terminal layout. Its operation rules are described below:

Transport between a container crane and a container yard is performed by unmanned equipment, which are given orders on wireless communication with a centralized control system to travel. AGVs can trace position, direction and accurate speed, and also have various functions to inspect engine temperature, fuel level, etc. These functions are performed by grid transponder installed under paved road utilizing a navigation and wireless communication system. Unmanned equipment periodically report its current position to a centralized control system monitoring travel of all equipment with a wireless communication system, and a centralized control system decides the order of equipment travel.

Loading and discharging with AGV are performed under a container crane. After a container is loaded on an AGV from a ship, an AGV travels to the kiosk, a seaside transfer point of an ASC, by the centralized control system. Loading is performed in reverse order to discharging. An empty AGV travels to the transfer point designated by a centralized control system to take over container from an ASC. And then, when a loaded AGV travels to a C/C designated by a centralized control system, loading operations begin. In most cases, an AGV transports containers between a container yard and a C/C. To smooth the flow of containers in a terminal, an AGV is used for transporting containers between an ASC auxiliary yard, an ASC yard and an empty container yard.

An ASC, automatic RMGC, is used for operation of containers stored in a yard. A container yard consists of blocks perpendicular to quay. Only regular and reefer containers are stored in ASC blocks. Other types

of containers are required to have special conditions for storage therein. Non-standard containers deviating from standard specifications are stored in a separate block. In case an ASC is out of order, it can be replaced with another ASC in the same block until the ASC is repaired in both perpendicular and parallel terminal layouts.

To ensure smooth receiving and delivery operations in a yard, at least a certain number of ASCs should be secured. Export containers are distributed to ASC blocks, and then are given final storage position by the ASC receiving information of final storage position for the container from a centralized control system. In case of transporting containers from a ASC yard to seaside or landside, the centralized control system instructs the ASC to travel to the container. On landside, a transfer point of kiosk type is also planned at each ASC block. Import containers are transported to these transfer points by ASCs and loaded to trucks by SC (straddle carrier). Export containers are loaded to trucks by ASCs at these transfer points.

- Features
  - Containers to be stored perpendicularly to quay
  - Simple stevedoring system of seaside containers (C/C/AGV/ASC)
  - AGVs to be separated seaside and landside which results in more narrow traveling scope and less stop space
  - Large terminal apron size
- Layout Alternatives
  - ASCs traveling perpendicularly to quay
  - Allocation of one ASC and operation of separate maintenance equipment for each yard block
  - Adoption of separate system (SC/Road Truck) for receiving and delivery

operations

- Automation alternatives
  - Container handling equipment in a yard: ASC per block
  - Container crane: Automation of loading/discharging above apron only
  - Apron ↔ Yard: Automation (AGV)
  - In yard: Automation of ASC
  - Import: C/C → AGV → ASC → Yard → ASC → SC → Truck
  - Transshipment: C/C → AGV → ASC → AGV → C/C
  - Export: Truck → SC → ASC → Yard → ASC → AGV → C/C

3) AGV-CATC System

AGV-CATC system, unlike the AGV-ASC or AGV-ATC system, is applied to a perpendicular terminal layout of yard whose AGV transport route differs from that of the system mentioned above. In other words, the AGV-ASC or AGV-ATC system has a kiosk zone on seaside and landside to discharge and load containers with a yard crane there. In AGV-CATC system, an AGV approaches directly to a yard crane or a transfer point to load and discharge containers. A yard crane is of cantilever type and containers are transferred below the cantilever of a yard crane.

Travel of AGV and overall control and operation of CATC are not separately described because it adopts the same system as in the 2 systems mentioned above. But, its features are that eyport and import containers are loaded to outside trucks in a separate buffer yard through remote controller and manual equipment.

The discharging and transfer point of the AGV-CATC system is established on road for transporter in a yard. There may be many transfer points depending on block length.

- Features
  - Container to be stored in parallel with quay
  - Relatively complicated container handling system (C/C/AGV/CATC/RMGC)
  - Requiring small apron size (comparing with container handling system applied to a perpendicular terminal layout)
  - Personnel in charge of remote control and manual operation of RMGC are required for landside receiving and delivery operations in a buffer yard.
  - The number of spaces for decision of stop positions increases as AGV enters each container stacking position and its travel scope is wide.
  - Unmanned and economical
- Layout alternatives
  - ATCs travel in parallel with quay.
  - Routes for AGVs and outside trucks are completely separated.
- Automation alternatives
  - Container handling equipment in a yard: CATC Type
  - Container crane: Automation of loading/discharging.
  - Apron ↔ Yard: Automated (AGV)
  - In yard: Automation of AGV and guided operation of external truck
  - Import: C/C → AGV → CATC → Yard → AGV → CATC (remote) → Buffer yard → CATC (guided) → Truck
  - Transshipment: C/C → AGV → CATC → Yard → CATC → AGV → C/C
  - Export: Truck → CATC (guided) →Buffer yard → CATC (remote) → AGV → Yard → CATC → AGV → C/C

4) AGV-OHBC System

AGV-OHBC system is suitable for the terminal having a large part of

their cargos on transshipment containers. The PSA of Singapore has adopted this system, but it is not completely automated. Not much information about the detailed operation system is known, but it is more suitable for handling huge volume of transshipment containers within a short time than for handling export and import containers.

- Features
  - Containers to be stored in parallel with quay
  - Relatively complicated stevedoring system (C/C/AGV/RMGC or OHBC)
  - Requiring less apron and terminal size
  - Personnel in charge of operation of a RMGC are required for landside receiving delivery and discharging operations in a yard.
  - The number of spaces for decision of stop positions increases as AGV enters each container stacking position and its travel scope is wide.
  - Transport of export containers in a yard occurs.
  - High installation cost
- Layout alternatives
  - Container handling equipment: One OHBC per block, one CTRMGC per block
  - OHBC/RMGC travel in parallel with quay.
  - Routes for AGVs and outside trucks are completely separated.
- Automation alternatives
  - Container crane: Only loading/discharging above apron is automated.
  - Apron ↔ Yard: Automated (AGV)
  - In yard: AGV automated, external chassis manned or unmanned
  - Import: C/C → AGV → RMGC → Truck
  - Transshipment: C/C → AGV → OHBC → AGV → C/C
  - Export: Truck→RMGC (temporary storage (manned/unmanned))→AGV →OHBC→AGV→C/C

5.3.5 Yard Layout Plan for an Automated Container Handling System

1) Outline

This section describes outline of basic plan for yard layout alternatives. <Figure 5-17> and <Figure 5-18> show architecture of terminal including container flow for each yard layout.

Yard layouts can be divided into 2 different types (layouts parallel with and perpendicular to quay) whose combinations of handling equipment differ. The contents of this section are logistic flow of each container handling system in each layout in consideration of overpass, various structures and a buffer yard required to be established in a yard for the connection with outside trucks and yard cranes.

Alternatives for establishment of an overpass and a buffer yard are reviewed in parallel layout, and alternatives for entrance of outside truck in a yard and establishment of a buffer yard are studied in perpendicular layout. By doing so, equipment connection and kinds of containers to be handled in each sector are reviewed and layout type is also compared.

2) Parallel Layout System

i) Ship ↔ Container crane operation: export/import
Manual or semi-automatic operation system

ii) Container crane ↔ Apron (AGV) operation: export/import
Semi-automatic or automatic stevedoring system (Trolley type of a C/C)

iii) Apron(AGV) ↔ Yard transport: export/import
Automated transport system (AGV)

iv) AGV ↔ Yard Crane ↔ Yard operation: export/import
Automated transfer (AGV, CATC, OHBC) system

v) Storage space in yard ↔ Buffer yard transport: receiving/delivery

Automated transfer (AGV, CATC, OHBC) system

vi) Storage space in yard ↔ Gate transport: receiving/delivery
Semi-automatic (remote control of a yard crane) or automated transfer (OHBC) system

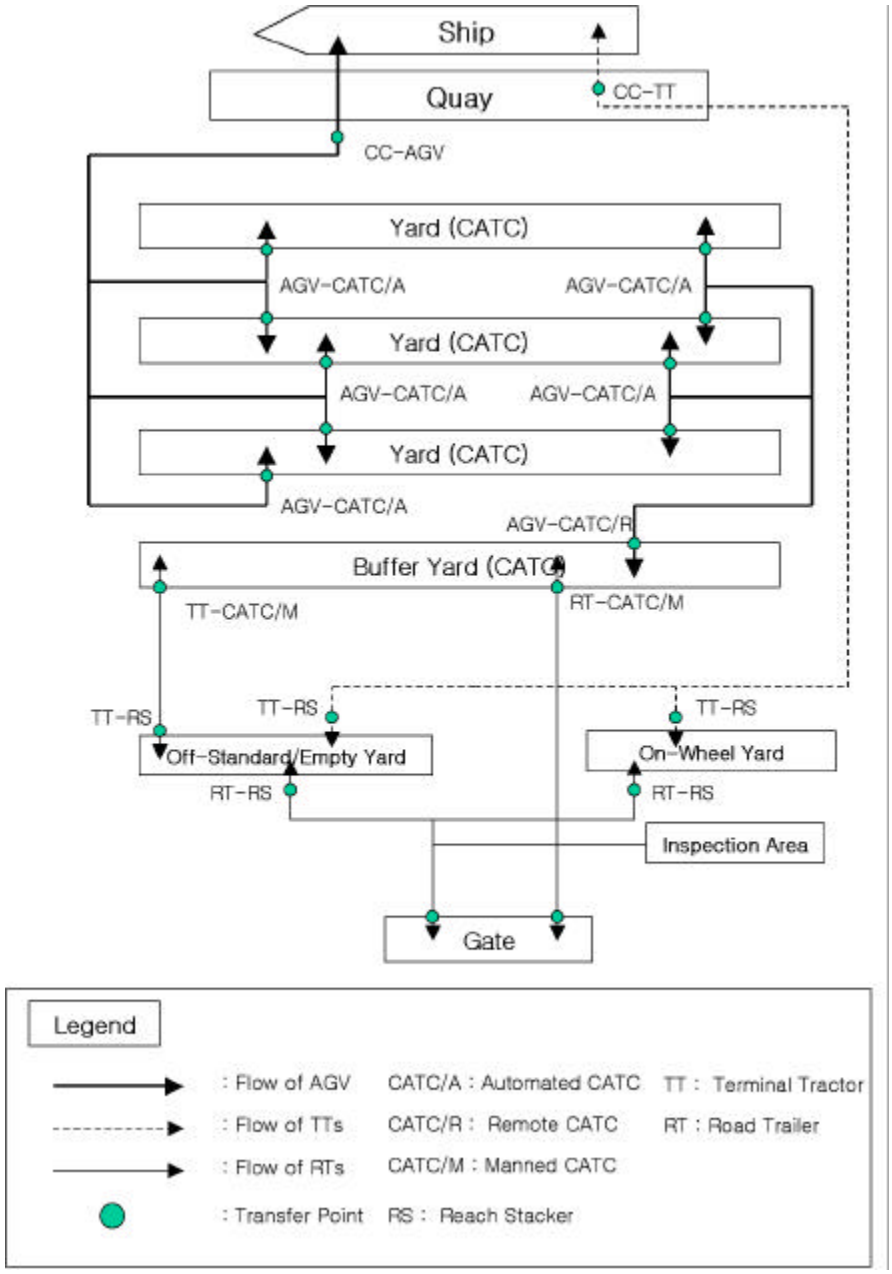
vii) Dangerous cargos and others
Export/import, receiving/delivery: manual discharging system using trailers

viii) Empty container
Export/import: manual, semi-automated or automated transfer system
Receiving/delivery: manual, semi-automated or automated transfer system

ix) Reefer container: Automated transfer system

※ Features of a buffer yard
- Buffer yard ↔ yard automated equipment: fully unmanned and automated (AGV)
- Buffer yard ↔ outside truck: semi-automated guide (or remote control)
- Analysis of alternatives for receiving and delivery operation policies
- Designing of container handling equipment, location, storage space and interface between gates and routes.

<Figure 5-17> Logistics of Parallel Layout



3) Perpendicular Layout

i) Ship ↔ Container crane: export/import
Manual or semi-automated stevedoring system

ii) Container crane ↔ Apron (AGV): export/import
Manual, semi-automated or automated discharging system(Trolley type of C/C)

iii) Apron (AGV) ↔ Yard: export/import
Automated transport system (AGV)

iv) AGV ↔ Yard Crane ↔ Yard: export/import
Automated transfer (AGV, ATC) system

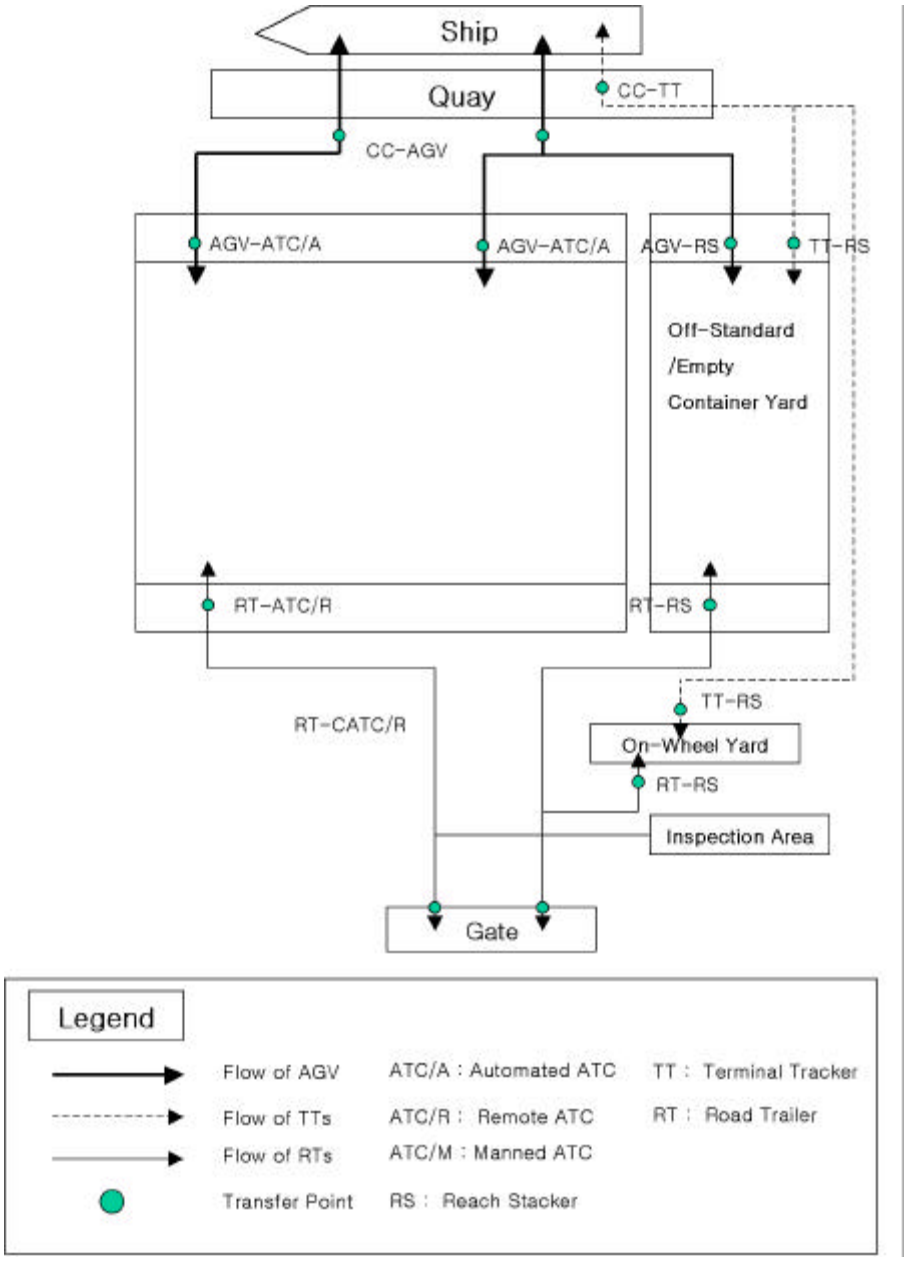
v) Storage space in a yard ↔ Gate transport sector: Gate-in/gate-out
Semi-automated (Yard Crane remote control) or automated (AGV, ATC) transfer system

vi) Dangerous and other containers
Export/import, receiving/delivery: Manual transfer system by trailers

vii) Empty container
Export/import: Manual, semi-automated or automated transfer system
Gate-in/gate-out: Manual, semi-automated or automated transfer system

viii) Reefer containers: Automated transfer system

<Figure 5-18> Perpendicular Layout



4) Comparison of Yard Layouts

Characteristics of each yard layout, architecture of equipment and connections with outside trucks are summarized as follows:

<Table 5-13> Comparison of Yard Layouts

Classification	Parallel layout	Perpendicular layout
Kind of terminal	· Applied to conventional and semi-automated terminal · Layout of all existing terminal - Domestic: All - Overseas: PSA, OSAKA, HIT, Kaosiung, EUROKAI, Kawasaki, etc.	· Applied to automated terminal and SC terminal - Domestic: None - Overseas: ECT, KINGSTON, Kaosiung, etc.
Architecture of equipment	· RTGC+Trailer · RMGC+Trailer · CATC+AGV · OHBC+AGV · OHBC+Trailer	· SC-transporter not required · ASC+AGV · ATC+AGV
Features of layout	· Rapid travel speed · Large turning radius and irregular operation available · No limited factors · Mammed operation (easy control) and wide operation scope · Mainly horizontal run + hoist operation · Yard flexibility: Easy change · Complicated and long transport route and long transport · Easy access to a yard	· Slow travel speed · Small turning radius and irregular operation available · Allowed trucks limited · Unmanned operation (difficult control), small operation scope · Mainly direct run + hoist operation · Yard flexibility: Layout change impossible · Simple and short transport route · Difficult access to a yard
Plan for automatic operation	· C/C : Only loading/discharging above apron automated · Apron↔Yard: Automated (AGV) · In yard : Automation by AGV, manned operation of external trucks, automated rail operation · Import : C/C→AGV→RMGC(manned/unmanned)→Truck/rail · Transshipment : C/C→AGV→RMGC(unmanned)→AGV→C/C · Export : Truck/rail→RMGC(manned/unmanned)→AGV→C/C	· C/C : Only loading/discharging above apron automated · Apron↔Yard: Automated (AGV) · In yard : Automation by AGV, Manned/unmanned operation of external truck/Rail · Import : C/C→AGV→ASC(loaded)→AGV→RMGC(manned/unmanned)→truck/rail · Transshipment : C/C→AGV→ASC (loaded)→AGV→ C/C · Export : Truck/rail→RMGC(manned/unmanned)→AGV→ASC(loaded)→AGV→C/C
Connection with outside trucks	· Establishment of an overpass · Establishment of a buffer yard	· Access of outside trucks to a yard · Establishment of a buffer yard

5) Comparison of Yard Layout, Considering Combination of Container Handling Equipment

Advantages and disadvantages of automated container handling systems and studies on an optimal yard layout are reviewed in this section.

From the study on the correlation between container handling systems and yard layouts, it was found that the AGV-ASC system is the most proper system for a perpendicular layout and the AGV-CATC system for a parallel layout. The AGV-OHBC system was excluded in this discussion because transshipment containers are mainly handled.

<Table 5-14> Comparison of Yard Layout Considering Combination of Equipment

Classification	Advantages	Disadvantages
AGV-ASC (Perpendicular layout)	• Attested and commercialized system • Simple flow system of AGV and vehicles • Excellent mobility of yard cranes • Automation between quay and yards • Remote control of connection with outside trucks	• Manual equipment required for the connection with outside trucks
AGV-CATC (Parallel layout)	• Relatively simple flow system of vehicles as yard cranes can be operated below external cantilever • Relatively less number of equipment is required than other type.	• Separate sector required for connection with outside trucks
AGV-OHBC (Parallel layout)	• Advantageous in handling large volume of containers in transshipment	• Expensive reinforced concrete structure required in yard • All yard operation is not automated.

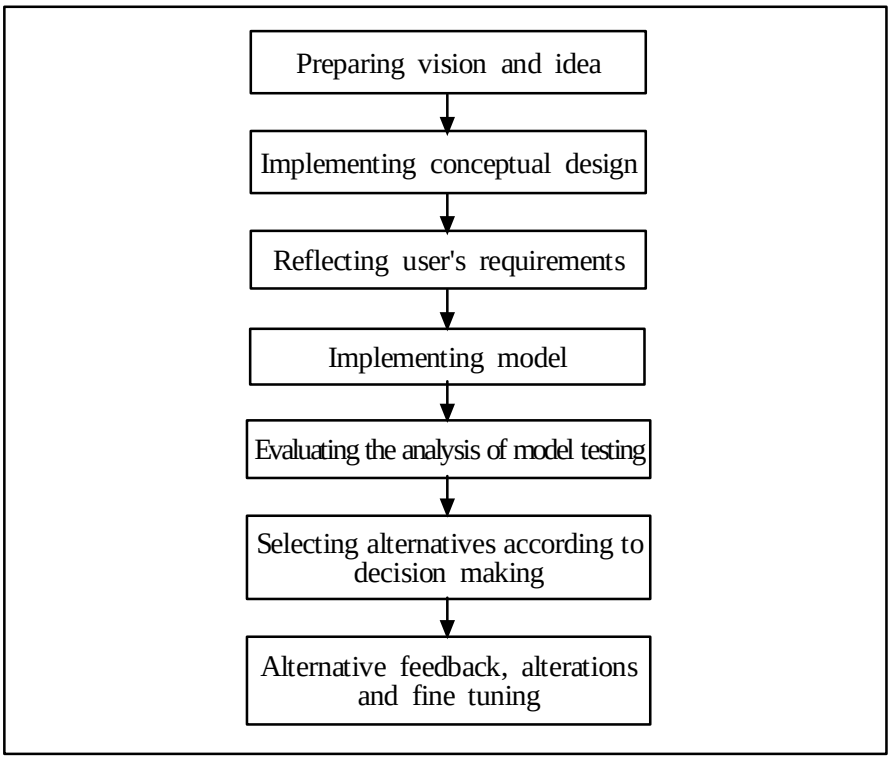
5.3.6 Logistics Flow and Container Handling Equipment

1) Outline

The factors influencing logistics of a terminal are operational environment, location, size, operational strategies, and labor circumstances in a terminal.

In this section, logistics of an automated terminal for each terminal layout and basic factors concerning operational strategies, container handling systems, applicable container handling equipment, etc. are discussed. Stages required for developing new terminal logistics are described in <Figure 5-19>.

<Figure 5-19> Flow of Developing Logistics System



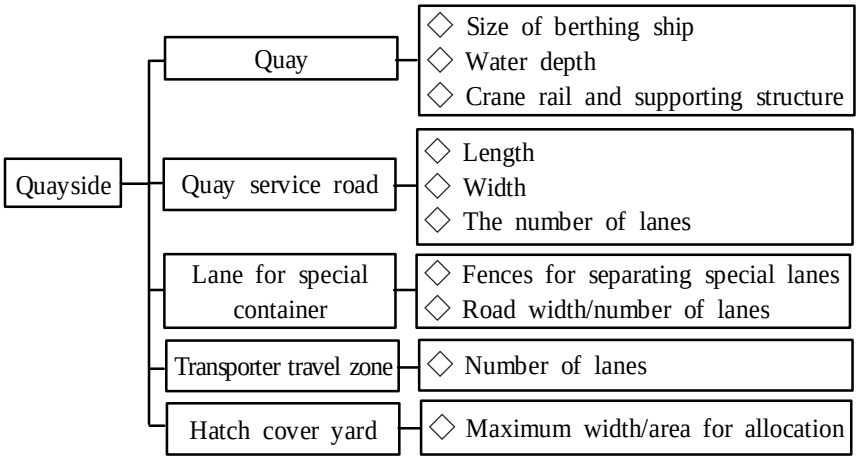
2) Quayside Area

In quayside area, ships and container cranes, and container cranes and transporters meet and containers are transferred between equipment at transfer points. Traffic of outside trucks are allowed only in a certain zone of a terminal including a service road. The zones allocated for the connection with outside trucks are separated from internal operation zones with fences and barriers. The zone allocated for the connection with outside trucks exists between the front of quay and the transfer point of a container yard. <Figure 5-20> shows factors to be considered when this zone is designed.

In other words, 5 components including quay, service road, lane for special containers, transporter travel route and a hatch cover yard should be considered in quayside area. In each component, its length, its width, its functions and its roles also should be considered. Their functions and specifications can differ depending on the type of the operating C/Cs.

Quayside area can be classified into the ECT type and the CTA type of HHLA. Both of them are reviewed in this study.

<Figure 5-20> Analysis of Factors for Quay



(1) ECT Type

① Service road

The road between quay and the crane rail is used for traffic of ship service (bunkering vehicles, managers, ship crew, etc.), traffic of terminal workers (shift, meal, repair/maintenance, etc.) and visitors. The ECT designed 8.5m wide service road in quayside area on the basis of actual empirical data considering optimal traffic flow and safety. C/Cs are operated between service road in quay and lane for special containers.

② Special lane

Road for special containers (unstandardized or dangerous cargos of special type) is located in front of crane rail and used for transport of containers and cargos, not using AGVs. Transport is performed by a tractor and chassis system. Fences are established to separate AGV zone and special lanes. In ECT type, fences are set up between an AGV zone and a special lane. Lanes for special containers are also used for routing of external trucks transporting expensive matters.

③ Rail span

In ECT type, rail span of a C/C consists of several lanes for transporting containers from a C/C to a AGV. In general, one lane is dedicated to each C/C. The number of lanes depend on the total number of C/Cs. Maximum width of rail span has been about 30.5m in general until now, but now is designed to be 30.5-35m in order to secure stability of cranes and the minimum number of lanes in preparation for call of super post-Panamax class ships in the future.

④ Backreach

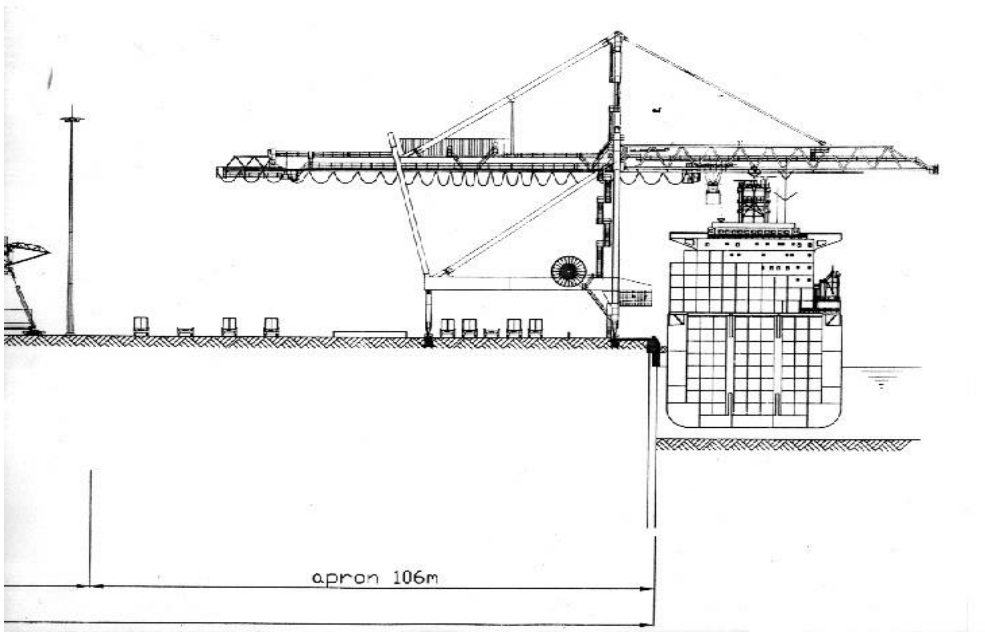
In the ECT type, this zone is designed to allow AGVs to travel perpendicularly to quay. The zone where traffic of AGV is not allowed

is the zone where hatch cover is located. Containers can be temporarily placed in this zone. The zones where AGV travel is allowed or not are decided in advance.

⑤ Zone between backreach of a C/C and a yard

It is located between backreach of a C/C and transfer points of stacking space (ATC-seaside, TC/M-seaside and MT-seaside). It includes AGV travel lane for access to ATC blocks and travel zone where transporter entering quay after operation in an ATC block turns and travel is made perpendicularly to quay. AGV traffic is operated by logistics flow system, in which AGV traveling to a certain C/C by order of control center is not hindered by another AGV.

<Figure 5-21> Zone Between Backreach and Yard in ECT Type



(2) CTA type

① Zone between seaside rail and quay

This zone is used as quay service road in ECT type, but it is used for preventing inclination of ships, repairing quay, supporting cranes, etc. and its width is about 3m in CTA type.

② Rail span

This zone is about 30.5-35m wide, and consists of 2-3 lanes for handling special containers around the most seaside rail. In other areas, it consists of zones for traffic for ship service (bunkering, traffic of managers, ship crew, etc.), traffic of terminal workers (shift, meal, repair/maintenance, etc.) and visitors, and for hatch cover storage.

Lanes for special containers (transporting off-standard or dangerous cargos) are located at seaside between C/C and rail fence and used for transporting containers and cargos, but do not use AGVs. Transport is performed by tractors and chassis system. In the CTA type, fences are set up between storage for hatch covers and lanes for special containers. Lanes for special containers are also exceptionally for direct routing of outside trucks including transporting expensive matters.

In this study, 3 special lanes are established 10m wide in consideration of CTA type. Accordingly, these 3 special lanes, the zone where hatch covers are stored and the zone where hatch covers are not stored are applied to AGV travel and waiting zones.

Length of entire rail span including all the above zones is set up as 30.5-35m. And, if possible technically, it is desirable to be designed to have 30.5m in order to reduce the area of apron.

③ Backreach of a C/C

In the CTA type, the AGV operation and travel zone consists of several

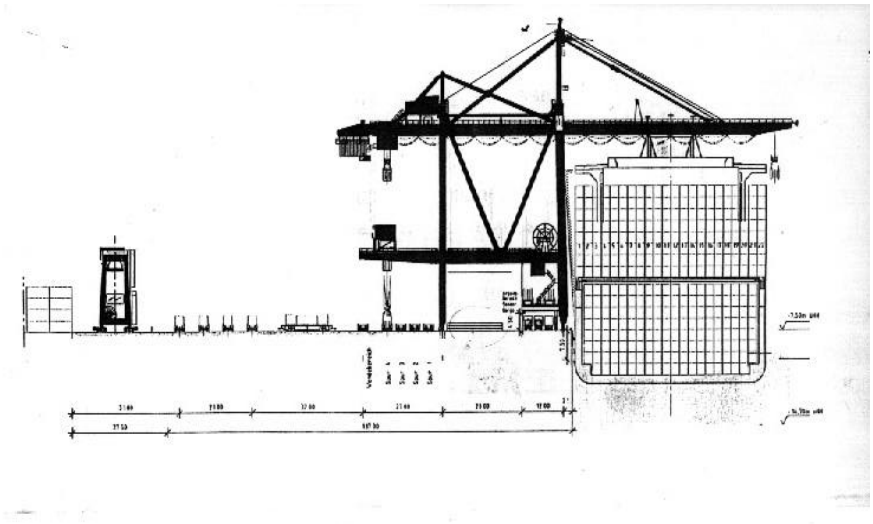
lanes to transport containers from C/Cs. In general, one dedicated lane is allocated to onc C/C and the number of lanes depends on the total number of C/Cs.

In the CTA type, lane width is about 4m. Accordingly, in case the CTA type is applied to this study and a maximum of five C/Cs are allocated to 8,000 TEUs class ship, 5 AGV travel lanes and 1 passing lane are required. In case a lane is designed to be 4m wide including right and left safety distance, entire back reach width is described as follows:

- A : Allowance between center line of landside rail and AGV = 2m
- B : 4 lanes (discharging/loading lanes)×4m (lane width) = 16m
- C : Allowance between discharging/loading lane and travel lane = 3m
- D : 1 lane (travel lane)×4m (lane width) = 4m

  Width of back reach = A + B + C + D = 25m

<Figure 5-22> Backreach of CTA Type



④ Zone between back reach of a C/C and a yard

The zone between back reach of a C/C and a yard is for AGV travel which is located between seaside container stacking block and backreach of a C/C in parallel layout, and between yard block kiosk entrance and backreach of a C/C in perpendicular layout. This zone consists of AGV U-turn sector and 4 AGV travel (both-way) lanes.

In this study, the width between backreach of a C/C and a yard was estimated as follows:

- A : Width of AGV U-Turn sector = 26.5m
- B : 4 lanes (AGV travel lane + allowance) × 7m (lane width) = 28m

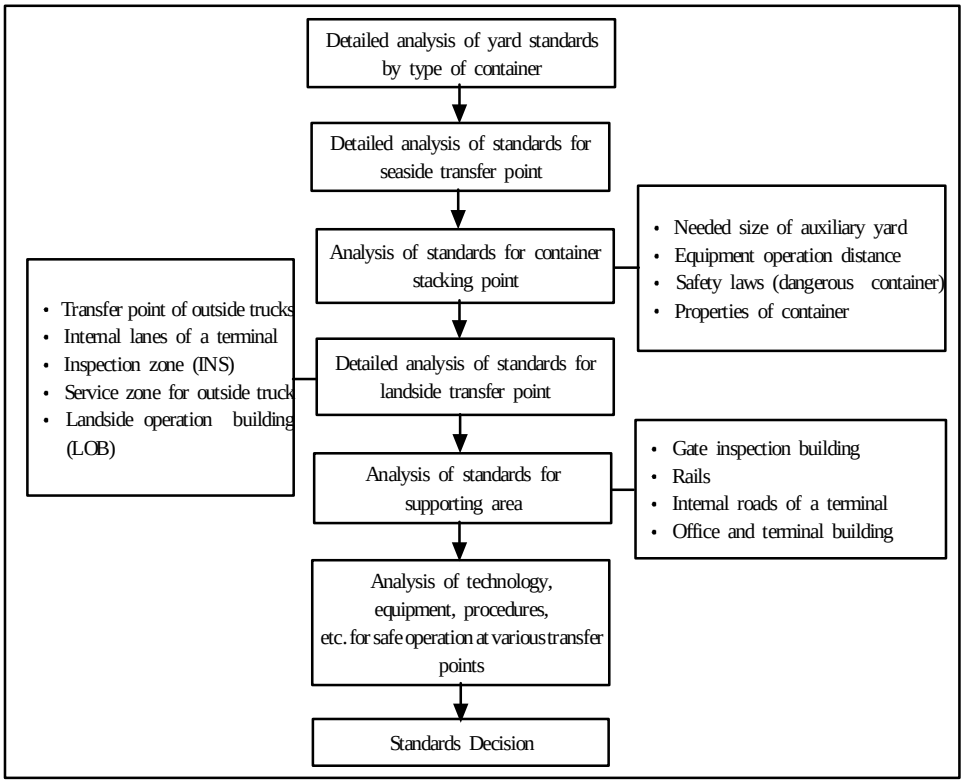
  Width = A+ B = 54.5m

3) Container Yard

In this section, various container yards designed at the development stage are described. Stages and contents of analysis of a container yard is shown in the following figure.

Step-by-step analysis defines storage space for kinds of handled container and studies the seaside transfer point. Analysis establishes functions, roles and standards for container yard through analyses of standards of storage position, landside transfer point and other supporting zones.

<Figure 5-23> Analysis Stage of Container Yard



For seaside or landside storage of containers, a container yard should be decided upon. This depends on type, size, dimension of containers and characteristics of cargos. Container condition can be another factor. If a container yard is made on the basis of data, the location of each block in a yard is decided on the following bases:

- Needed size of each block
- Equipment operation scope
- Safety laws (dangerous containers)
- Laws concerning characteristics of containers (off-standard and refrigerator containers)

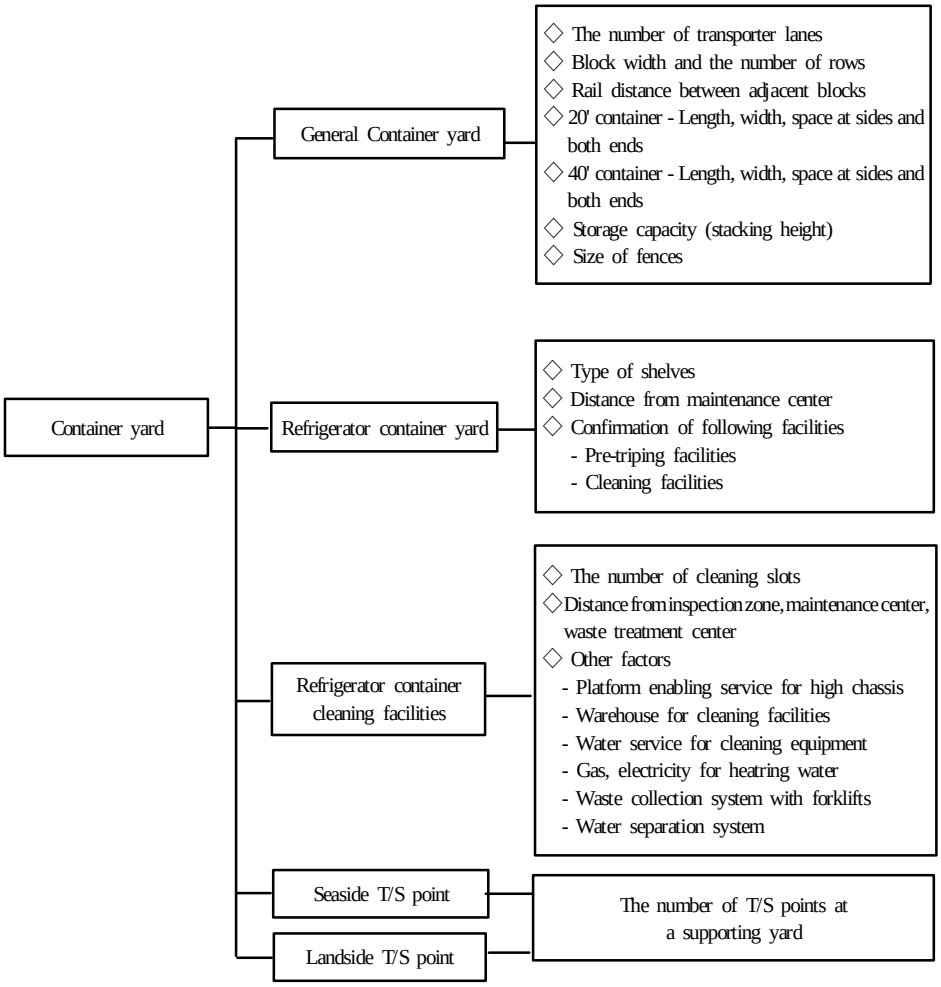
Type and size of container arriving at a terminal can be found from the information given by terminal users. If possible, this information should be inspected and corrected.

- Arrival through seaside: inspected by an inspector at a C/C
- Arrival through road: inspected by an inspector at a gate
- Transport of container after inspection at inspection point: inspection by an operator at a container handling equipment
- Transport of container between landside transfer points: inspection by a remote controller at container handling equipment

In most cases, system information can be obtained from type, size and code at container storage stacks. Criteria for storing containers in a ATC yard are as follows:

- General containers are handled by AGVs and outside trucks.
- General container are handled by ATCs.
- General container are stored in ATC yard.
- Container shall not exceed 20´, 40´ and 45´ in length, 8´ in width and 9.6´ in height.
- Container having no top rail is stored most above.
- Container having no cover is not stored above, but stored on the ground.
- IMO container of other than type 1 and 7 is allowed to be stored in separate storage. IMO type 1 (explosives) and 7 (radioactivity) are not allowed to be stored in a ATC yard but stored in chassis type in an on-wheel yard. Other yards are subject to the same rules. Analysis of container storage space and related factors are shown in <Figure 5-24>.

<Figure 5-24> Analysis of Container Storage Space and Related Factors



In general, container storage space consists of a general container yard, a refrigerator container yard, an empty/refrigerator container cleaning facilities, seaside and landside transfer point, etc.

(1) Automated Container Yard

An automated container yard is operated with automated container handling equipment such as an ATC and a CATC, and used for handling general

containers, refrigerator containers, repair-free and inspection-free empty containers, etc. A port of a block can be allocated for storage of refrigerator containers. The transfer point of an ATC lane is located at landside (ATC-landside) and seaside(ATC-seaside) in perpendicular layout. Containers are exchanged between an ATC and an AGV at seaside, and between an ATC and an outside truck at landside. In a parallel layout, containers are exchanged at transfer points of each block and a buffer yard may be set up for the connection of automated handling equipment with outside trucks. Supporting facilities including lighting, electricity, pipeline networks, etc. are established in each block. In a perpendicular layout, space between blocks can be used as service road for maintenance. All specifications can be adjusted depending on economy and productivity. Automated container yards are classified as follows:

- High stacking space for general containers: Elastic layout for storing general container of 45′ long and 8′ wide
- Space for connecting and storing refrigerator container: Providing temperature controlling heating for tank container
- Containers are exchanged between an ATC and an AGV at seaside transfer points (perpendicular layout).
- Containers are exchanged between an ATC and an outside truck at landside transfer points (perpendicular layout).
- Containers are exchanged between an ATC and an AGV at transfer points of each block (parallel layout).
- Yard storage strategies depend on a terminal layout.

① General container yard

This zone consists of ATC yards for storing general and refrigerator containers in an automated system. A container stack is 20′ long with

distance between containers of 0.4m and 8′ wide with distance between containers of 0.4m. Containers not loaded under this condition cannot be stored in automated yard but stored in the ATC of the manual yard. Loaded, repair-free and inspection-free empty containers are stored in an automated yard. Some IMO (dangerous) containers are also handled in a yard as for general containers in consideration of geographical situations, but subject to certain conditions to be controlled by a centralized control system. But, IMO containers on chassis are stored in an on-wheel yard.

In case of a plan for entrance of an outside truck in a yard, a container is laid out perpendicularly to quay, in which each block consists of 2 ATCs (1 external ATC and 1 internal ATC) or 3 ATCs (1 external ATC and 2 internal ATCs) and 2 auxiliary blocks. In such a block, the container-AGV connection point is automated and the container-outside truck connection point is remotely controlled.

② Refrigerator container yard

A separated yard should be provided for storing containers requiring refrigeration and heating. This yard is equally distributed to several blocks in perpendicular layout and should be able to store enough inbound and outbound containers from seaside and landside. It shares certain blocks in parallel layout. The platform should be designed to be equipped with certain electricity to ensure one-over-three or higher stacking of refrigerator container. As many connection points as required for an ATC should be made and access road also should be designed for access to a refrigerator container yard.

Additional activities including connection to refrigeration monitor and temperature monitoring are required for handling refrigerator containers. Position for optimal cycle time of refrigerator monitor should be selected

and refrigerator monitor is provided by a refrigerator vehicle (RCAR).

For safety, certain criteria and procedures (communications) are required. Each reefer container has a connection point at location. In particular, before receiving an order to transport reefer container from centralized control system, refrigeration monitor should transmit to a centralized control system the record showing that the reefer container is not connected.

③ Transfer point between container handling equipment

ⓐ Parallel layout plan 1 (for establishing an overpass)

As blocks are in parallel layout with quay in the plan for establishing overpass, the plan does not have separate seaside and landside transfer points. This layout plan depends on length of blocks, but has transfer points connected to AGVs by block. Unlike perpendicular layout, it does not have a limit to the transfer point, which depends on length of block. Containers are exchanged below cantilever of CATCs equipped in each block. All operations are automated in exchange of a container between a CATC and an AGV.

The overpass level road is established for connection with outside trucks. and can be used only with outside trucks. As connection with a CATC is remotely controlled, no limit exists in transfer points. However, as accurate positioning is required for trucks it is better to establish a certain limit.

ⓑ Parallel layout plan 2 (for establishing a buffer yard)

In the plan for establishing a buffer yard, the same method is applied to transfer points of AGVs, type of equipment, block layout type, etc. The only difference is that a separate buffer yard, instead of an overpass, is established behind a yard for connection with outside trucks. The plan for establishment of a buffer yard is the same as the above in layout of transfer points with AGVs, type of equipment, blocks, etc., and only differs from the above in terms of establishment of a separate buffer yard behind a main

yard for the connection with outside trucks instead of an overpass. This layout also depends on length of blocks, but has transfer points to connect with AGVs in each block. Unlike perpendicular layout, it does not have a limit in transfer point but depends on length of a block. Containers are exchanged below cantilever of a CATC established in each block. Exchange of containers between a CATC and a AGV is automated.

A buffer yard is established for the connection with outside trucks. As it is connected with AGV on CRMGC seaside and with external truck on landside, CRMGC is operated by a worker. Therefore, a separate transfer point is not required for the connection with outside trucks.

ⓒ Plan for entrance of outside trucks into a yard (Perpendicular layout 1 and 2)

Transfer points provided for all ATC blocks on landside depend on block width in perpendicular layout. In the plan for entrance of outside trucks into a yard, a block is equipped with 2 ATCs (1 external ATC and 1 internal ATC) or 3 ATCs (1 external ATC and 2 internal ATCs). An internal ATC transfers containers at a landside transfer point (ATC-landside). An ATC approaches to landside transfer point through space between 2 transfer points (landside and seaside) in consideration of safety. Safety procedures and devices are required for preventing the interferences of outside trucks and ATCs.

When containers are transferred an ATC and an AGV at seaside transfer point, all operation is performed by an automated system, and the number of transfer points also depends on block width.

(2) Off-Standard Container Yard

Off-standard containers above or below standards are handled by a special crane (ATC/manual) or a R/S (Reach Stacker). An ATC/manual has characteristics and specifications similar to ATC but is given a manual

operation. An ATC/manual should have spreader which is taller than standard height and has movable flipper. Off-standard containers taller than certain height (of special limit or off-standard A type) can be handled by an ATC/manual, but off-standard containers shorter than certain height (non-standard B type) cannot be handled by automated equipment. Accordingly, non-standard B type is handled by a R/S in a separate off-standard yard. A separate non-standard yard should be constructed for off-standard containers. An ATC/manual yard should store as many off-standard containers as possible to reduce the number of manual transport and terminal chassis. If it is impossible to set up a separate ATC/manual yard, a separate non-standard should be established.

An off-standard yard is located behind a container yard and used for the interface of yard trucks in a parallel layout, while it is located on left or right of an automated container yard for the connection with yard trucks in perpendicular layout.

(3) Empty Container Yard

Empty containers can be stored in either a general automated ATC yard or an empty container yard. In addition to the function of storage, an empty container yard has spaces for inspection and repair. Most empty containers of good condition are stored in a ATC yard and should ensure rapid gate-in and gate-out of empty containers to landside. Inspected and repaired containers are transported to a ATC yard. Repair and cleaning facilities are also installed in a empty container yard. An empty container yard should be designed so large as to accommodate re-distributed empty containers.

Container handling equipment in an empty container yard includes RS and FL.

Like off-standard container yard, an empty container yard is laid out

behind a container yard in parallel layout for transport to yard truck. A left or right automated container yard is used for the connection with yard trucks in a perpendicular layout.

(4) On-Wheel Container Yard

A chassis carrying a container is stored in an on-wheel yard. In this yard, a container cannot be stored in an ATC or ATC/manual yard as its type and size are different. Containers be stored in an on-wheel yard are as follows:

- Special non-standard containers (non-standard type B)
- Dangerous container (subject to IMO rules) grades 1 and 7
- Non-standard A type container in case ATC/manual is used
- Non-standard C type container, bulk cargo not stored in container but stored in wheel trailer

An on-wheel yard has several separate slots and can use devices for connecting several reefer containers.

Like a non-standard yard, an on-wheel yard is located behind an automated container yard in parallel layout for transport to a yard truck, and a left or right automated container yard for the connection with a yard truck in a perpendicular layout.

(5) Facilities Related to a Container Yard

Facilities required for operation are as follow:

- Transfer points for outside trucks: Transfer point of container to external truck is determined and it should cause no waiting.
- Internal terminal lane: If a rail terminal is constructed in a terminal, lanes should be designed for transport between a container yard and a rail terminal, and also designed to set up lanes required for travel of external trucks to a yard.

- Landside Operation Building (LOB): A landside operation building is required to monitor a container yard. In general, it is located at the place where not only the status of yard and operations of equipment can be fully monitored but also where a control system of automated container handling equipment can be operated.

(6) Safety in Container Yard

Following technologies, devices and procedures are required for safety at a number of transfer points.

- Physical measure: In the design of the equipment and the transfer points, provisions are turned to one another to safeguard safety. In this respect, one can think of dimensions, driving speed at transfer points, barriers and marking of areas
- Sensor technology for identifying accurately a transfer point and the location of equipment
- Proper operation rules including training programs for manual operations with terminal workers
- Order adjustment system to prevent simultaneous operation of manual and automated equipment in transfer zone
- Preparation for inaccurate location of manual equipment
- Emergency switch button for all equipment
- Adjust devices for automated equipment in a process control system

4) Rail Terminal

(1) Outline

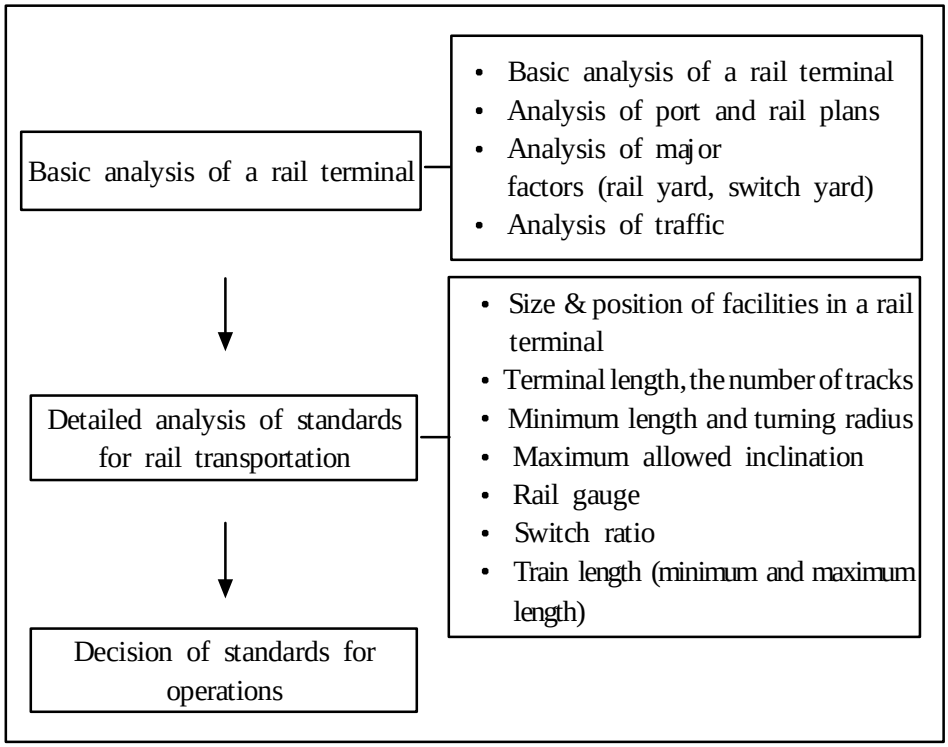
This section discusses facilities required for a rail yard. A rail terminal consists of a rail yard and a switch yard.

For a detailed plan for size and facilities of a rail yard, it is considered

that forecast of containers should be handled in a rail terminal and plan for future expansion of national rail network nationwide should be reviewed.

Specific matters to be considered are described in <Figure 5-25>.

<Figure 5-25> Stages of Analysis of Rail Terminal



(2) Rail Yard

A rail yard should be located at landside of a automated container terminal, whose functions are to load and unload containers to trains. Major equipment of rail terminal are rail cranes.

(3) Switchyard

A Switchyard should be located at landside of an ACT, and is used for waiting or changing container trains on empty tracks connecting a marshaling

yard and a rail yard on empty tracks of a rail terminal. Safety and stop tests requiring accuracy can be performed in a switchyard of a rail terminal, but allocating trains is not performed in a swithchyard.

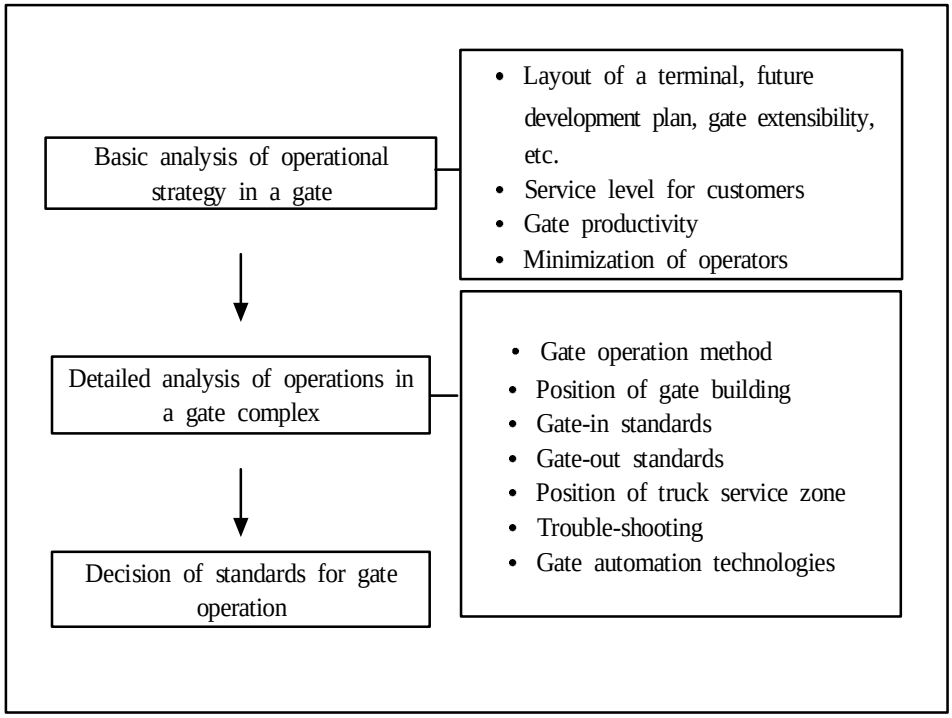
5) Gate Yard

(1) Outline

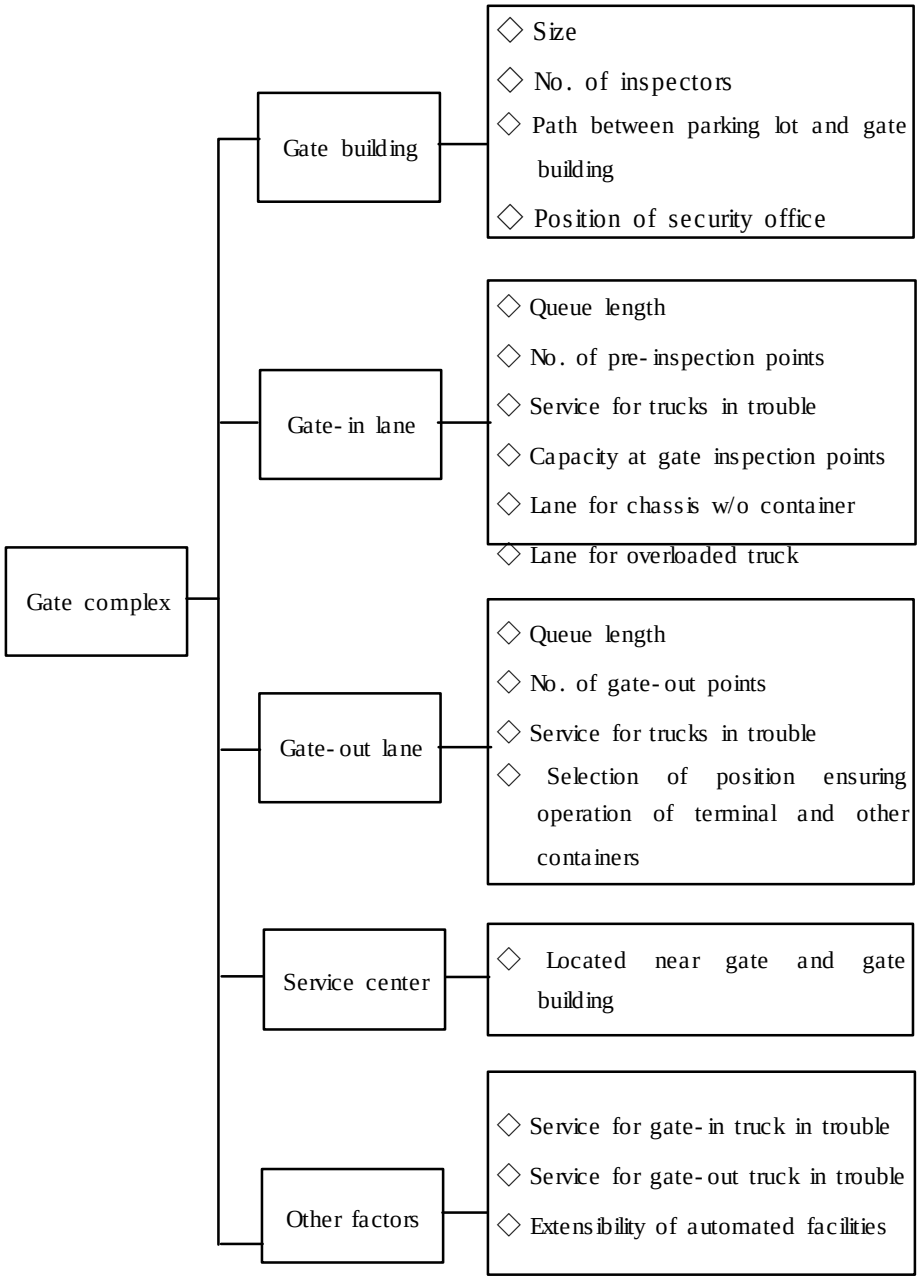
The purposes of a gate complex are as follows: high productivity at gate, flexibility for increased traffic, better service for customers including transportation firms, shipping firms, etc. and minimum operation personnel.

The master plan for the gate operation in an ACT is established through the following stages of analysis.

<Figure 5-26> Stages of Analysis of Gate Yard



<Figure 5-27> Analysis of Factors Related to Gate Yard



(2) Functions of a Gate Complex

① Gate-in safety inspection

Safety inspection is made for all container carriers and other vehicles entering the terminal, terminal workers, customers (shipping firms, shippers), etc. Inspection of all vehicles entering the terminal ensures understanding how many vehicles have entered the terminal for an arriving time and inspection of gate-out vehicles.

Drivers bring bar code cards when entering the ACT. Terminal issues cards for drivers who do not have bar code cards. Safety inspection is automatically performed when drivers submit their bar code cards confirmed by a computer system.

② Gate-in confirmation

Gate-in confirmation is made with communications between gate operators and drivers and processing of information transmitted from terminal system. About 90% of gate-in and gate-out container carriers provide information for terminal in advance through EDI, and only about 10% of container carriers provide information for the terminal in writing when arriving at the gate. Such prior provision of information through EDI ensures rapid and simple processing of operation at gate.

For rapid processing of arriving trucks providing information through EDI in advance, a separate lane is given for trucks bringing documents with empty chassis vehicles. In addition, a separate lane is also allocated for gate-in confirmation of non-standard containers.

Since the of the weight of a container is also required for load planning, weight meters are installed at lanes of gate. Gate-in trucks for carrying empty containers are given travel point in yard from terminal system. In addition, when problems are found in gate-in trucks, gate operators instruct trucks drivers to move to the trouble station to solve the concerned problems.

③ Gate-in container inspection

Gate operators perform the inspection of containers condition, such as type, size, external brokerage of container, IMO of empty container, sealing of full container, etc. When the inspection is completed, they provide truck drivers with printed-out inspection report. For gate-in trucks with empty chassis, however, such inspection is not required.

④ Customer service center

A truck driver moves his truck to the customer service center when gate-in documents are not be processed or there is a problem in the IMO label. He contacts his office by phone or fax as to correct the documents in the customer service center and then tries processing them again at the gate. It is surveyed that about 5% of all gate-in containers face such problems.

- 3% of 90% trucks whose information is processed by EDI system (=3%)
- 20% of residual 10% other trucks (=2%)

⑤ Gate-out container inspection

Gate operators inspect the container number, container type and size, the inside of an empty container, etc. for gate-out containers. After inspection, he issues and delivers the inspection report to truck driver. Processing procedures are as same as gate-in operation.

⑥ Customs office

Gate-in container is not obliged to submit any document to the customs office. There is no customs officer at the gate-in lane because all customs clearance procedures for export containers are processed via electronic equipment before the truck arrives at the gate. Exports containers also do not receive gate-out inspection, and its physical inspection for customs clearance is made when container is stored in terminal. When a truck arrives at the gate, its inspection has been already completed. Therefore,

the customs officer and customs clearance zone are not required for gate-out export containers.

⑦ Gate-out security inspection

It is the same as gate-in security inspection.

(3) Contraction of a Gate Complex

Alternatives at each stage of for the construction of a gate complex are closely related to the development of main roads in the port. Gate is the commencement point of operation of an ACT, and should be designed to smoothly handle arrivals and departures of containers considering annual traffic.

(4) Preliminary Gate Operation

Preliminary gate is located ahead from the main gate which includes shipper and forwarder offices and drivers' lounge. About 20% of entire trucks use these facilities. A truck can stay there for 15 minutes on average.

(5) Gate Operation Flow

① Functions of gate according to flow of containers

ⓐ Arrival

Truck driver enters terminal area from public road. Before entering terminal, truck driver can enter either preliminary gate or directly gate-in zone.

ⓑ Preliminary gate

Preliminary gate includes offices of transportation firms, its agents, inspection firms, government agencies, etc. Trucks and office employees' private cars are allowed to be parked here.

ⓒ Gate-in zone

When lanes are busy, trucks can wait in the buffer area in front of gate-in

lane. When, when a lane is cleared, the truck moves to the lane. Truck moves on the weight installation at the lane. The weight checked is transmitted to the computer system of terminal. This weight is used only for loading plan. The weight described in cargo receipt is not required to be inspected.

At gate-in processing point, the truck driver presents his truck ID card (i.e. bar code card). The terminal system compares information of truck, driver and container from both the ID card presented by truck driver and EDI. Through these procedures, the truck driver is registered and processing for entrance into terminal is initiated. During the process, the camera system recognizes the number and the type of a truck and container with the CCR (Computer Character Recognition).

A camera system in all directions of container obtains static video image of the container. This image is used for processing at the gate. This image is stored for 3-6 months for reference to probable claim (claim for natural damage). Finding facts and information of the type and the size of a container can be automatically performed with the static video images obtained by CCR. For a full container, its seal number is read with electronic equipment. If all information is correct, the truck driver is given an instruction including information of a travel point.

Sometimes an empty container is also loaded at the guide line. In this case, the container number will not be important and the terminal system or operator decides seaside stack, proper transport point in a yard and the container number. Inspector works with wireless data (from computer system) and communicates with his supervisor. It is assumed that an inspector receives the message including the instruction of a traffic lane to which a truck has to go for service through his computer. At peak times, all gate-in lanes are opened. But, some lanes can be closed if gate-in lanes are not busy. In this case, less manpower will

be required for handling and inspection.

ⓓ Exceptional gate-in operations

Truck drivers not using the EDI system should submit documents to operators in identification office above gate-in lane. To deliver original documents to them, truck drivers put their documents in the cartridge and use pneumatic post system. Operators should manage data entry required for terminal computer system.

The operator in the office above a traffic lane should inspect IMO label for all IMO containers. He checks external image of container to confirm whether its label is correctly attached or not. If the label is not correctly attached, the driver can immediately go out to gate-out zone to correct and attach IMO label as instructed.

Sometimes, the CCR (Computer Character Recognition) system cannot recognize a container number. In this case, operator uses recorded image of container for putting container number in the terminal computer system. If the type and the size of a container are incorrectly recognized, correction is performed through the same procedures.

If it is impossible to recognize a label electronically, the inspector checks the label attached to container to put information in the terminal computer system. The inspector works on ground.

After all empty containers are inspected, an inspector opens the door of an empty container to check emptiness and then inputs the empty container condition in the terminal computer system.

In case of an empty chassis, the CCR system can automatically confirm whether a container is loaded on the chassis or not.

If some automated gate facilities are in trouble, an operator and an inspector should manually provide service for a truck from time to time.

A gate-in lane is prepared for non-standard containers. This lane is wider than other lanes in width and does not have limit in height as it does not have a confirmation booth.

If a truck driver took the wrong way to arrive at the gate-in building (i.e., preliminary gate), he can go out directly through the gate without entering the terminal.

ⓔ Customer truck driver has to exit the gate complex through the gate-out traffic lane.

ⓕ Terminal main road + transport point

Passing the gate-in traffic lane, a truck driver moves to the designated transport point and parks his truck at one of the transport slots. Through this transport slot, a truck driver can deliver or receive a container. After that, he can move to the gate-out traffic lane.

ⓖ Gate-out zone

There is the buffer area in front of gate-out traffic lanes, where a truck driver waits if the lanes are busy with gate-out operation. When a lane is cleared, truck driver moves to the lane.

For gate-out operation, a truck driver stops his truck and submits his ID card (i.e. bar code card) to the console. A camera system checks the truck and its container and recognizes the number, the type and the size of the container through CCR. The camera takes static images of a container from all sides and above. Taken images are used for gate operation and stored for 3-6 months for evaluation of probable claim such as automatic loss of registration. Checked items and information of the types and the sizes of containers are automatically stored by CCR in static video images. Marking of the full container is read by electronic equipment. There is no weight

installation in a gate-out zone.

During such operations, a terminal system checks the correctness of a container number and the condition of a chassis and also compares them with the handling plan in a terminal. If all information is correct, a gate-out door is opened and a truck can exit the terminal.

A gate-out inspector also uses wireless data and voice communications for operation in the same manner as in gate-in operation. An inspector brings a portable computer with him to receive any message showing the lane in which he has to serve a truck.

All gate-in lanes are opened when traffic is heavy. In case traffic is light, however, some lanes are closed and less personnel will be required for an operation and an inspection.

ⓗ Exceptional gate-out operation

There are some cases in which a CCR system cannot correctly recognize a container number. In this case, an operator puts the container number in terminal computer system seeing stored container images. In case the container number is incorrectly read, the operator takes the same procedures.

In case marking cannot be electronically recognized, an inspector checks marking number attached to the container and puts the information in a terminal computer system. Inspector works on ground.

All empty containers are subject to inspection. An inspector opens the door of a container to confirm that it is empty and puts confirmation in a terminal computer system.

Chassis without container can be automatically identified with a CCR system. Unlike a gate-in operation, there is no inspection of IMO label in a gate-out operation.

When a part of the automated gate facilities are in trouble, an operator and an inspector serve trucks manually.

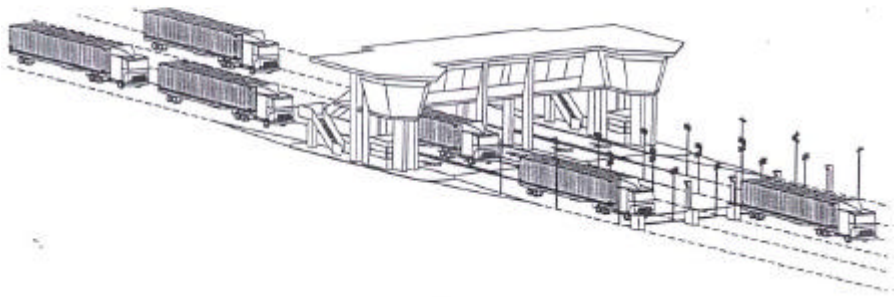
One of gate-in lanes is allocated for non-standard containers. This lane is wider than others in width and has no limit in height.

② Departure

Completing the gate-out operation, a truck driver can either drive to a public road or move to the building in the preliminary gate to check subsequent works.

A security officer also inspects trucks before they leave the gate. This inspection is made on the side of the departing road from the terminal.

<Figure 5-28> Overview of Gate



③ Classification of operation type depending on gate operation flow

The flow of gate operations is classified as follow:

First, gate-in confirmation and container inspection is performed at a gate (1-step gate)

Second, gate-in confirmation and container inspection is made at different gates (2-step gate)

Third, security inspection, gate-in confirmation and container inspection are made separately (3-step gate).

ⓐ 1-step gate

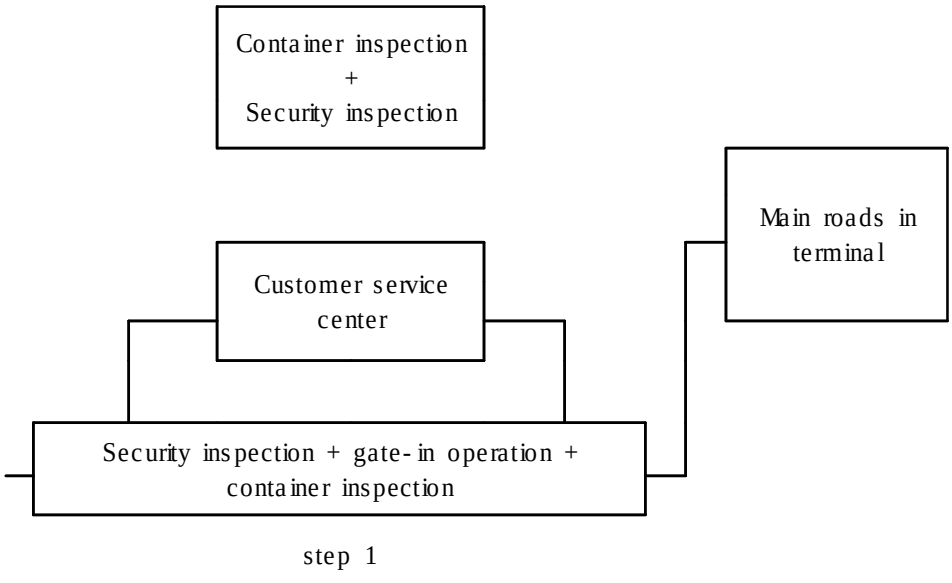
The flow of gate operations shown in <Figure 5-29> can be summarized as follow:

First, terminal operation is economical because security inspection, gate-in confirmation and container inspection are performed at one gate.

Second, a separate lane is allocated for a gate-in operation of a chassis without container and a gate-out operation of empty container because container inspection is not required for them.

Third, a separate lane is allocated for a gate-in operation of the truck which has not provided information in advance through EDI.

<Figure 5-29> The Flow of 1-step Gate Operation



ⓑ 2-step gate

The flow of a gate operation shown in <Figure 5-30> is summarized as follows:

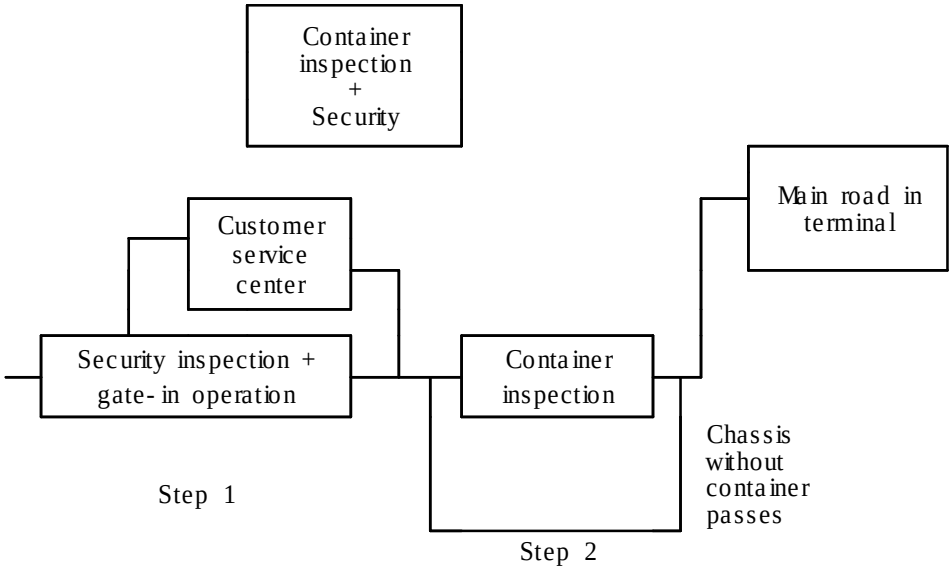
First, the operation flow of a 2-step gate is different from that of a 1-step gate. Security inspection and gate-in operation are performed at the first gate, and container inspection at the second gate.

Second, a chassis without container passes the second gate without any operation because container inspection is not required there.

Third, a separate lane is allocated for gate-out operation of an empty container and a chassis without container because container inspection is not required there.

Fourth, a separate lane for security inspection and gate-in operation is allocated for the truck which failed to provide information in advance through EDI.

<Figure 5-30>. The Flow of 2-step Gate Operation



ⓒ 3-step gate

The operation flow shown in <Figure 5-31> is summarized as follow:

First, the difference between the 2-step and the 3-step gates is that security inspection and gate-in operation are separated, and security inspection and container inspection are separated in a gate-out operation.

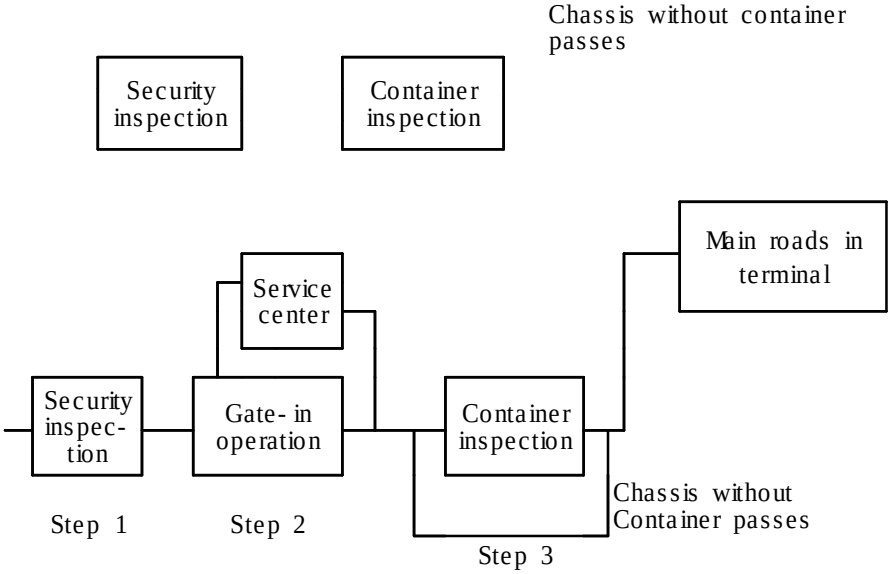
Second, trucks with container and other trucks can be performed at a same building.

Third, a chassis without container passes the third gate without any operation in both gate-in and gate-out operations because container inspection is not required.

Fourth, a separate lane is allocated for the truck which failed to provide information in advance through EDI.

Fifth, the 3-step gate system requires more land and more personnel than the 2-step gate system.

<Figure 5-31> The Flow of 3-step Gate Operation



ECT/Delta terminals adopt the 3-step gate system for the following reasons:

First, the Dutch Customs House is applying tight customs clearance procedures to ships and also operates a separate security station for gate-in and gate-out trucks.

Second, the 3-step gate system is adopted, but at request of a truck driver, he is allowed to pass freely at each step. But, the truck is tightly checked in case of a gate-out operation.

Third, the 3-step gate system requires lots of land and personnel, but the time truck drivers consume at the gate is reduced.

Fourth, Delta terminal is used in many European countries. Accordingly, truck drivers from various countries are required to be alerted through separation of safety inspection and gate-in confirmation.

6. Design and Evaluation of an ACT

6.1 Outline

Design of container a terminal may greatly vary depending on pre-conditions. It is very important to set up and review pre-conditions complying with the design of an automated terminal through analysis of newly automated discharging systems and equipment. In this chapter, actual cases considering above-mentioned system architecture and operational strategies are suggested in order to explain ACT design and its evaluation process. The contents of this chapter are: analyzing conditions and contents required for design of terminal and prepared analytical scenarios for two design alternatives of parallel layout and perpendicular layout, and then, summarizing results of capacity analysis for each scenario for various factors through simulation. Also we review drawing out productivity of an integrated operation with analysis results of capacity of berth and yard. This is not only important criteria on comparison of various alternatives in making decision for the design of a terminal but also provides data enabling prior comprehension of problems in design.

6.2 Simulation Scenarios

In the actual case to be explained in this chapter, it was assumed that quay is 1,050m long. Capacity and productivity of terminal greatly vary according to makeup of discharging equipment and system, and heavily dependent on layout. Accordingly, design alternatives are prepared in different cases of parallel layout and perpendicular layout.

6.2.1 Parallel Layout

When an external truck enters the yard block in a parallel layout, operation control is difficult in general, which may be a major cause for accident. Therefore, external trucks do not enter marshaling yard by setting up buffer yard in parallel layout.

6.2.2 Perpendicular Layout

Unlike parallel layout, the method of operating CTA in which external truck directly enter transfer point of each block in marshaling yard is introduced in this layout.

6.3 Berth and Yard Capacity Analysis

The major purposes of analyzing quay capacity and required yard capacity are to review length and traffic of quay and estimate the number of C/Cs required and berth utilization for each scenario for each traffic volume, and to decide yard capacity depending on reviewed and estimated quay traffic. The detailed contents of analysis are as follow:

- Influence of quay traffic on LPC (Lifts per call)
- Estimation of the number of quay cranes required for efficient operation
- Berth utilization
- Comparison of yard required for container storage

6.3.1 Criteria on Deciding Capacity Through Simulation

Service levels for norm-time excess rate and waiting ratio of ships were reviewed in order to judge whether particular simulation results are acceptable or not.

6.3.2 Procedures of Analysis

1) Scenarios

(1) Scenarios by Annual Handling Volume

- ○ 720,000 TEUs: Based on 240,000 TEUs per berth
- ○ 1 million TEUs: Based on 330,000 TEUs per berth
- ○ 1.2 million TEUs: Based on 400,000 TEUs per berth
- ○ 1.35 million TEUs: Based on 450,000 TEUs per berth
- ○ 1.5 million TEUs: Based on 500,000 TEUs per berth

(2) Scenarios by Ship Arrival Pattern

In connection with ship arrival, 3 different scenarios were reviewed : 1) equal ship arrival interval, 2) ± 6 hours and, 3) ± 12 hours difference between planned and actual ship arrival interval.

- ○ Equal ship arrival interval as planned (Scenario 1, Low Peaking)
- ○ Change in ship arrival plan : ±6hours (Scenario 2, Medium Peaking)
- ○ Change in ship arrival plan : ±12hours (Scenario 3, High peaking)

(3) Scenario by LPC of Arriving Ship

Average LPC greatly influences quay capacity because quay operation rate to total operation time increases as LPC increases. In addition, the number of cranes allocated increases as LPC increases, and LPC increases in general as size and length of ship increase.

- ○ Makeup of LPC scenarios

Considering that average LPC of Pusan PECT was 860 in 1999 and ships also tend to get large, 3 different LPC scenarios were made up, in which LPC increases by 50% and 100% from the present LPC.

- 860LPC scenario
- 1,285LPC scenario
- 1,680LPC scenario

- ○ Analysis of causes for LPC increase

(4) Summary of Scenarios Made up

Scenario	Annual handling volume (TEU)	Ship arrival pattern	LPC
1	720,000	Low peaking	860
2	720,000	Low peaking	1,285
3	720,000	Low peaking	1,680
4	720,000	Medium peaking	860
5	720,000	Medium peaking	1,285
6	720,000	Medium peaking	1,680
7	720,000	High peaking	860
8	720,000	High peaking	1,285
9	720,000	High peaking	1,680
10	1,000,000	Low peaking	860
11	1,000,000	Low peaking	1,285
12	1,000,000	Low peaking	1,680
13	1,000,000	Medium peaking	860
14	1,000,000	Medium peaking	1,285
15	1,000,000	Medium peaking	1,680
16	1,000,000	High peaking	860
17	1,000,000	High peaking	1,285
18	1,000,000	High peaking	1,680
19	1,200,000	Low peaking	860
20	1,200,000	Low peaking	1,285
21	1,200,000	Low peaking	1,680
22	1,200,000	Medium peaking	860
23	1,200,000	Medium peaking	1,285
24	1,200,000	Medium peaking	1,680
25	1,200,000	High peaking	860
26	1,200,000	High peaking	1,285
27	1,200,000	High peaking	1,680
28	1,350,000	Low peaking	860
29	1,350,000	Low peaking	1,285
30	1,350,000	Low peaking	1,680
31	1,350,000	Medium peaking	860
32	1,350,000	Medium peaking	1,285
33	1,350,000	Medium peaking	1,680
34	1,350,000	High peaking	860
35	1,350,000	High peaking	1,285
36	1,350,000	High peaking	1,680
37	1,500,000	Low peaking	860
38	1,500,000	Low peaking	1,285
39	1,500,000	Low peaking	1,680
40	1,500,000	Medium peaking	860
41	1,500,000	Medium peaking	1,285
42	1,500,000	Medium peaking	1,680
43	1,500,000	High peaking	860
44	1,500,000	High peaking	1,285
45	1,500,000	High peaking	1,680

2) Input Data Setup

(1) Makeup of Arrival Data

- ○ Ship type by LPC and its ratio
- ○ Ship type ratio for each LPC scenario
- ○ Relation of ship type to ship length

(2) Allocation of Cranes

- ○ In case of Pusan terminals, C/Cs were allocated up to 5 per vessel. Based on historical date and regression results, C/Cs will be allocated by LPC.

(3) General Input Data

- ○ TEU conversion rate 1.5, with 20' and 40' containers amounting to 50% each
- ○ Ratio of arriving containers as follow:
  - Export/import containers vs transshipment containers = 62.7 : 37.3
  - Import vs export = 50.1 : 49.9
  - Full container vs empty container = 89 : 11
- ○ Considering mean dwell time is 4 days on average and distribution of storage period is based on empirical table.
- ○ Productivity of quay is based on 30 lifts/h in terms of total productivity per hour.
  - 30 lifts/h considering that cycle time productivity of dual hoist C/C is 60 Lifts/h, and C/C operation efficiency and C/C operation rate are 0.67 and 0.75, respectively.
  - 25.5 lifts/h when theoretical productivity of single hoist C/C is always 45 lifts/h.
  - Accordingly, productivity is targeted to be higher than conventional method by 33%.

○ Considering seasonal peak factor is 1.2

6.3.3 Results of Quay Capacity Simulation

1) Reasonable Handling Capacity at 1,050m Quay Length

Simulation results of quay capacity read as follow:

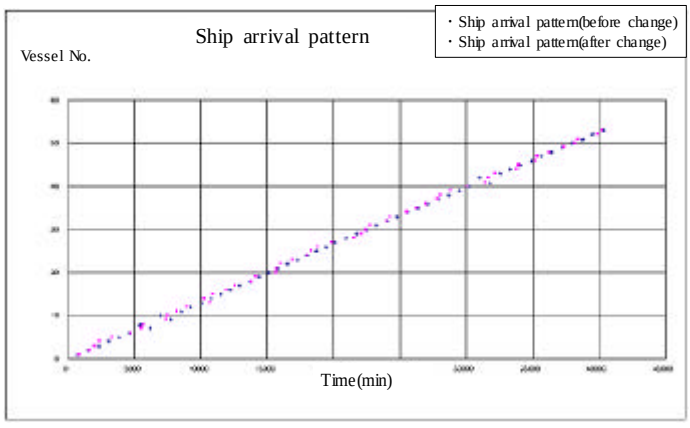
○ To achieve quay capacity of 99% in 27 scenarios, the number of C/Cs required for satisfying ship waiting rate and norm time excess rate was estimated and berth utilization rate and quay capacity at that time were analyzed.

○ The number of arriving ships was estimated by calculating weekly traffic for each scenario and dividing it by average LPC.

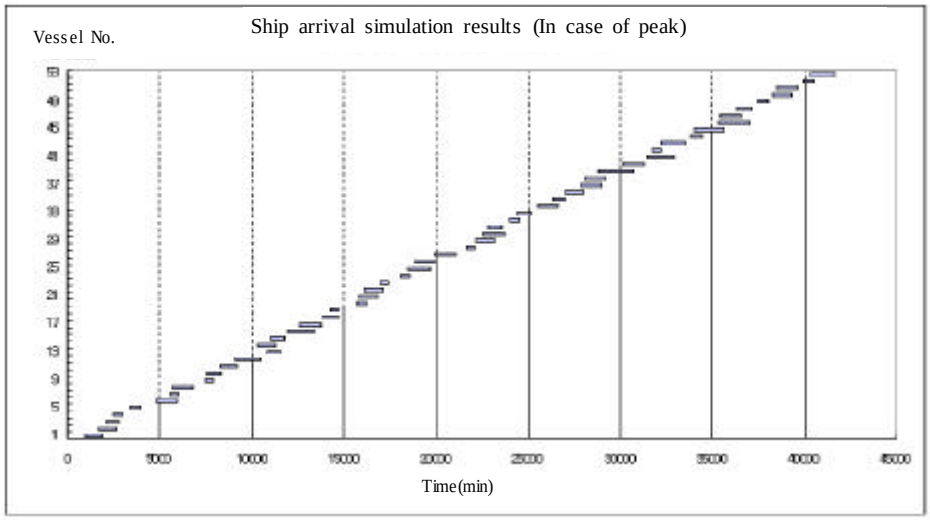
○ For a newly arriving ship, its berthing time, ship length and LPC are decided. When it berths, its waiting is decided according to available quay length and the minimum number of available C/Cs within the concerned space.

○ Period of each simulation was 6 weeks.

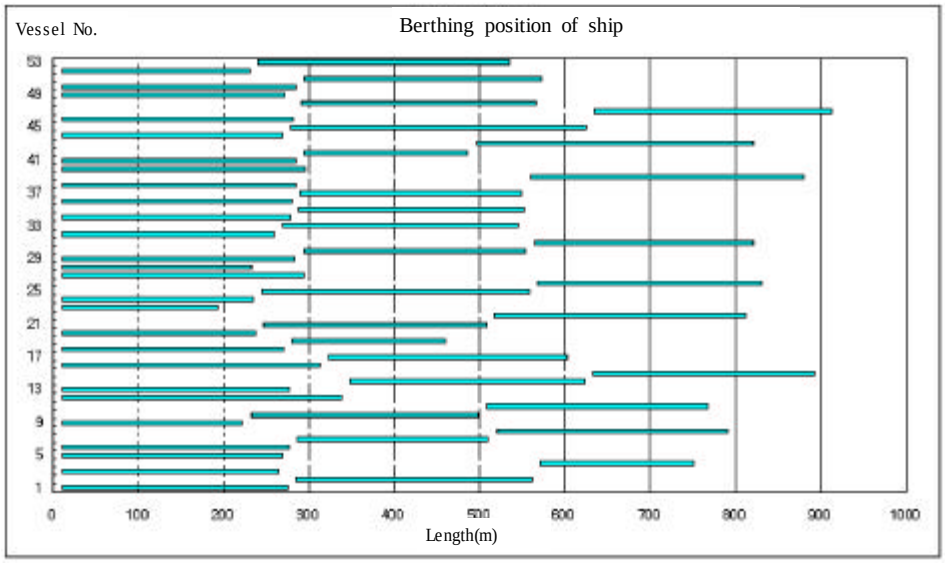
<Figure 6-1> Ship Arrival Pattern



<Figure 6-2> Ship Arrival Simulation Results (In Case of Peak)



<Figure 6-3> Berthing Position of Ship



(1) 1 million TEUs Scenario

The simulation results of waiting probability and norm time excess of 95%-percentile satisfied the limit of 1% and 5% respectively in every case generated from the combination of LPC scenario of ship type change and peaking scenario of ship arrival pattern. In this case, the proper number of C/Cs is estimated to be 10 for medium and high peaking.

<Table 6-1> Simulation Analysis of 1 million TEUs Traffic

LPC	Peaking	Number of C/Cs	Waiting probability of vessel	Norm Time Excess 95%-quantity	99% Berth occupancy
860 LPC	L	9	0	0	77
	M	10	0	0	86
	H	10	0.6	0	86
1,285 LPC	L	9	0	0	63
	M	10	0	0	63
	H	10	0.8	0	84
1,680 LPC	L	9	0	0	63
	M	10	0	0	62
	H	10	0	0	85

(2) 1.2 million TEUs Scenario

The simulation results of waiting probability and norm time excess of 95%-quantity satisfied the limit of 1% and 5% respectively in every case generated from the combination of LPC scenario of ship type change and peaking scenario of ship arrival pattern. However, the scenario with LPC of 860 does not satisfy the limit of 1% of waiting probability ratio at medium and high peaking. In this case, the proper number of C/Cs is estimated to be 11 at medium and high peaking.

<Table 6-2> Simulation Analysis of 1.2 million TEUs Traffic

LPC	Peaking	Number of C/Cs	Waiting probability of vessel	Norm Time Excess 95%-quantity	99% Berth occupancy
860 LPC	L	10	0	0	86
	M	11	1.9	0	99
	H	11	4.7	0	99
1,285 LPC	L	11	0	0	63
	M	11	0	0	86
	H	12	0.7	0	89
1,680 LPC	L	11	0	0	64
	M	11	0	0	63
	H	11	0	0	87

(3) 1.35 million TEUs Scenario

The simulation results of waiting probability and norm time excess of 95%-quantile satisfied the limit of 1% and 5% respectively in every case generated from the combination of LPC scenario of ship type change and peaking scenario of ship arrival pattern. However, the 860 LPC ship type change scenario does not satisfy 1% of queue ratio at medium and high peaking. In this case, the proper number of C/Cs is estimated to be 11 at medium and high peaking.

<Table 6-3> Simulation Analysis of 1.35 million TEUs Traffic

LPC	Peaking	Number of C/Cs	Waiting probability of vessel	Norm time excess 95%-quantile	Max. occupied Length
860 LPC	L	11	0.4	0	912
	M	11	3.3	0	1,061
	H	11	5.4	0	1,060
1,285 LPC	L	11	0	0	959
	M	11	0	0	958
	H	11	0.6	0	958
1,680 LPC	L	11	0	0	682
	M	11	0.8	0	682
	H	12	0.8	0	958

(4) 1.5 million TEUs Scenario

The simulation results of waiting probability and norm time excess of 95%-quantile satisfied each limit only at low and medium peaks in case of 1,285 LPC and 1,680 LPC scenarios. It is estimated that 1.5 million TEUs scenario cannot be accepted with quay length of 1,050m.

<Table 6-4> Simulation Analysis of 1.5 million TEUs Traffic

LPC	Peaking	Number of C/Cs	Waiting probability of vessel	Norm time excess 95%-quantile	Max. occupied Length
860 LPC	L	11	3.3	0	86
	M	12	4.8	0	99
	H	12	5.6	0	99
1,285 LPC	L	11	0.6	0	91
	M	12	1.1	0	92
	H	12	2.8	0	92
1,680 LPC	L	11	0.0	0	91
	M	12	0.7	0	94
	H	12	2.9	0	94

2) Conclusion

As container carriers are getting larger, the maximum quay traffic capacity satisfies service levels at 1,050m quay with 1.35 million TEUs. The number of C/Cs is estimated to be 11 at medium and high peaking. In this case, however, the number of spare C/Cs required has not been considered.

6.3.4 Simulation Results of Maximum Storage Capacity (TGS)

The maximum storage capacity was estimated through simulation of the maximum storage capacity required for the 1.35 million TEUs scenario. In this case, medium and high peaks were analyzed, as ship arrival pattern scenario aims to analyze maximum storage capacity at peaks. For arrival

of trucks for delivery operation before the ship arrival and trucks for receiving operation after ship departure, empirical distribution for dwell time of 7-days was used. T/S containers were considered to be stored for 10 days. Yard storage after seaside and loading/discharging operations were analyzed through a 7-week simulation, in which the number of containers stored for 4 weeks after the first 2 weeks was shown. The maximum storage capacity is not required to be considered because it causes excessive storage demand a yard. Required storage capacity was estimated with 95% percentile. This means that maximum storage capacity is relevant only for the time less than 5%.

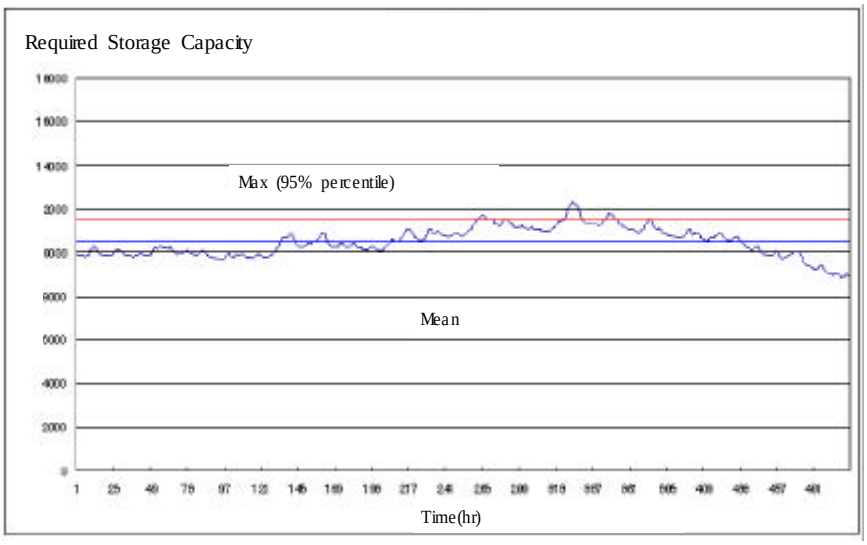
1) Medium Peaking Scenario

In 1,285 LPC scenario, the maximum storage capacity of 95% percentile was estimated as 14,465 VAN. This means that more than 14,465 containers are stored only for hours less than 5%.

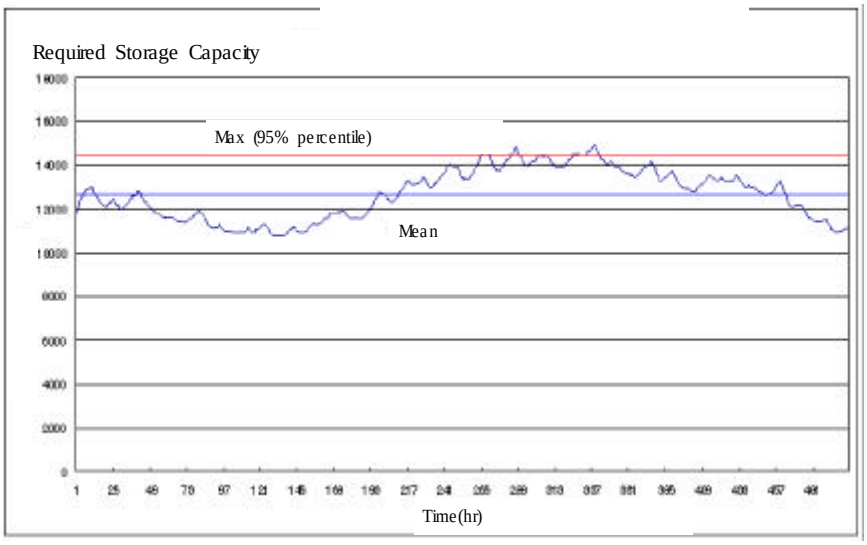
<Table 6-5> Maximum Storage at Medium Peaking

Scenario	Average Storage Capacity (VAN)	Maximum Storage Capacity 95%-percentile(VAN)
860 LPC	10,479	11,538
1,285 LPC	12,688	14,465
1,680 LPC	11,453	13,015

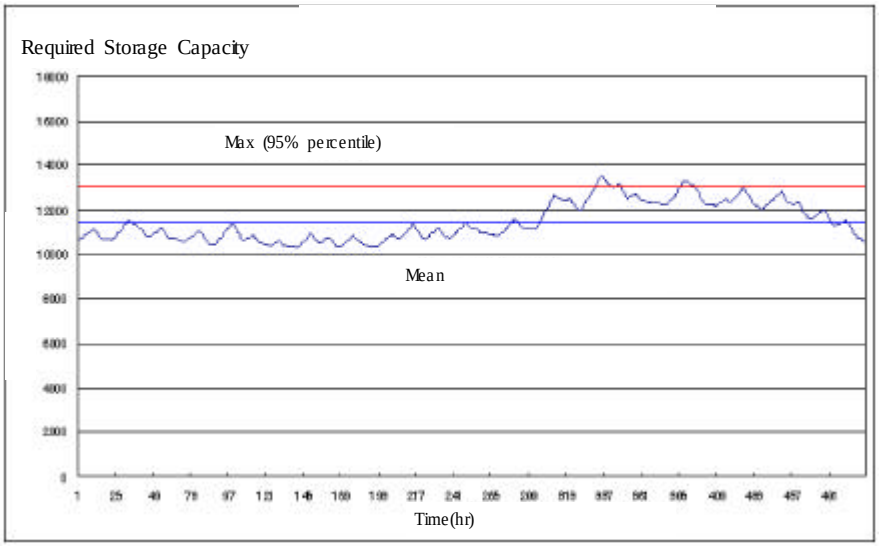
<Figure 6-4> Storage Space Required
(1,350,000TEU, Medium Peak, Average LPC=860, CASE 1)



<Figure 6-5> Storage Space Required
(1,350,000TEUs, Medium Peak, Average LPC=1,285, CASE 1)



<Figure 6-6> Storage Space Required
(1,350,000TEU, Medium Peak, Average LPC=1,680, CASE 1)



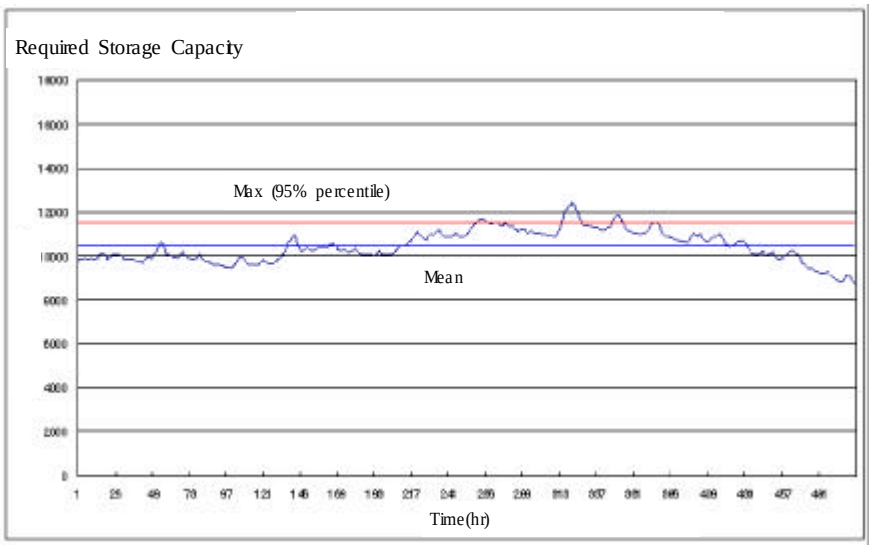
2) High Peaking Scenario

At the high peaking scenario in which ships arrive within ±12 hours comparing with the original schedule, the maximum storage capacity is estimated at 14,802VAN in case of 1,285 LPC scenario.

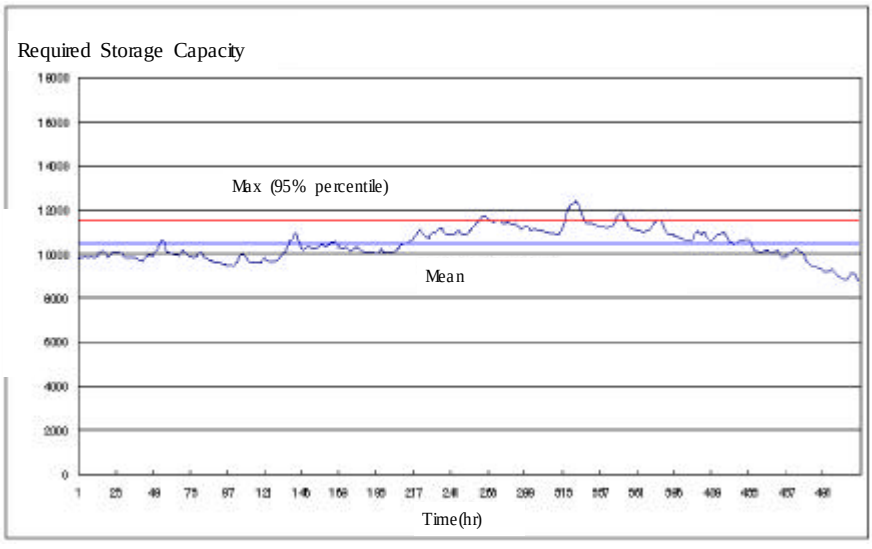
<Table 6-6> Maximum Storage Space at High Peaking

Scenario	Average Storage Capacity (VAN)	Maximum Storage Capacity 95% percentile(VAN)
860 LPC	0,463	11,556
1,285 LPC	12,878	14,802
1,680 LPC	11,508	13,247

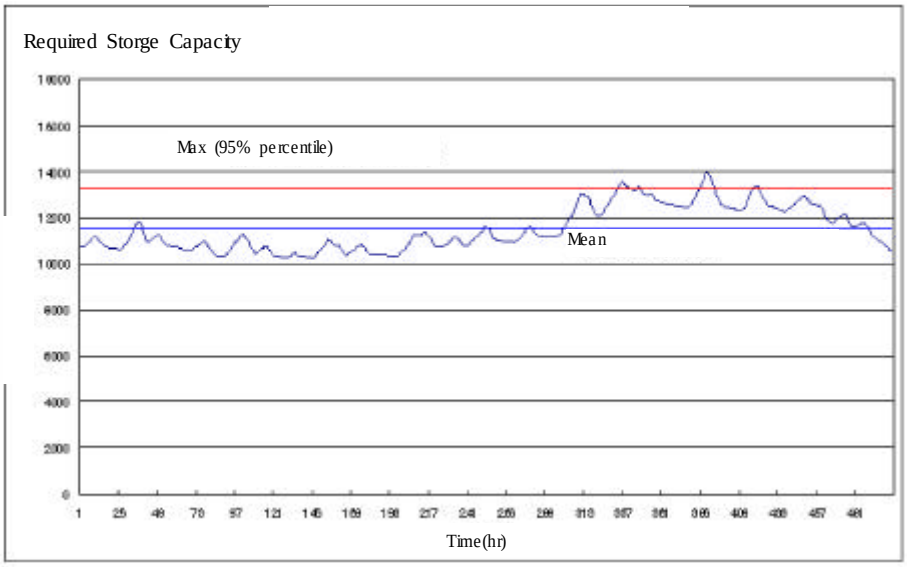
<Figure 6-7> Storage Space Required
(1,350,000TEUs, High Peak, Average LPC=860, CASE 1)



<Figure 6-8> Storage Space Required
(1,350,000TEUs 11 C/Cs, High Peak, Average LPC=1,285, CASE 1)



<Figure 6-9> Storage Space Required
(1,350,000TEUs, High Peak, Average LPC=1,680, CASE 1)



3) Results of Analysis

<Table 6-7> Maximum Storage Space(TGS)

	Throughput (VAN)	Storage Capacity Factor	Maximum Storage Capacity (VAN)	Maximum Storage Capacity (TEU)	Stacks	Total	Total TGS Considering seasonal peak
Full Container	11,045	57%	19,378	29,067	5	5,813	6,976
Empty Container	2,958	75%	3,944	5,916	5	1,183	1,420
Depot Empty	254	75%	338	507	5	101	122
Off-Standard Container	553	75%	737	1,106	3	368	442
On-Wheel Container	150	100%	150	225	1	225	270
Reefer Container	112	75%	150	225	3	75	90
Subtotal	15,072	-	24,697	37,046	-	7,766	9,320
Considering Gate-peak	388	57%	681	1,021	5	205	245
Total	15,460	-	25,378	38,067	-	7,971	9,565

6.4 Terminal Simulation Analysis

The major purpose of terminal simulation analysis is to figure out yard layout and estimate terminal size, productivity and the number of equipment required for each layout alternative. The details are as follow:

- Yard block analysis (Block length and width)
- Detailed yard layout
- AGV-ATC Simulation
- Estimation of productivity and number of equipment required

6.4.1 Yard Block Analysis

This section analyzes block length to decide the number of yard sections and block width to decide the number of ATC rows in parallel layout. Yard block analysis is a preliminary analysis stage for design of detailed yard layout, in which following points are assumed for simple analysis.:

- 1.35 million TEUs scenario and maximum storage capacity of 9,565TGS.
- AGV cycle time is calculated with average speed of each path in consideration of number of returning sections, crossings and merging.

1) Analysis of Number of Yard Sections

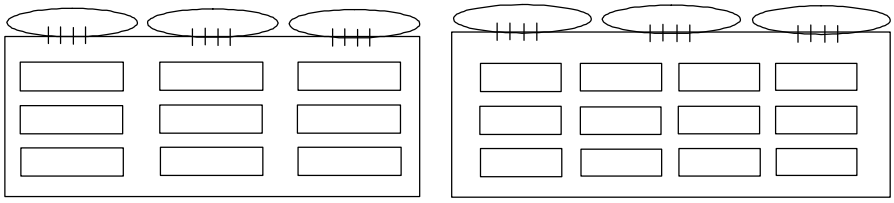
(1) Pre-Conditions

- Analyses are made for scenarios in which the numbers of yard sections are 3 and 4 in 1,050m quay length.
- As the number of sections increases, the percentage of road size in yard increases and the net storage space decreases. Accordingly, traffic control in apron becomes complicated and the number of AGV turning paths on transport route increases which results in decreases

of average operation speed of AGV.

○ When there are 2 sections, it was analyzed that length of a block gets longer by 500m, and ATC operation cycle time gets longer and AGV waiting deteriorates productivity of C/C.
(Analysis of block length, 300m and 600m, in design of Pusan New Port shows that C/C productivity is 28.8 and 20 lifts/h respectively.)

○ Section operation method



○ Based on 12 rows of block

○ In terminal with quay length of 1,050m and terminal width of 600m, 6 runs were designed on the basis of experience net storage space ratio of 67%.

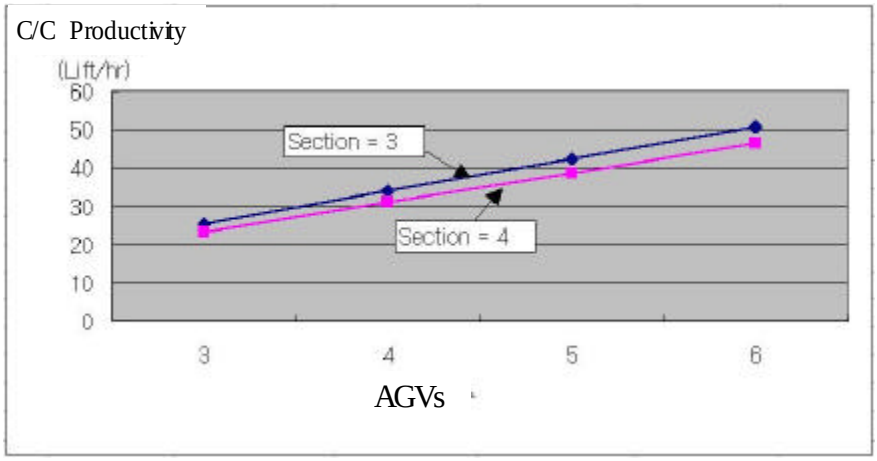
(2) Comparison of C/C Productivity

The number of AGVs per C/C, layout of 3-sections is superior to that of 4-sections in productivity. This is due to the increase of average cycle time of AGV as the number of sections is increased to 4.

<Table 6-8> Comparison of C/C Productivity in Each Section Scenario (lifts/hr)

Scenario	3 Sections	4 Sections
3 AGVs / C/C	25	19
4 AGVs / C/C	33	26
5 AGVs / C/C	42	32
6 AGVs / C/C	50	39

<Figure 6-10> Comparison of C/C Productivity to Number of Sections



2) Analysis of Number of Block Rows

For 1.35 million TEUs scenario, the number of equipment and productivity of C/C are analyzed for each scenario for number of block rows in order to decide specifications of yard crane.

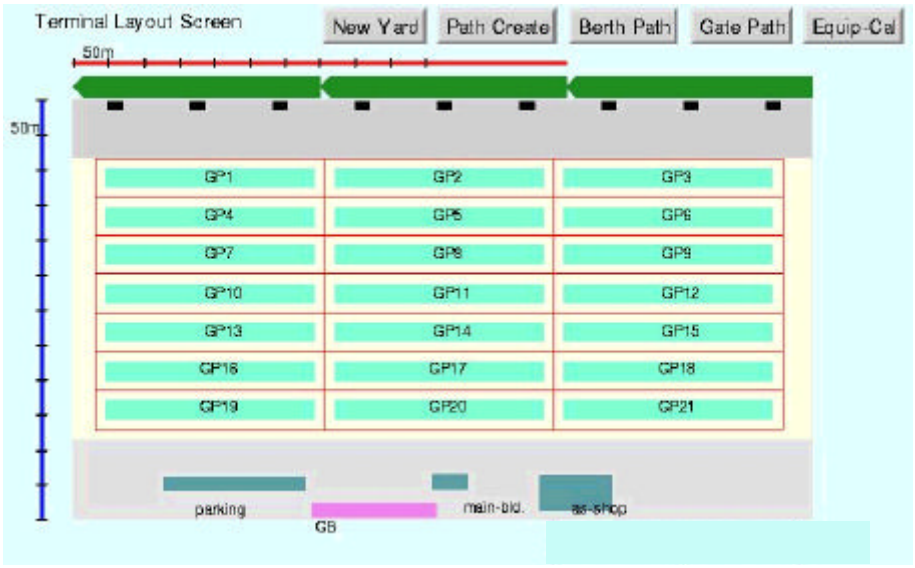
○ Scenario for number of block rows

(1) Layout for Each Scenario

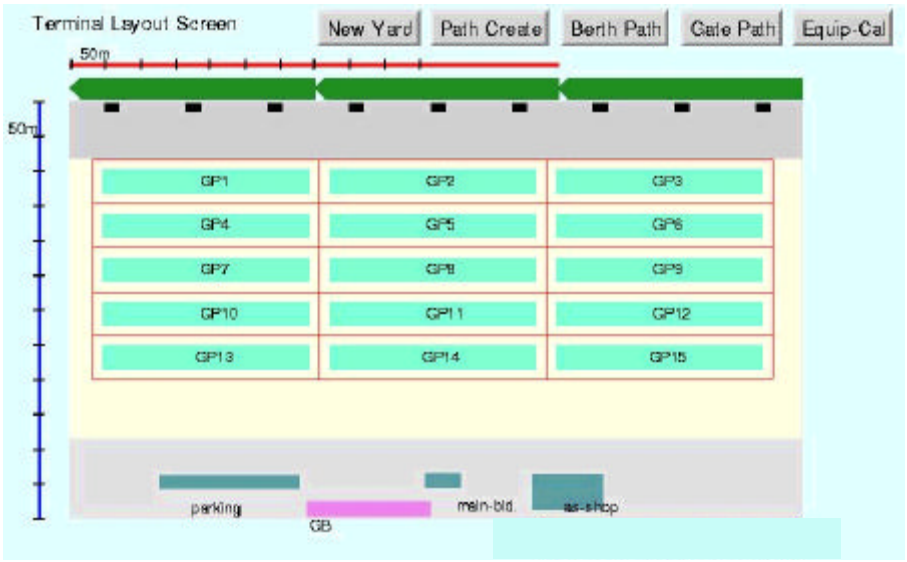
- Throughput : 9,565TGS
- Quay Length : 1,050m, Terminal Depth : 600m
- Empirical area ratio of Net Container Yard Storage Area : 67%

As result of design, the similar TGS conditions were satisfied with 7 runs in 9-row layout, 5 runs in 12-row layout and 4 runs in 15-row layout. However, required depth from quay to yard is 475m with 9-row, 400m with 12-rows and 375m with 15-rows. Therefore, the required depth from quay to yard of 375m with 15-rows turns out to require the minimum yard area.

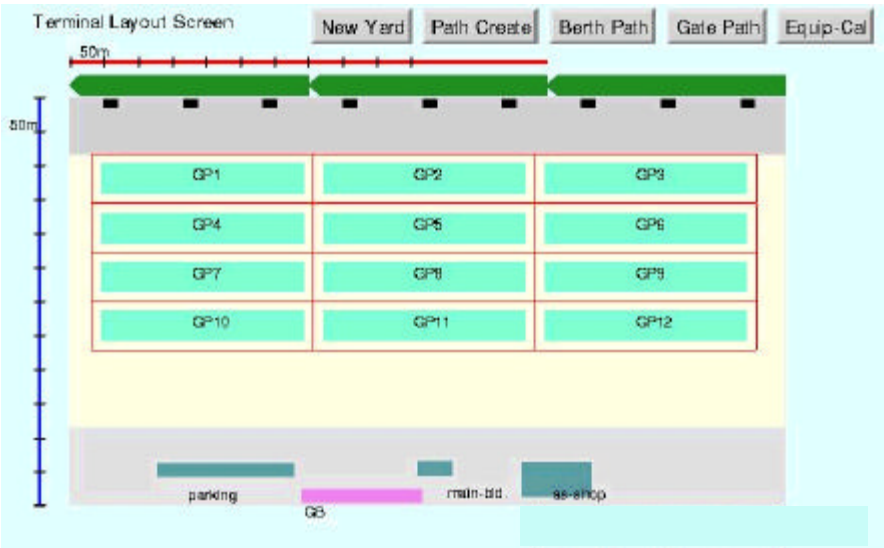
① 9-row layout



② 12-row layout



③ 15-row layout



(2) Analysis of Net C/C Productivity

Criterion of layout comparison is C/C productivity which is estimated in ratio to total operation hours and net operation hours. Productivity per net operation hour includes number of hatch cover moves, gantry time and AGV waiting time. Q/C productivity for layout comparison is defined as net productivity of container moving from ship to AGV. Specifically speaking, it was considered that theoretical productivity of dual hoist C/C is 60 lifts/h, and net productivity of loading and discharging containers in one bay of ship is 55 lifts/h which is 91.4% of theoretical productivity due to the difference in stacking positions in bay and number of rows. This figure is a mean value which was applied to estimate pure productivity of single trolley crane in Crane Sim model of Liftech of the United States.

(3) Comparison of Purposes for Using Productivity

<Table 6-9> Comparison of Purposes for Using Productivity

Classification	Terminal simulation analysis
Purpose	For comparison of layouts
C/C productivity value	- 55 Lifts/hour - Pure productivity of dual hoist C/C (in case of travel of container in a bay of ship to AGV)
Purpose of use	For comparing number of equipment required for layout and productivity of quay
C/C estimated productivity value	- Lower than 55 Lifts/hour It is because of hatch cover travel, gantrying, delayed AGV service - Higher than 30 Lifts/hour It is because of non-productive time such as breakbulk work, stevedoring rehandles, or crane breakdowns.

(4) Estimation of Number of ATCs Required for Each Layout Scenario

○ Number of ATCs required for each layout
T = R×N (R : Number of runs, N : Number of equipment for each run)

○ Estimating the number of ATCs required for each run satisfying the net productivity of C/C, 55 lifts/h, by changing the number of ATCs for 9, 12 and 15-row scenarios

○ Number of ATCs to be analyzed for each run should be in the range of 2 7.

○ In this case it is assumed that waiting AGV causes no deterioration of productivity.

○ As the function of ATC productivity by scenario resulted in the number of ATCs required for each run were 28 with 9-rows, 25 with 12-rows, and 24 with 15-rows respectively.

<Table 6-10> Number of ATCs Required for Scenarios of Number of Block Rows

Scenario	Number of ATC per run	Total number of ATC	C/C productivity (lifts/hr)	ATC productivity per run
5Tiers 9Rows	4	28	58.5	106.1
5Tiers 12Rows	5	25	54.9	131.9
5Tiers 15Rows	6	24	55.0	165.0

(5) Analysis of C/C Productivity for Each Layout Scenario

- Analyze C/C productivity for each scenario with estimated number of ATCs and changing the number of AGVs from 3 to 8.
- Determine the appropriate number of AGVs on condition that C/C productivity doesn't increase while the number of C/C increases.
- As the result, estimated number of AGVs per C/C were 5 with 9-rows, 6 with 12-rows, and 7 with 15-rows.

<Table 6-11> Number of AGVs and Productivity of C/C for Scenarios of Number of Block Rows

Number of AGVs per C/C	5 Tiers 9 Rows	5 Tiers 12 Rows	5Tiers 15 Rows
3	22.3	24.1	24.6
4	29.7	32.1	32.8
5	37.1	40.2	41.0
6	37.3	44.1	49.2
7	37.3	44.1	55.0
8	37.3	44.1	55.0

C/C productivity was found to be the most advantageous (most cost effective) in a 15-row scenario when the number of AGVs per C/C is 5, 6 and 7. In terms of yard area required for the same yard TGS, 12 and 15-row scenarios require the depth of terminal from quay to yard of 400m and 375m respectively and 12-row scenario requires 26,250㎡ of yard.

6.4.2 Design in Each Layout Alternative

1) Analysis of Maximum Yard Size

Maximum yard size to be designed for each layout alternative was analyzed in the following criteria.

- Based on 1.35 million TEUs containers
- Ratio of net yard area to total terminal area:
  Parallel layout: 67% (Based on JWD)
  Perpendicular layout: 71% (Based on KPC)
- Analysis of dwell time storage capacity factor, rate of container mix are same as previous one.

Analysis results of yard size are as follow.: The yard capacity of 9,565 TGS is available for all alternatives when 1.35 million TEUs of containers are handled.

<Table 6-12> Result of Storage Capacity Analysis

	Parallel layout 1 (5Tiers 15Rows)	Parallel layout 2 (5Tiers15Rows)	Perpendicular layout 1 (5Tiers10Rows)	Perpendicular layout 2 (5Tiers 6,13Rows)
Max. Storage Capacity(TGS)	11,538	11,538	12,244	12,085
Net / Gross Area ratio	83 %	83 %	78 %	78 %

2) Block Specs for Each Layout Alternative

<Table 6-13> Block Specs for Each Layout Alternative

	Parallel layout		Perpendicular Layout	
	Layout 1	Layout 2	Layout 1	Layout 2
Number of blocks	15Rows, 12	15Rows, 12	10Rows, 20	6Rows+13Rows, 14
Block length	270m	270m	228m	275m

6.4.3 Terminal Layout Drawing

289
ccxxxviii

200
€ cx c

6.4.4 Comparative Analysis of Terminal Layout

Classification	Parallel layout	Perpendicular layout
ATC Architecture	Yard : One-over-five stacking, 15 rows Buffer yard : One-over-five stacking, 12 rows	1 block 2 equipment: One-over-five stacking. 10/11 rows 2 blocks 3 equipment: One-over-five stacking, 6/13 rows
Layout - Block - Run	– Large yard block available – Number of blocks increases due to buffer yard – Less ATC rail and piling work required	– Large yard block impossible – Number of blocks is much higher than in parallel layout 1. – ATC rail and piling work increase.
	– Running scope gets wide as AGV can reach each container stacking position.	– Running scope gets small as AGV does not enter each container stacking position.
	– Running route is complicated as there are AGV runs.	– Running route is simple as there is no AGV runs for external trucks.
	– AGV can approach to discharging point in yard and its running distance is smaller than in perpendicular layout.	– ATC running distance is very large. – Block size is limited as width and length of block are limited.
	– Apron size is smaller than in perpendicular layout. – Simple apron running route – 4 crossing and merging points in apron	– Apron size is larger than in parallel layout. – Apron running route is complicated. – There are many crossing and merging as AGV travels perpendicularly in apron. – Number of ATCs required increases.
H/W Infra.	– High level road and underpass are not required, but additional interface space, yard operation facilities and discharging equipment are required.	– Vertical interface space is additionally required for receiving/delivery operations trucks. – Facilities are required for control of receiving/delivery operations trucks. – Additional yard crane and transporter are not required.
Traffic control	– AGV running route and traffic control are complicated and running time gets higher than in alternative 1, because gate-in, gate-out, discharging and transport routes co-exist.	– Travel can be simply controlled due to complete separation of seaside and landside transport routes.
Operation system	– In yard operation, remote gate operator in buffer yard to be allocated to ATC for buffer operation – Complicated system control because container in yard should be re-operated in buffer yard – receiving/delivery operations trucks to observe closing time – Different from operation system of conventional terminal	– Remote control personnel should be allocated to ATC, as it is difficult to separate ATC from seaside and landside operations completely. – Different from discharging operation system of conventional terminal

Classifi-cation	Parallel layout	Perpendicular layout
Equipment operation	− Buffer yard causes increase of container transport and in terminal. − Use of large ATC and parallel layout of 1,050m quay parallel enables transport between blocks, but addition of buffer yard equipment requires more equipment comparing with parallel layout alternative 1.	− Move of external truck to yard block requires less expense. − Adoption of small ATC requires more equipment. − Less time is required for move in direction of gantry travel than in parallel layout. − Maintenance and high stacking are settled through allocation of 2-3 cranes to each block in consideration of disadvantages of perpendicular layout including maintenance and low stacking.
Layout alterna-tives	− Complete separation of seaside/landside AGV from routes for external trucks (Establishment of buffer yard in parallel with quay line) − Stacking size: 12Blocks,600TGS (=15x40) Buffer size: 3 Blocks, Total: 7,200 + 720TGS − Buffer yard lowers area efficiency of terminal comparing with alternative 1. − It is required to set up yard operation policies according to use of buffer yard.	− Complete separation of seaside AGV and landside route for external truck centering on ATC block − Stacking size: 20 Blocks, 360GS (=10x36) Total: 7,200TGS − Direct entrance of external truck into kiosk requires establishment of efficient yard operation.
Automa-tion alterna-tives	Container crane: Automated discharging in apron	Container crane : Automated discharging in apron
	Apron↔yard: Automated (AGV)	Apron↔Yard: Automated (AGV)
	Yard: AGV for ships (Automated ATC), AGV for receiving/delivery operations (Automated ATC)	Yard: AGV for ships (Automated ATC), External truck (Remotely controlled automated ATC)
	Import: Q/C→AGV→ATC→Yard	Import: Q/C→AGV→ATC(unmanned)→Yard
	Transshipment: Q/C↔AGV↔ATC↔Yard	Transshipment: Q/C↔AGV↔ATC(unmanned)↔Yard
	Export: Yard→ATC→AGV→Q/C	Export: Yard→ATC(unmanned)→AGV→Q/C
	Gate-in: Truck→ATC (manned)→Buffer yard→ATC (remote automated)→AGV→Stacking yard	Gate-in: Truck→ATC (remote automated)→Yard
	Gate-out: Yard→ATC (manned)→AGV→Buffer Yard→ATC (remote automated)→Truck	Gate-out: Yard→ATC (remote automated)→Truck

Classifi-cation	Parallel layout	Perpendicular layout
Safety & mainte-nance	– Buffer yard block enables prevention of delay for gate-in truck, but planned operation of gate-out truck is difficult. – External truck positioning error does not occur. – Irrespective of arrival order – No problem exists as external truck and yard inside are separately operated centering on buffer yard.	– There is no safety problem and danger because ATC is not completely separated with separate structure. – Troubled equipment can be replaced with other discharging equipment in block.
Discharging equipment	– Buffer yard crane and gate-in and gate-out transporter are additionally required for discharging at buffer yard.	– Additional transporter is not required for gate-in and gate-out operation in yard.
Construc-tion of base facilities	– Buffer yard construction required	– High speed travel of discharging equipment causes extra expenses for civil engineering works, etc.
System set-up	– AGV travel facilities for ship, gate/traffic control facilities and AGV travel facilities for receiving/delivery operating AGVs are required. – Complicated communications system	– AGV travel facilities for ships and facilities for gate/truck control are required. – Simple communications system
Required area	– Addition of buffer yard causes increase of gate size and lowers area efficiency comparing with alternative 1.	– Increase of apron size lowers terminal area efficiency.

6.4.5 Target C/C Productivity

It was found through analysis of quay capacity at automated terminal that optimal quay capacity with the length of 1,050m is 1.35 million TEUs when productivity per gross work time is 30 lifts/hr. In this simulation model, the target C/C productivity to handle 1.35 million TEUs is calculated by dividing productivity per gross work time by the rate of operation 0.75 in which berthing and deberthing time, crane preparation time, deberthing preparation time, etc are considered. Accordingly, the combination of equipment ensuring productivity of 40 lifts/hr is selected through simulation for each layout alternative. In case productivity exceeds 40 lifts/hr, in other words, if productivity per gross work time exceeds 30 lifts/hr, it means the combination of equipment is excessive for 1.35 million TEUs. If there exists

a track-off relation that C/C productivity may increase with the increase of the number of both AGV and ATC, an economical alternative should be selected by considering both the number and price of AGV and ATC.

6.4.6 Analysis of Equipment Required for Perpendicular Layout

1) Estimation of Cycle Time Distribution of ATC Operation

(1) Input Conditions

- ○ Decision of productivity level is difficult because both alternatives of allocating 2 ATCs to a perpendicular block and 3 ATCs to 2 blocks are new concepts of automated systems.
- ○ Accordingly, it is necessary to estimate distribution by applying the ATC cycle time that greatly reflects productivity to vessel operations and receiving/delivery operation of external trucks.
- ○ Stacking and allocation strategies are established as follows in simulation of ATC cycle time:
  - Stacking in block to be made in random grounding method
  - Operation on FIFO basis for both operations for loading/discharging and receiving/delivery operations job are based on FIFO
  - Equipment should be allocated with the nearest equipment method.

① 1 Cycle time of ATC in a bay

Unit : second

	5Tiers 6Rows ATC	5Tiers 10Rows ATC(external)	5Tiers 10Rows ATC(internal)	5Tiers 13Rows ATC
Empty Trolley Move	6.7	13.4	8.1	11.0
Empty Hoist(Storage area)	10.1	12.4	9.6	15.8
Container Capture	10.0	10.0	10.0	10.0
Loaded Hoist(Storage area)	17.2	27.7	16.3	27.7
Loaded Trolley Move	7.7	13.4	9.1	12.0
Loaded Hoist(AGV)	24.0	35.3	24.0	35.3
Empty Hoist(AGV)	13.4	19.1	13.4	19.6
Gate Out · Load Shuffle stack	96.0	96.0	96.0	96.0
1 Cycle time	89.0	131.2	90.5	131.3

② Time and number of bays required for each equipment

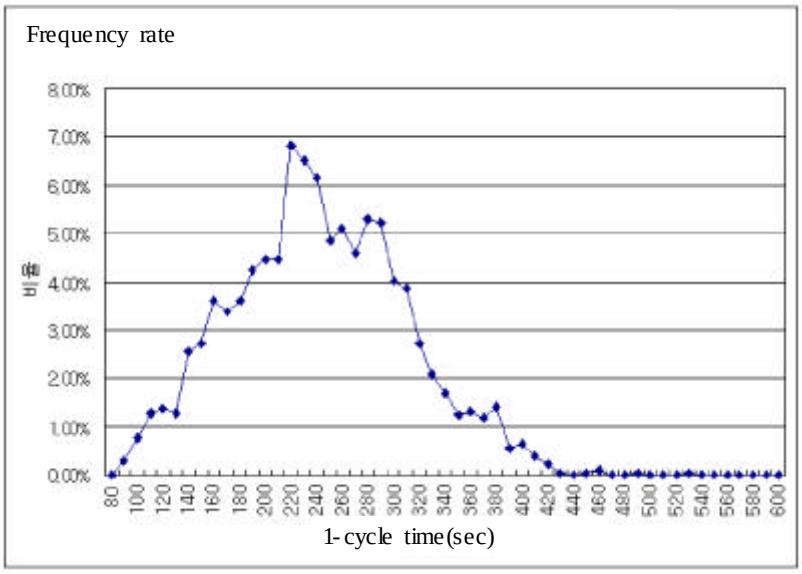
Unit : second

	5Tiers 6Rows ATC	5Tiers 10Rows ATC	5Tiers 13Rows ATC
1 Bay	9.856	10.5984	12.3307
n Bay	9.856+ 1.856*n	10.5984+ 3.0984*n	12.3307+ 4.3307*n
Number of Bay	41Bays	36Bays	41Bays

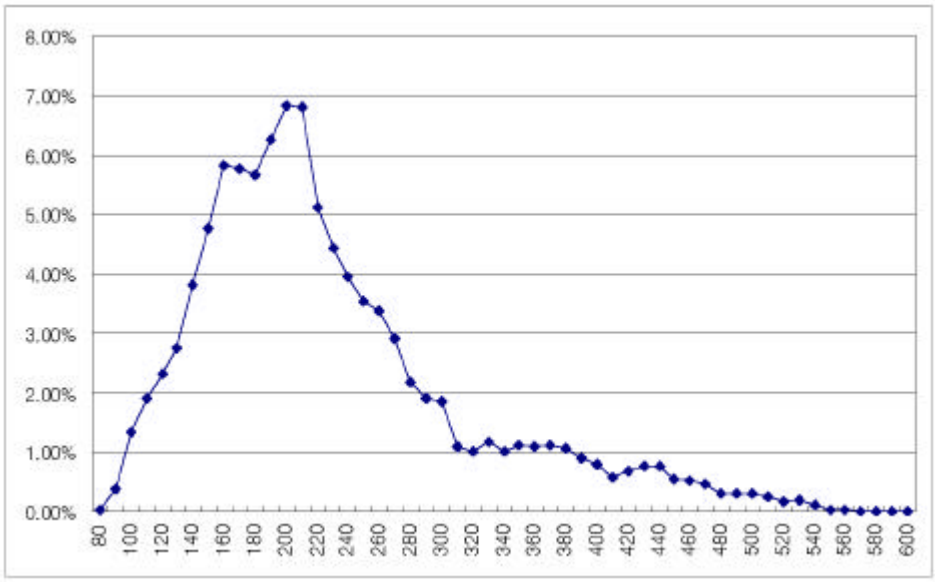
③ Analysis of simulation results

The following graph shows 1 cycle time (X axis) required for operations of ship and external truck and frequency corresponding to the cycle time (Y axis). Average cycle time of ATC is 238 seconds in perpendicular layout and 225 seconds in perpendicular layout 2.

<Figure 6-11> 1 Cycle Time Distribution of ATC in Perpendicular Layout 1 (Mean : 238sec)



<Figure 6-12> 1 Cycle Time Distribution of ATC in Perpendicular Layout 2 (Mean : 225sec)



2) Analysis of Simulation for Calculating Required Equipment

The following is recommended to prevent problems.:

Total number of AGVs for a ship = Number of C/Cs allocated to arriving ship × number of AGVs for a C/C

- ○ Allocation of blocks in perpendicular layout is based on waiting of AGV at ATC.
  - Block is allocated based on concept of berth.
  - C/C allocation depends on size of ship LPC.
- ○ The number of AGVs tested for each C/C was from 4 to 9
- ○ ATC operation occurs with pear value of discharging and loading at vessel operation and external truck operation.

(1) Perpendicular Layout

In case of perpendicular layout 1 using 44 AGVs, average C/C productivity is 38.4 moves. Average C/C waiting ratio for AGV is 28.8%. C/C productivity with 55 AGVs is 43.6 moves. This increased C/C productivity by 13.6% and decreased C/C waiting time rate for AGV by 19.1% when compared with 44-AGVs scenario. In case of the 66-AGVs scenario, C/C productivity is 45.8 lifts/hr which greatly exceeds target C/C productivity of 40 lifts/hr. Ratio of C/C waiting time for AGV is 15%, showing no great improvement when compared with the 55-AGVs scenario. Accordingly, the proper number of AGVs required is 55.

<Table 6-14> Test Results of Productivity Analysis (Perpendicular Layout 1)

AGV Scenario	C/C Productivity		Ratio of C/C waiting time for AGV(%)
	Lifts/hr	Increased rate(%)	
44 AGVs	38.4	-	28.8
55 AGVs	43.6	13.6	19.1
66 AGVs	45.8	5.1	15.0
77 AGVs	47.2	3.1	12.4
88 AGVs	47.9	1.4	11.2
99 AGVs	48.3	0.9	0.9

In case of perpendicular layout 2 using 44 AGVs, average C/C productivity is 45.9 moves. Average C/C waiting ratio for AGV is 14.8%. C/C productivity with 55 AGVs is 48.5 moves. This increased C/C productivity by 5.6% and decreased C/C waiting time rate for AGV by 10% when compared with 44-AGVs scenario. Accordingly, the proper number of AGVs required is 44.

<Table 6-15> Test Results of Productivity Analysis (Perpendicular Layout 2)

AGV Scenario	C/C Productivity		Ratio of C/C waiting time for AGV(%)
	Lifts/hr	Increased rate(%)	
33 AGVs	39.2	-	27.3
44 AGVs	45.9	17.1	14.8
55 AGVs	48.5	5.6	10.0
66 AGVs	49.4	1.9	8.3
77 AGVs	50.0	1.2	7.2
88 AGVs	50.1	0.2	7.0
99 AGVs	50.6	1.0	6.1

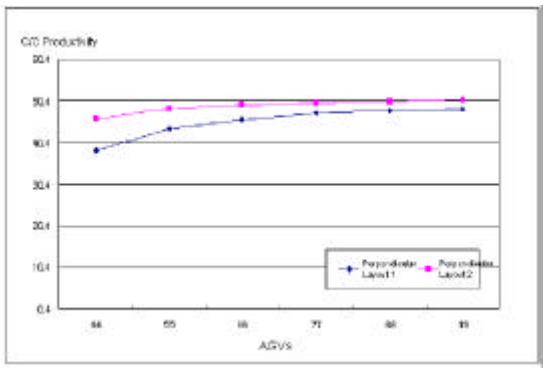
(2) Required Equipment and Productivity

In case of perpendicular layout 1, the number of ATCs is already fixed with the number of blocks required for handling 1.35 million TEUs and cannot be adjusted depending on target productivity. Accordingly, the scenario is selected which satisfies the nearest target C/C productivity depending on change in number of AGVs. In this case, C/C productivity is 43.6 lifts/hr for perpendicular layout 1, and 45.9 Lifts/hr for perpendicular layout 2. Required equipment and productivity of C/C are as follows.

<Table 6-16> Required Number of Equipment and C/C Productivity

	Perpendicular Layout 1	Perpendicular Layout 2
Required Number of Equipment - ATC - AGV	 40 ATCs 55 AGVs	 42 ATCs 44 AGVs
C/C productivity	43.6 Lifts/hr	45.9 Lifts/hr

<Figure 6-13> C/C Productivity in Perpendicular Layout

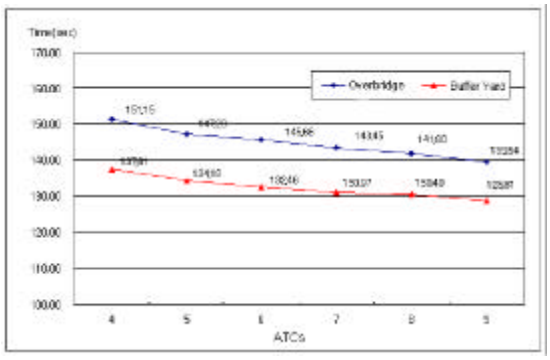


6.4.7 Analysis of Productivity and Equipment Required for Parallel Layout

1) Estimation of ATC Cycle Time Distribution

It is based on block layout of 5 rows and one-over-fifteen stacking. ATC cycle time is estimated by each run. ATC cycle time distribution is measured by the scenario that the number of ATCs in the range of 4 9 is allocated to each run. The distribution estimation result (average value) is shown in the following figure. Unlike the perpendicular layout, the ATC operation was frequently made in a bay for a ship in parallel layout.

<Figure 6-14> Result of Distribution Estimation(Mean Value)



2) Parallel Layout Alternatives

(1) Analysis of Buffer Block Size and Equipment Required

It is important to discuss how to operate a buffer yard in an automated container terminal which will be used for resolving the difficulties to which the interaction between external manned trucks and internal unmanned equipment led. The determination of fleet size of material handling equipment is an important issue in designing the buffer yard in automated container terminals. Buffer capacities could be determined by simulation. By using response surface methodology (RSM) for efficient experimentation, the optimal combination of design parameters under applicable operational strategies is obtained.[33)]

① Buffer block size

- ○ Buffer TGS includes daily TGS for external truck operation and refrigerator container TGS.
- ○ Buffer yard is estimated to have the storage capacity factor of 45% for improving receiving/delivery operations efficiency.
- ○ Accordingly, buffer yard TGS is 928 in total.
- ○ Block is designed to have 320TGS for each block and 960TGS in total with 10 rows + 2 lanes for each block.

② Buffer yard equipment

- ○ As result of gate simulation, the required number of ATCs is estimated as 6 in total keeping the maximum number of waiting trucks as 20 of 132 trucks. This is the number of trucks at peak hour of a day.

33) Bae, J. W., Yang, C. H., Kim, K. H., "Determination of Fleet Size of Equipment in Buffer Yard of an Automated Container Terminal by using a Response Surface Methodology", *Journal of the Korean institute of Port Research*, Autumn, 2000, pp.121 129.

○ Require number of AGVs is estimated by calculating the number of AGVs required for outward external truck operation, storing gate-in containers in buffer yard at peaks.

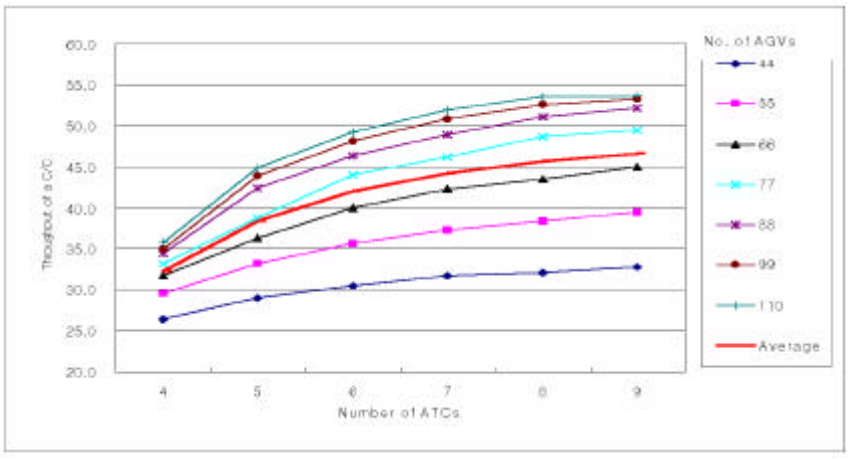
- As only 16 trucks per hour arrive an hour on average from 11:00 o'clock at night to 6:00 o'clock in the morning, containers which arrive within a day can be transported to yard during that time.
- It is estimated that 4 AGVs per block, total 12 AGVs, are required.

(2) Simulation Results

○ Simulation results of productivity and required number of equipment (parallel layout 1)

C/C productivity and AGV waiting time were tested while increasing the number of ATCs from 4 to 9 in each run. As result, the alternative showing C/C productivity of the nearest target productivity of 40 lifts/hr was the combination of 7 ATCs and 66 AGVs per run. The alternative of 28 ATCs and 66 AGVs shows C/C productivity of 41.8 lifts/hr.

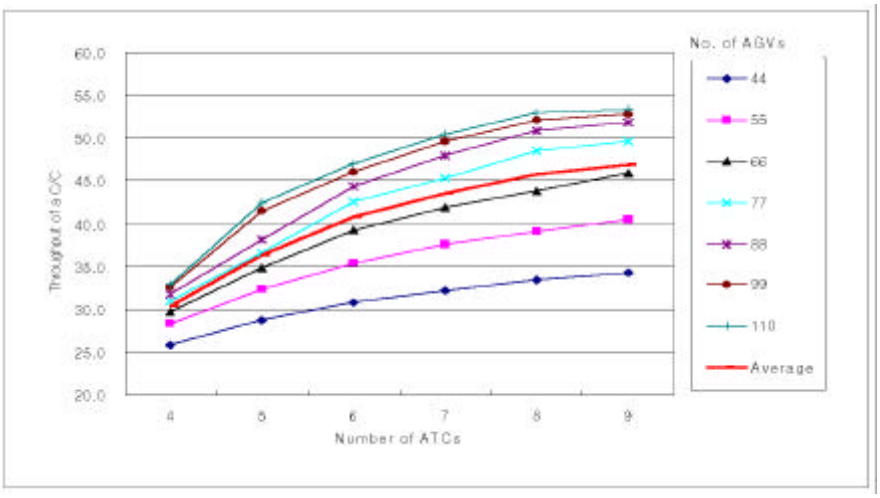
<Figure 6-15> C/C Productivity of Parallel Layout 1



○ Simulation results of productivity and required number of equipment (parallel layout 2)

C/C productivity and AGV waiting time were tested while increasing the number of ATCs from 4 to 9 in each run. As result, the alternative showing C/C productivity of the nearest target productivity of 40 lifts/hr was the combination of 7 ATCs and 66 AGVs per run. The alternative of 28 ATCs and 66 AGVs shows C/C productivity of 42.2 lifts/hr.

<Figure 6-16> C/C Productivity of Parallel Layout 2



3) Comparative Analysis of Required Equipment by Alternative

The following is a comparison of layout alternatives of optimal equipment combination nearest target productivity of 40 lifts/hr (30 lifts/hr in terms of the productivity per gross work time operation hour) in an automated terminal model handling 1.35 million TEUs annually.

In parallel layouts, productivity were determined near 40 lifts/hr because it was possible to adjust both the number of ATCs and AGVs. In case there

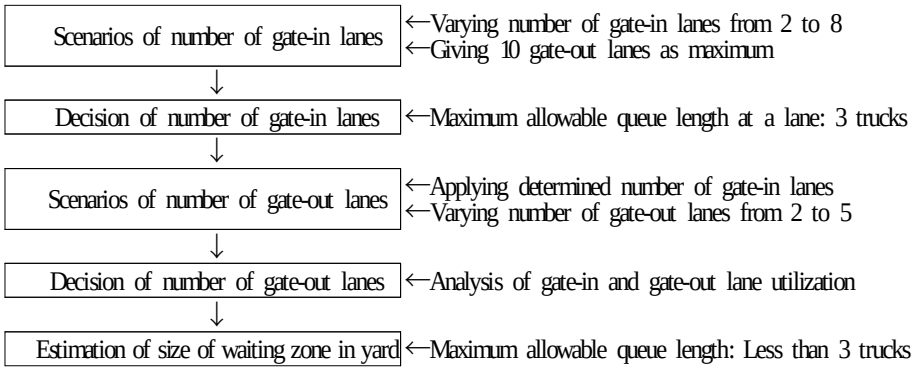
is little difference in productivity, the required number of ATCs in parallel layouts is less than in perpendicular layouts because ATC travel distance and cycle time in parallel layouts is less than in perpendicular layouts

<Table 6-17> Results of Simulation

	Perpendicular layouts		Parallel layouts	
	layout 1	layout 2	layout 1	layout 2
Equipments needed ATC AGV	 40 55	 42(28+14) 44	 28 66	 34(28+6) 78(66+12)
C/C Productivity (Lifts/hr)	43.6	45.9	41.8	42.2

6.5 Gate Analysis

The purpose of gate analysis is to decide the number of gate-in and gate-out lanes and estimate size of waiting zone for trucks in yard. Experiments are made by varying operation conditions of terminal and number of lanes. The flow of the experiment is shown in the following figure. Gate analysis is focused on the two purposes : queue length at lanes and turnaround time of external trucks.



6.5.1 Gate Operation Conditions

1) Analysis of Gate-in and Gate-out Trucks at Daily Peaks

The following table shows the number of maximum gate-in and gate-out trucks at daily peaks of export and import containers at the 1.35 million TEUs scenario.

<Table 6-18> Estimation Number of Maximum Gate-in & Gate-out Trucks at Daily Peaks of Export & Import Containers

	Formula
	Formula with actual data
Annual Throughput (lifts/year)	Annual Throughput(TEU) × Box/TEU rate
	1,350,000 TEU/year × 1.5 = 900,000 lifts/year
Annual Throughput (Excluding transshipment and costal containers)	Annual Throughput(lifts/year) × 62.7%
	900,000 lifts/year ÷ 62.7% = 564,300 lifts/year
Weekly Throughput (lifts/week) Mean	Annual Throughput(lifts/year) ÷ 52weeks
	564,300 lifts/week ÷ 52 = 10,852 lifts/week
Daily Throughput (lifts/day) Mean	Weekly Throughput(lifts/week) ÷ 7days
	10,852 lifts/week ÷ 7 = 1,550 lifts/days
Daily Throughput (lifts/day) Daily Peak	Weekly Throughput(lifts/week) × Day peak factor
	1,550 lifts/day × 125% = 1,938 lifts/day
Daily Throughput (litfs/day) Seasonal Peak	Daily Throughput peak (lifts/day) × Seasonal peak factor
	1,938(lifts/day) × 120% = 2,325(lifts/day)

<Table 6-19> Daily Maximum Export & Import of Gate-out & Gate-in Containers and Classification of Containers

		Rate	lifts/day
Input	Full Container	32.3	751
	Empty Container	17.8	414
Output	Full Container	45.8	1,065
	Empty Container	4.1	95
Total		100.0	2,325

The following table shows the number of gate-in and gate-out empty containers to be re-distributed in which 17% of import full containers applied.

<Table 6-20> Estimation of Empty Containers to be Re-distributed

Import Full Container	751
Rate	17 %
Depot empties for inward external truck operation	128
Depot empties for outward external truck operation	128

It was estimated that gate-in trucks of full and empty containers for double cycle is 20% of gate-in trucks of full and empty containers. Gate-in and gate-out bare chassis trucks are estimated as shown in the following table.

<Table 6-21> Estimation of Gate-in & Gate-out Bare Chassis Trucks

	Formula
Number of bare chassis for inward external truck operation	Number of Full & Empty Container trucks for outward external truck operation - (for Double Cycle) Number of Full & Empty Container trucks for inward external truck operation
Number of bare chassis for outward external truck operation	Number of Full & Empty Container trucks for inward external truck operation - (for Double Cycle) Number of Full & Empty Container trucks for inward external truck operation or Number of Full & Empty Container trucks for inward external truck operation × 80%

The following shows the ratios of gate-in and gate-out containers by truck type.

- Total gate-in and gate-out trucks at daily peaks in 1.35 million TEUs scenario: 2,325 trucks.
- Gate-in: 1,065 full containers, 224 empty containers, 1,036 bare chassis
- Gate-out: 751 full containers, 542 empty containers, 1,032 bare chassis

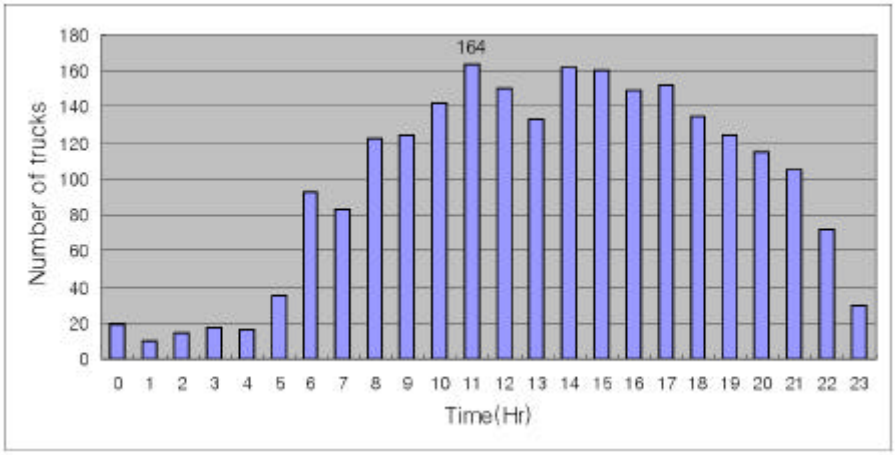
<Table 6-22> Total Number of Gate-in & Gate-out Trucks at Daily Peaks

Gate-in truck type	Rate (%)	Number of trucks (Lifts/Day)	Gate-out truck type	Rate (%)	Number of trucks (Lifts/Day)	Gate-out truck type	Rate (%)	Number of trucks (Lifts/Day)
Full	45.8	1,065	Full	12.0	128	Full	32.3	751
			Empty	8.0	85			
			Bare Chassis	80.0	852			
Empty	9.6	224	Full	12.0	27	Empty	23.3	542
			Empty	8.0	18			
			Bare Chassis	80.0	179			
Bare Chassis	44.6	1,035	Full	57.7	598	Bare Chassis	44.4	1,032
			Empty	42.3	438			
Total	100	2,325	Total	100	2,325	Total	100	2,325

2) External Truck Arrival Pattern

For truck arrival pattern at each time zone for a day, the data of Pusan New Port was applied.

<Figure 6-17> Truck Arrival Pattern by Time Zone



3) Truck Pass Time

Average gate pass time was estimated on the basis of actual data of Pusan Port and design data for Pusan New Port. The average gate pass time differs with Full/Empty Container, the use of EDI, Gate-In/Out type.

<Table 6-23> Average Gate Pass Time

unit : sec

		Full Container	Empty Container	Bare Chassis
Gate-in	Truck No. and Container check	20	20	25
	Seal check	30	30	-
	Exterior Damage check	60	60	-
Gate-out	Truck No. and Container check	20	20	20

4) Other Pre-conditions

(1) EDI Use Ratio and Truck Identification Error

It is assumed that 90% of trucks provide their information via EDI at gate and truck. Identification error rate at gate-in is 5%.

<Table 6-24> Entry Mixes

Container Truck Type		EDI use	Truck check Error	Fraction	Cumulated Fraction
Gate -in	Full Container	Yes	No	38.36	0.3836
	Full Container	Yes	Yes	2.91	0.4127
	Empty Container	Yes	No	8.00	0.4927
	Empty Container	Yes	Yes	0.63	0.4990
	Bare Chassis	Yes	No	37.26	0.8716
	Bare Chassis	Yes	Yes	2.84	0.9000
	Full Container	No	No	4.31	0.9431
	Full Container	No	Yes	0.32	0.9463
	Empty Container	No	No	0.90	0.9553
	Empty Container	No	Yes	0.07	0.9560
	Bare Chassis	No	No	4.13	0.9973
	Bare Chassis	No	Yes	0.27	1.00
Gate -out	Full Container	Yes	No	32.4	0.324
	Empty Container	Yes	No	23.3	0.557
	Bare Chassis	Yes	No	44.3	1.00

(2) Other Conditions

○ Daily traffic concentration rate: 25% of entire traffic
○ Customs inspection is not made at gate.
○ Gate is opened for 24 hours.
○ The number of gate workers is not limited.
○ Public lane is used.
○ Gate type is 1-step gate.
- Automatic recognition system is used for identifying vehicle and container number.
- Inspection of damaged container and storing of data are made through CCD camera.

6.5.2 Gate Simulation Analysis Results

1) Gate-in Queue

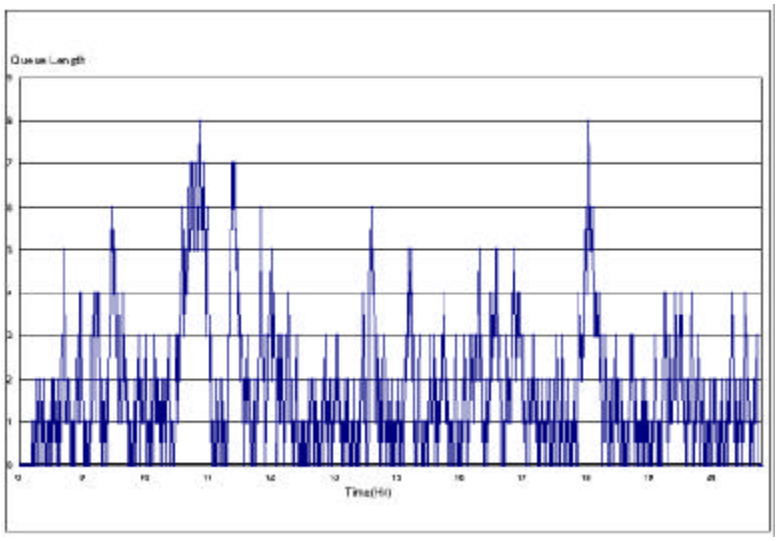
The required number of lanes at gate is analyzed with the number of trucks of overflow queue of 99% percentile after estimating the length of overflow queue of gate-in trucks generated according to distribution of peaks of a day. Queue length of a lane at peak can physically vary depending on design gate, but it was limited to 3 in maximum in terms of service level for shippers. In fact, however, enough parking lot should be secured outside the gate in actual design of gate so prevent waiting of external trucks on public road. The following shows maximum queue length and mean queue length of lanes of 99% percentile and maximum pass time and mean pass time at 95% percentile, as the number of gate-in lanes increases from 2 to 8.

<Table 6-25> Result of Gate-in Queue Analysis

	Waiting truck queue for each lane (99% Percentile)	Waiting truck queue for each lane (Average)	Gate pass time (95% Percentile)	Gate pass time (Average)
2 Lanes	422	215	289	143
3 Lanes	15	4	5.9	2.7
4 Lanes	8	2	2.8	1.6
5 Lanes	4	2	2.4	1.5
6 Lanes	3	1	2.4	1.4
7 Lanes	3	1	2.4	1.4
8 Lanes	2	1	2.4	1.4

As the maximum number of waiting trucks is 2 for each lane when there exists 4 gate-in lanes, it satisfies the criterion that the maximum number of waiting trucks per lane is 3. But, gate pass time does not improve any more despite increase of the number of lanes over 5 Therefore the proper gate pass time is 2.8 minutes at 95% percentile in case of 4 lanes. Accordingly, the proper number of gate-in lanes is 4.

<Figure 6-18> Gate-in Queue Length (99% Percentile) - 4 lanes



2) Queue in Yard

It is required to decide the size of truck waiting zone in the yard. This depends on the number of trucks passing through gate-in and waiting for the service of YC. As cycle time of yard crane differs between terminal layout alternatives, queue in yard should be analyzed separately for each alternative. In perpendicular layout, ATCs should keep a certain distance for both gate-in and gate-out trucks. In parallel layout, inward external truck operation is processed in buffer yard, but outward external truck operation is processed with AGV at marshaling yard and this requires much time. One transfer point is assigned in each block for external trucks in the case of a perpendicular layout. The number of transfer points may differ depending on the number of equipment in parallel layout. However, in the case of outward external truck operation in parallel layout, 3 transfer points are given for each ATC of outward external truck operation because 2 external trucks can be served additionally while AGV is in outward external truck operation. The following are transfer points and average operation time for gate-in and gate-out trucks for each layout.

<Table 6-26> Average Operation Time

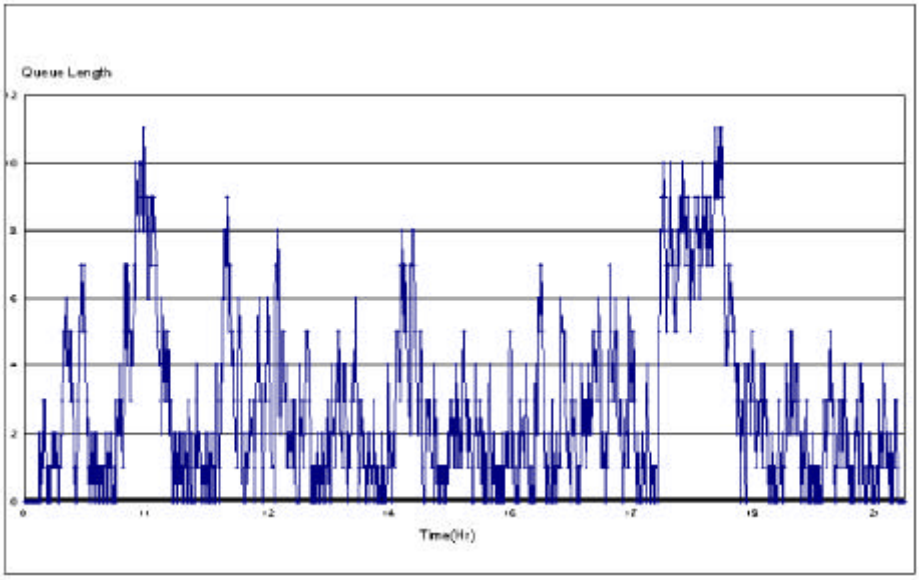
	Perpendicular layout 1	Perpendicular layout 2	Parallel layout 1	Parallel layout 2
Number of Transfer points	20	14	21	14
Mean inward external truck operation time (sec)	531	366	443	87
Mean outward external truck operation time (sec)	593	379	475	521

<Table 6-27> Simulation Result of Queue in Yard

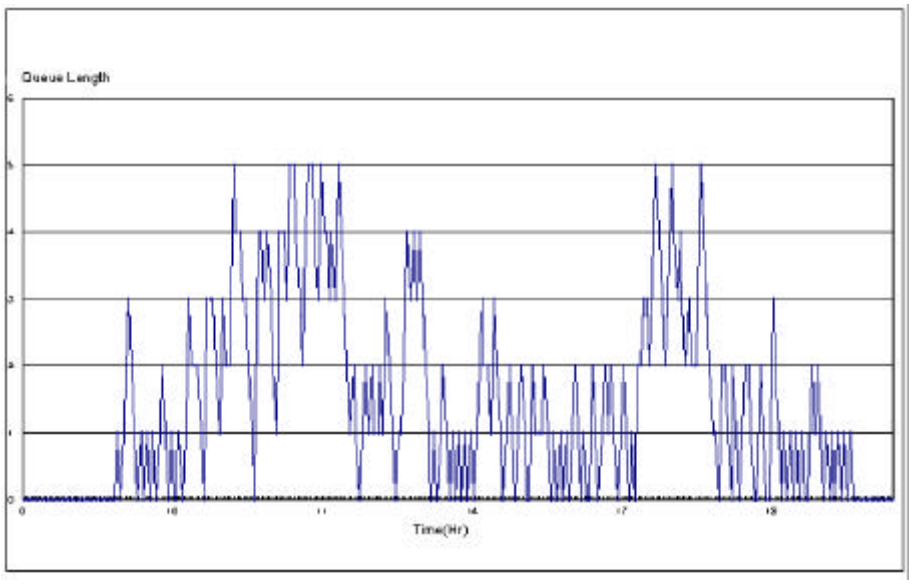
	Perpendicular layout 1	Perpendicular layout 2	Parallel layout 1	Parallel layout 2
Number of waiting trucks (99% Percentile)	5	7	11	11
Number of waiting trucks (Average)	2	2	3	3
Maximum truck waiting time (95% Percentile)	17 sec	2.5 min	2.8 min	2.9 min
Average truck waiting time	4 sec	27 sec	31 sec	34 sec

In each layout, the length of 11 trucks are maximum. This minimizes the truck waiting space, and maximum waiting time of waiting trucks was less than 3 minutes and this cannot be a big problem.

<Figure 6-19> Maximum Queue Length (99% Percentile) - Perpendicular Layout 1



<Figure 6-20> Maximum Queue Length (99% Percentile) - Parallel Layout 1



3) Gate-out Queue

Through analysis of the number of waiting trucks at a gate-out lane in each layout, it was found that 3 lanes are required because 9 trucks came to wait at 2 lanes in case of parallel layout. In perpendicular layout, however, it was estimated that 2 gate-out lanes are enough because it does not incur deviation from the target level.

<Table 6-28> Maximum Queue Length (99% Percentile)

	Perpendicular Layout 1	Perpendicular Layout 2	Parallel Layout 1	Parallel Layout 2
2 Lanes	2	2	2	9
3 Lanes	1	1	1	8
4 Lanes	0	0	0	6

4) Turn Around Time

Through analysis of turn-around time of external trucks in the terminal in each layout, it was found that the below-estimated size is proper because it falls under the target maximum stay time which is less than 20 minutes (95% percentile).

<Table 6-29> Simulation Result of Truck Turn Around Time

unit : min

	Perpendicular layout 1	Perpendicular layout 2	Parallel layout 1	parallel layout
Mean Turn-around time	17.7	13.7	18.3	15.1
Maximum Turn-around time (95% Percentile)	18.4	20.1	20.7	17.1

7. Economic Feasibility Study

7.1 Logistic Control of Automated Container Terminal

Important factors in designing container terminals are location, space, handling equipments, operation conditions, etc. Container terminals may be designed in different aspects, and operations at seasides and yards may require different equipments. Seaside operations require gantry cranes of high productivity. Lots of technical advancements have been recently made in such gantry cranes. Meanwhile, yard operations require various equipments such as straddle carriers, fork lifts, yard cranes for rail transport, wheel-type yard cranes, tractor-trailers, etc.

The advent of advanced container terminals adopting advanced technologies makes terminal operators and equipment makers hopeful. Various advanced terminal equipment including OHBC (OverHead Bridge Crane), AGV (Automated Guided Vehicle), ASC (Automatic Stacking Crane), self-unloading ships, etc. are being used. Advanced technologies for designing container terminals are still under development. However, the designing of terminals is focused on handling as many containers that are equal to the amount of money invested whichever technology is applied to. The most advanced automated terminal in Europe is the Delta Container Terminal in Rotterdam. Its loading/unloading systems consist mainly of quay cranes equipped with double trolley, ASCs, AGVs, etc.

Factors to be considered in comparing conventional terminals with automated terminals include layout of terminal site, required number of equipment, kinds of equipment, yard operation system, civil engineering works, etc. It is expected that technologies to be commonly used for

both terminals such as EDI, automatic information processing systems, automatic container identification systems, etc. will be continuously developed.

As a quay crane is very expensive, it should be utilized to the fullest. So, a sufficient number of yard cranes should be equipped in the yard. Delayed service of the yard crane may cause delay of loading and unloading onto and from ships and increase the duration of a ship's staying at terminal. Therefore, yard should be designed to satisfy such a service level depending on conventional or automated terminal through simulations.

To estimate the total annual cost per container in two different kinds of terminals, various economic data (machine's life, operation expenses, equipment price, interest rates, etc.) has been referred in this study.

Conventional terminals have been developed by adjusting the execution drawing for LAP (Large Asian Port) worked by a certain company for developing a new Asian port to meet our conditions. Its flow planning has been made to allow trucks to directly enter the yard to take in and out containers as in the general conventional terminal. It is designed to transport containers between ships and container yards with yard tractors and use RMGC (Rail Mounted Gantry Crane) for work in the container yard.

The quay is 1,400m long, the depth of yard is 390m, and the yard area of the terminal reaches 546,000m^2. The stacking capacity of general full containers is 8,400 TGS, and the stacking capacity of empty containers and reefer containers to be collected and handled in separate blocks is 1,440 TGS and 710 TGS, respectively. The yard is designed to be in parallel with the quay and consists of a total of 28 blocks, of which 12 front blocks are for export containers and 16 backside blocks for import containers.

The container cranes used for unloading ships are in single hoist type handling a maximum of 44 containers per hour. However, excluding meal

time and tie-up/untie time, its net capacity including reset time and probable troubles is 25 containers per hour. In connection with the RMGC operated in the container yard, performances of three alternatives (RMGCs in 6 rows and 5 tiers or 9 rows and 5 tiers or RTGCs in 6 rows and 5 tiers) have been studied in terms of quay crane productivity, cycle time of yard tractors, yard cranes productivity, etc. In this study, it has been found that the configuration of RMGCs with 9 rows and 5 tiers yields the best results.

The proposed model of an automated container terminal has been basically designed to have a terminal site of which the quay length is 1,400m and depth is 600m. It was modeled after the Kwangyang Port Phase III of 4-berths terminal site. The reason for this is due to the equal shape and size of the terminal site of Kwangyang Port Phase I of 4-berths. This enables direct comparison. However, the Kwangyang Port Phase I of 4-berths terminal has been designed to have the throughput of 960,000 TEUs per year, far less than the present throughput per berth at the Pusan port. Therefore, the proposed model of an automated container terminal is basically designed to handle 1,770 thousand TEUs with 4 berths referring to the conventional 4-berth terminal of LAP having been recently designed to handle 1,780 thousand TEUs a year. Accordingly, the proposed model of the automated container terminal is based on the detailed planning of Kwangyang Port Phase I in ground configuration and civil engineering area, and the detailed planning of LAP in equipment and annual container handling volume. Among the annual handling volume of 1.77 million TEUs, 63% is transported by road, 25% by rail and 12% by coastal.

The proposed operation system of the automated container terminal is partially changed from the system adopted by the Britain's Thames Port and the Japan's Kawasaki Port. In the flow planning, trucks' access to the yard has been minimized and intersection of trucks and AGV

has been prohibited in the yard. AGV is used for transport of containers between ships and yard, and RMGC is used for any work in the yard. And, by locating railroads in the yard, the number of transport equipment used for in and out containers has been minimized.

The quay crane is the dual trolley type with net handling capacity of 25 containers per hour, and the RMGC in the yard is the cantilever type for connection with AGV and trucks. In connecting the RMGC and trucks, loading/unloading is remotely controlled, and each unit of RMGC is operated by a worker in the terminal as truck drivers cannot always put their trucks at the right position required by the automatic positioning system of RMGC. To optimize the route of RMGC, containers are stored in 15 rows and 5 tiers.

The quay length is 1,400m and the depth of yard is 391m and total yard area of the terminal is 547,400㎡. The total container storage capacity is 11,193 TGS: storage capacity of general containers and refrigerator containers capacity is 10,764 TGS and 429 TGS, respectively. In connection with terminal layout, containers are stored in parallel blocks to quay. And, there are 20 RMGC blocks including a block for refrigerator containers, of which 12 blocks at seaside are for export and transshipment containers and 8 blocks at landside for import containers. However, flexibility is given in switching blocks depending on the use. The yard adjacent to the railroad is designed to be used only for handling containers to be transported by rail.

An automated container terminal is operated in the following systems.: Transshipment containers are transported from berth to AGV through C/C and then to the transshipment yard through RMGC, and outbound transshipment containers are transported in the reverse flow. Import containers are transported from berth to AGV through C/C and then to the import yard, of which some are not transported from the rail

yard to AGV but directly delivered through railway station and some are delivered from import yard to trucks. Export containers arriving by truck or rail are delivered to yard RMGC and stored in the export yard for a certain period of time and then delivered from yard RMGC to ships through AGV.

7.2 Analysis of Simulations

In this study, simulation has been made for the yard of a container terminal which ranges from unloading of containers from ships with unloading equipment to bringing containers out of the gate with transport equipment. Yard simulations are correlated to the probability depending on distributions of ship arrival, unloading time, error rate, arrival time of shipper-requested specific transport equipment, etc. In this study, however, it is assumed that these are independent factors of each other. Such an assumption is theoretically contradictory, but actually persuasive for the following reasons:

First, unloading is always performed when a ship arrives at the terminal. But, there may be the case in which distribution of equipment breakdown (MTBF=Mean Time Between Failure) should be taken into account.

Second, there is no such case that insufficient storage capacity in the yard delays unloading. In other words, unloading may be delayed due to **i**) delay of transport equipment, **ii**) delay of yard crane, and **iii**) insufficient storage capacity in yard. Unloading delay is not caused by insufficient stacking capacity in yard.

Third, distribution of ship arrival is characterized to be related closely to productivity of unloading equipment.

In designing TGS, both the peak throughput and the storage capacity factor

have been taken into account. Accordingly, the yard area does not become a factor restricting the simulation any more, and waiting in the yard is influenced only by yard layout, flow system of transport equipments, and distribution of service hours of transport equipment (AGV, truck) and storing equipment (RMGC, ASC). In addition, yard simulation data depends on distribution of operation hours of unloading equipment.

Yard simulation data represents productivity of quay's unloading equipment reflecting information of terminal, ship, operation and cargo, other restrictive factors, etc. Terminal information include size and number of berths, size and productivity of unloading equipment established at berths, tonnage of ships arriving at berths, etc. Ship information includes tonnage and characteristics of ships. Operation information includes berthing order of ships waiting at the anchorage, berth and yard operation policies, etc. Cargo information includes cargo volume, physical characteristics, shipping port of cargo, etc. Restrictive factors include maximum number of ship's unloading equipment available, area of yard available, number of transport equipment, number of stacking equipment in yard, etc.

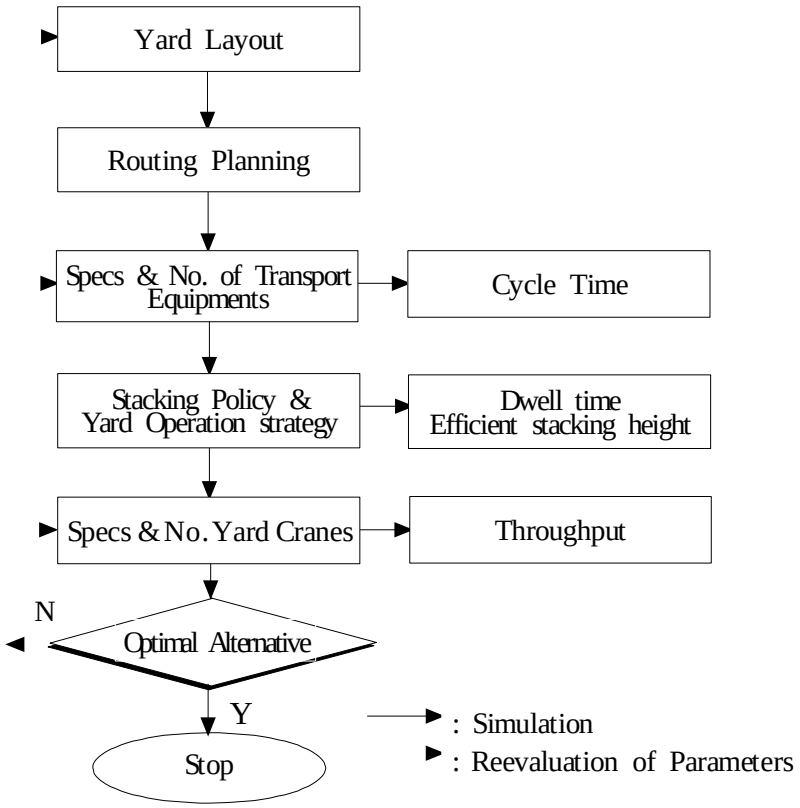
Unloading containers from a ship depends on productivity of its unloading equipment. Suppose that the time required for unloading a container is defined in random variable X and it has the probability distribution function of F(X). In general, in consideration of randomness, F(X) is known to have exponential distribution or gradual exponential distribution for waiting system. However, the distribution function of container unloading time from ships is assumed to have uniform distribution. In this study, as the difference between the upper and lower limit module of uniform distribution is not great, it is assumed that containers should be unloaded at a certain fixed interval. If the unloading interval is assumed to be constant, its distribution is in direct proportion to productivity of unloading equipment.

Yard simulation is performed in three stages; **i**) Route planning of transport equipment, **ii**) Yard transport equipment configuration, and **iii**) yard stacking policy. In the route planning of transport equipment, the rules related to transport direction (for example, decision of transport direction in case of traffic j am) are decided according to layout of the blocks which are designed for cargo characteristic such as export, import, railroad, refrigeration, CFS cargos, etc. Then the cycle time of the transport equipment is calculated for each alternative. When transport equipment delivers a container to a certain block, yard stacking equipments (RMGC, ASC, OHBC, S/C) store it in a certain place. The block in which a container is to be stored is decided according to the yard operation strategy among the group of blocks for import, export, refrigerator, and CFS containers. Then the stacking place is decided according to the stacking strategy for blocks such as FIFO, probability distribution, etc. The number of containers handled by equipment for a unit time is calculated based on transport distance, speed, stacking conditions, etc.

As it takes lots of time and effort to draw out yard layout through simulation, it is desirable to prepare a basic layout for each alternative and select a layout suggesting the most optimal alternative after comparing results obtained in simulation. Accordingly, all the alternatives of yard layout should be reviewed in advance and simulation should be made for all alternatives. If a layout is made for an alternative, a flow system of transport equipment is decided and the average cycle for which transport equipment stores a container in the yard and moves to the ship again is calculated on the basis of the layout. Additional simulation is performed varying productivity of yard cranes such as load, speed, etc. As indicated before, yard simulation is a bidirectional waiting network, and so, average stock of containers and average number of storing days in the yard are decided according to in/out ratios at ships and gates. Alternatives for yard simulation are selected among the most optimal

ones for scenarios.

<Figure 7-1> Flow Chart of Yard Simulation



To design an automated container terminal, it is indispensable to set various pre-conditions and common conditions. Such conditions include terminal information such as quay length, number of berths, reference specifications of automatic equipment, operation information, container information such as available capacity, distributions and ratios of cargos for blocks, judgement rules, restrictive conditions to assess harmony with surroundings, etc.

Slot simulation is performed based on such information. In this stage,

data concerned with the number of TGS depending on the number of slots, daily throughput, throughput by transportation type, etc. are calculated and specifications of basic equipment, containers, transport vehicles, ships, etc. are decided.

When pre-conditions and common conditions are decided, apron layout design, yard layout modeling and basic yard design are performed as the phase I of clustering work, in which unloading capacity, C/C and AGV specifications and operation plan, basic yard layout, flow system modeling, slot modeling, etc. are planned.

When basic yard design is completed, the phase II of optimization work is performed. Detailed block modeling is performed. If container information, judgement rules, restrictive conditions and slot simulation results are satisfied, yard design is performed. If not, block modeling is continuously performed until they are satisfied.

When the work of phase II is completed, layout improvement work is performed based on the completed yard layout. The yard design in phase II is repeatedly performed again until it is satisfied. In this stage, the work is reviewed to satisfy export-import transport pattern. If not satisfied, block for optimizing each pre-condition and yard crane specifications is performed. If export-import transport pattern is satisfied, terminal layout is improved by optimizing flow system and class/object, and unloading simulation is performed by applying the principle of using the preceding ship's unloading data. Finally, model layout design and an operation plan are fixed.

In this study, such a series of procedures have been performed for each scenario, and informations of optimal yard layout and required equipment have been drawn out for each scenario.

7.3 Economic Feasibility Study

The most important factor to determine the estimated period of economic cost and benefit is to decide the economic life for any major investment or equipment. In general, estimated period is considered to be 20 50 years depending on concerned projects and the purpose of investment analysis. However, the economic life of major SOC investment is determined as 30 years from the end of investment, due to the great decrease of present value of expected expenses.

In addition, it is assumed that nominal discount rate is determined as 16.5%[34] which is the market interest rate in this study. And, to perform comparison and analysis with the constant price of 1998, the rate of a rise in prices is considered as 5% and actual discount rate as 10% according to the Fisher effect.[35]

In this study, future investments of two types of terminals are compared by the net present value.

In addition, it is assumed that facilities and equipment construction of conventional and automated container terminals will be finished during the period of year 2000 2005 and opened after 2006.

The cost in developing these two types of container terminals includes terminal expenses for civil engineering, construction, etc., operation & facilities expenses for equipment, and port operation and management expenses for labor, power, maintenance, etc. The terminal construction expenses are based on the estimated investments from 2000 to 2005. The expense of operation

---

34) Estimated average discount rate of corporate bonds due 3 years in 1998 (14.5%) + average spread (1.5%) on Korean SOC projects in 1996-1997 + average risk compensation rate (0.5%) of Korean SOC projects in 1996-1997

35) Fisher effect : R=(1+N)/(1+I)-1, where, R: actual discount rate, N: nominal discount rate, and I: expected price increase rate

facilities includes terminal equipment and their operation systems. When calculating the port operation and management expenses for labor, power, maintenance, and depreciation, the period of using this expense will be considered 30 years after complete terminal construction.

7.3.1 Comparison of Investment and Expense Items

1) Civil Engineering Expenses

For the civil engineering cost of conventional container terminal, the terminal construction cost of the Kwangyang Port phase I with 4-berth project is used. This is for comparison for the same civil engineering conditions as the automated container terminal based on the site of Kwangyang Port phase II or III. However, it has been considered that the automated container terminal requires more ground improvement costs than in the conventional terminal and the pavement method is different between the two terminals.

First of all, it has been considered that more ground improvement cost is required in the automated container terminal than the conventional terminal. Even though calculation is made on same conditions[36], sand piles should be installed at the interval of 0.939m in the automated container terminal,

---

36) - Correlation between consolidation-time coefficient of vertical direction (=radial direction) and consolidation degree
Tv = Tr = 1.781-0.993log(100-Uv%)
- Correlation between consolidation-time coefficient of radial direction and distance between sand piles
Tr = Cvr × t /de2
(Tr: Consolidation-time coefficient, Cvr: Coefficient of consolidation, t: Time of consolidation, de: Distance between sand piles)
- Calculation of time coefficients in case of automated and semi-automated container terminals using correlation formula between consolidation-time coefficient of vertical direction and consolidation coefficient

while they are to be installed at the interval of 1.086m in the conventional terminal. Accordingly, it is estimated that the cost of installing sand piles is higher by 34% in the automated container terminal than in the conventional terminal.

In a like manner, it is estimated that the conventional container terminal requires the ground improvement cost of about 93.5 billion won, while the automated terminal requires 125.2 billion won.

It is assumed that terminal area except apron is paved with concrete in the conventional container terminal, while navigation lanes of handling equipment and stacking area are paved with concrete block (I.L.B. pavement) which is stronger than concrete in the automated container terminal. In this case, pavement cost per square meter is more expensive by about 15%.

It is estimated that the whole civil engineering cost of the automated container terminal amounts to 453.4 billion won, higher by about 8.2% than 419.1 billion won of the conventional terminal.

<Table 7-1> Civil Engineering Costs

Unit : Million Won

Process	Unit	Q'ty	Unit price (Kwangyang Phase I)	Unit price Applied (Price inc rate 5%)	Conventional Terminal	Automated Terminal
A. Civil Eng. Cost						
1. Quay	m	1,400	65.7	84	117,392	117.392
2. Embankment	m	5,272	2.4	3	16,149	16,149
3. Dredging/Reclamation	1000m^3	2,428	15	19	46,792	46,792
4. Ground improvement	EA	1	73,234	93,467	93,467	125,246
5. Road pavement	EA	1	16,677	21,285	21,285	23,839
6. Water & Sewer	EA	1	13,217	16,869	16,869	16,869
B. Construction	EA	1	16,958	21,643	21,643	21,643
C. Telecommunication	EA	1	18.211	23,242	23,242	23,242
D. Railroad	EA	1	48,795	62,276	62,276	62,276
Total					419,115	453,448

2) Unloading Facilities Expenses

The number of pieces of equipment should be estimated which is plenty enough to operate all the sub-systems of the terminal smoothly. This is decided by trial and error method or simulation. In case of conventional terminal, equipment is decided with the site of Kwangyang Terminal Phase Ⅰ, and the result of detailed planning of LAP which designed the optimal cargo processing.

First of all, quay is designed to be equipped with 12C/Cs in total 3C/Cs in each berth of four 50,000-ton class berths. However, the dual trolley system is adopted in the automated container terminal, and the single hoist system in the conventional terminal. This is why the inland part of the dual trolley type C/C can be automated in future.

In connection with transport equipment from apron to container yard, the automated container terminal requires 76 AGVs and the conventional container terminal requires yard tractors. However, from operation experiences of the APL300 terminal in Los Angeles showing it is difficult to effectively operate more than 8 yard tractors for each C/C, it can be decided that the maximum number 7 of yard tractors are proper for a unit of C/C. Accordingly, 84 yard tractors and 84 chassis are required in total.

RMGC of 15rows-5tiers was used in automated container terminal, and that of 9rows-5tiers was used in conventional terminal. The RMGC in automated container terminal is mounted with various sensors for automation. The automated container terminal requires 22 of RMGCs: 17 RMGCs for loading and unloading in the container yard and 5 RMGCs for railway service. Meanwhile, the conventional container terminal requires 49 RMGCs of RMGCs: 41 RMGCs for buildings and 5 RMGCs for each run and 8 RMGCs for railway service. The automated container terminal does not separately require empty container handling equipment as it

is designed to handle empty containers in the yard, while the conventional container terminal requires 5 units of T/Hs, 5 Y/Ts and 10 chassis for handling empty containers.

Prices are different even between the same C/Cs and RMGCs since the specifications of required equipment are different. Price of automated equipment is based on the quotations of the manufacturing company and the foreign exchange rate of 1,400 won/$. The unit price of equipment purchased for the conventional container terminal are based on the recent actual purchase prices for the Pusan Port phase IV project. And, in consideration of recent fluctuations of foreign exchange rate, the applicable foreign exchange rate is adjusted from 900 won/$ to 1,400 won/$ for 30% of imported parts for C/Cs and yard cranes. As results, the total equipment price is estimated to the amount of 225.7 billion won for the automated container terminal, about 14% more than 198.7 billion won of equipment price for the conventional container terminal.

<Table 7-2> Equipment Purchase Price for Automated Container Terminal

Unit: Million won

		Price	Total
C/C	12	8,390	100,680
AGV	76	420	31,920
RMGC (Yard)	17	4,200	71,400
RMGC (Railways)	5	4,340	21,700
Total	-	-	225,700

<Table 7-3> Equipment Purchase Price for Conventional Container Terminal

Unit: Million won

	No. of Units	Price	Total
C/C	12	7,630	91,560
Loading/Unloading at ships			
- Y/T	84	80	6,720
- Chassis	84	13	1,092
RMGC (Yard)	41	2,200	90,200
RMGC (Railways)	3	2,200	6,600
Work with empty containers			
- T/H	6	400	2,400
- Y/T	7	25	175
Total	-	-	198,747

Unlike the conventional container terminal, the automated container terminal should be equipped with a navigation system for AGV operation. And, the navigation lanes should be equipped with transponders. Such automation related to expenses can be estimated as follows: the navigation system costs 8.4 billion won in total, as Mannesmann Demag quotes about 2.8 billion won (3.5 million Deutsche mark based on the exchange rate of 800 won/DM) for a system consisting of 30 sets of AGVs and 3 units are required in total.

In addition, as a transponder should be installed on very 4m of navigation lane, a total of 7,200 transponders should be installed over AGV navigation lane with the length of 28,000m. As Mannesmann Demag quotes 500,000 won for a transponder, a total of 3.6 billion won is required. Accordingly, the total expense of automation system is estimated as 12 billion won.

3) Labor Cost

One of the important reasons that the automated container terminal is in existence for is to make terminal unmanned and robotic. Accordingly, it can be expected that there will be a great difference in labor requirements between conventional and automated container terminals.

In other words, automated container terminals do not require most of equipment operators for transporting equipment and yard cranes located from apron to the automated section of yard. However, new manpower is required for administration, control, supervision and protection of automated sections.

Such new manpower for automated sections can be roughly divided into two groups: 1) Highly trained engineers in charge of administration, diagnosis, operation manual management of automated equipment in addition to the existing personnel simply in charge of maintaining C/C, AGV and RMGC, and 2) The personnel in charge of operating, maintaining and controlling the automaton system.

The manpower for control system is decided from the operation experience of the automated container terminal of ECT. The studies of Ballis, Golias and Abakoumkin estimated that 30 persons are required for controlling the system consisting of 12 ASCs and 24 AGVs based on the experience of ECT. If this ratio is applied in this study, about 82 persons would be required to control the system consisting of 22 RMGCs and 76 AGVs.

Manpower requirements for each job is estimated based on the labor input system presently adopted by PECT, 2 shifts a day with 3 teams. In addition to the average wage (direct labor cost) of BCTOC and PECT, 30% of indirect labor cost is taken into account. As a result, the annual labor cost of the conventional container terminal totals 33.3 billion won, while the annual labor cost of the automated container terminal totals nearly 17 billion, 51%

of that of the conventional terminal.

<Table 7-4> Annual Labor Cost

Unit : Million Won

Processes	Automated terminal	Conventional terminal
○ Loading/unloading at ships	Engineer:70x6p=420 Equip. operator:52x(1.5p x 3teams) x 12units=2,808 Assistant:37x(1p x 3 teams) x 12units=1,332	Equip.operator:52x(1.5px3teams)x 12units=2,808 Assistant:37x(2.0 x 3teams) x 12units =2,664
○ Ship-yard transport	Engineer:70 x 6p=420	Equip. opr:40x(1.3p x 3teams) x 84units=13.104
○ Trucking in yard	Engineer:70 x 6p=420 Maint:46x(0.5p x3teams) x 15units=1,035	Equip.opr:46 x (1.3p x 3teams) x 41units=7,335
○ Railways service		Equip.opr:46 x (1.3p x 3teams) x 3units=538
○ Work with empty containers		R/S eng.:46 x (1.3p x 3teams) x 6units=1,076 F/C eng.:40 x (1.3p x 3teams) x 7units=1,092
○ System controllers	Engineer:70 x 82p=5,740	
○ Maintenance workers	Maint:39 x 124p=4,836	Maint:39 x 119p=4,641
Total	17,011	33,258

4) Power, Maintenance, Depreciation Costs, etc.

In estimating the annual power costs of automated and conventional container terminals, power or diesel consumptions, equipment operation hours, etc. should be taken into account depending on specifications of equipment.

The equipment operation cost per hour depending on power or diesel consumption for each piece of equipment is based on the data drawn out by JWD of the US. The equipment operation time of C/C is calculated based on annual handling throughput and C/C productivity per hour, and the operation time of yard cranes is calculated based on the number

of yard lifts and productivity of yard cranes. In addition, the operation time of transport equipment between quay and yard are calculated by multiplying C/C operation hours by the number of transport equipments required for a unit of C/C.

<Table 7-5> Estimation of Power Cost

Unit : Million Won

	Annual use (hrs)	Hourly power cost ($)	Power cost
Conventional terminal			
C/C	41,176	50	2,882
RMGC (9 rows)	214,414	15	4,503
Y/T	288,2235	10.8	4,358
Total			11,743
Automated terminal			
C/C	47,200	50	3,304
RMGC (15 rows)	80,822	21	2,376
AGV	297,360	10.8	4,496
Total			10,176

Notes : For the hourly power cost of AGV, the power cost of Y/T is used, as engine driving forces are considered as same.

As a result, it has been found that the power cost of the automated container terminal having less RMGCs is less by 13% than the power cost for the conventional terminal.

In this study, maintenance costs for each structure and facilities incurred in maintaining, adjusting and painting them to keep them available are calculated based on the percentage of maintenance costs to assets suggested by the UNCTAD.

The annual maintenance cost of the automated container terminal is estimated to reach 14.2 billion won, 7% more than 13.2 billion won of the conventional terminal.

<Table 7-6> Maintenance Ratios for Assets

Unit : %

	Maintenance Ratio
Quay	1.0
Pavement	1.0
Access roads	1.0
Ancillary facilities	1.0
Buildings	1.0
Unloading equipments	5.0

Source: Port Development, UNCTAD

Depreciation costs refer to the costs required for replacing the equipment whose economic life ends before the analysis period of 30 years elapse with new equipment. Economic life of equipment is considered as follows: quay crane 20 years, RMGC 20 years, Y/T 8 years, cache 8 years (Classification of fixed assets and account settlement, the Ministry of Maritime & Fishery, Nov. 1983), and 8 years for AGV whose economic life is not set.

7.3.2 Comparison of Investments and Expenses by Present Value

For the automated and conventional container terminals, investments and cost for each item during construction period from the year of 2000 to 2005 and operation period of 30 years after 2006 are estimated in annual cost.

In addition, such annual costs are converted into present value based on the discount rate of 10% for invariable investments and costs for each year.

As results, it is found that the annual cost of the automated container terminal is estimated to reach 22.8 billion won, 3% less than 23.5 billion won of the conventional terminal. This indicates that the cost per TEU,

(dividing total costs by annual volume of containers handled) is 12,848 won in the automated container terminal, less by about 2.4% than 13,159 won in the conventional terminal.

The analysis result that the cost per TEU, (calculated by dividing annual total investments and operation costs by annual total volume of containers handled), is less by about 2.4% in the automated container terminal indicates that the automated container terminal is superior to the conventional container terminal in economics apart from many other economic and non-economic advantages accidental to construction of the automated container terminal.

We should add that some assumptions made in this study will be adjusted in future, but it is believed that the results from such adjustments will not differ from the existing results to great extents.

8. Conclusion

This research provides operation logic and theoretical background required to implement operation strategy and design of detailed layout of the first automated domestic container terminal that is planned to be constructed in KwangYang Port by researching the method of operation of automated container terminal, terminal layout, facilities scale, required fleet size, and path design. Executing simulation with port simulation model compared the suggested alternatives to supply useful information in decision making.

In Part 1, the necessity of developing an automated container terminal was analyzed with the goal of terminal performance level improvement preparing for the appearance of bigger container vessels. From trend analysis of international container terminal development, the success and the failure of case studies were examined, and the point of benchmarking to be applied to our automated terminal development was found.

Also, yard equipment, mobile equipment, gate, data communication, specified automated technology in each part related to terminal automation were analyzed in merit and demerit items, and the guideline to be applied to the automated terminal has been suggested.

In Part 2, operation and control logic in automated terminal layout was suggested and validation and verification through simulation of each alternative were executed.

The main topics of this research are ATC distribution, AGV allocation logic in case of parallel layout, and position allocation rule of storage bay of import/export container, and suggestion of logistics flow of the automated terminal, and the operation method of a buffer block in case of a perpendicular layout.

Simulation analysis for automated container terminal design was processed with the following sequence; capacity analysis → terminal simulation analysis → gate simulation.

Equipment combination and operation strategy of each alternative were suggested which satisfies C/C productivity, AGV waiting time, vessel waiting time rate and turn around time of external truck.

As a result, the productivity of an automated container terminal (productivity per total work time) was improved by 34%, from 22.4 lifts/hr to 30 lifts/hr This system was designed with the capacity of 450,000 TEUs per berth which is a similar level to the peak capacity of the conventional terminal in Pusan port.

The system was designed to improve service levels in order to play a role as a hub port in Northeast Asia. In other words, the vessel waiting time rate was decreased from 5% down to 1% and turn around time of external truck was decreased from 30 min. down to 20 min.

Finally, economical feasibility of an automated container terminal was analyzed. As the result showed, required initial investment cost for an automated container terminal is higher than a conventional one by 6%. However, in the respect of annual operation cost which contains labor cost, etc., the cost of the automated container terminal is lower by 25% than a conventional one. This means that the total cost of an automated container terminal will be decreased in 11 years after opening the terminal.

If it is impossible to oppose the trend of appearance of bigger vessels, and we think this trend will continue, then it is also necessary to construct a terminal with high productivity. Besides the effect of an automated container terminal with highly advanced technology for decreasing man power and increasing usage of land, the terminal with high productivity is the most realistic alternative in the future.

We hope that this research will be helpful in constructing an automated container terminal in Korea and in researching and designing automated container terminals globally.

References

Bae, J.W., Yang, C.H., Kim, K.H., "Determination of Fleet Size of Equipment in Buffer yard of an Automated Container Terminal by using a Response Surface Methodology", *Journal of the Korean institute of Port Research*, Autume, 2000, pp.121 129.

Ballis, A. and Abacoumkin, C., "A Container Terminal Simulation Model with Animation Capabilities", *Journal of Advanced Transportation*, Vol. 30, 1995, pp.37 57.

Bose, J. et al., "Vehicle Dispatching at Seaport Container Terminals Using Evolutionary Algorithms", *Working Paper*, Germany : Technical University Braunschweig, 1999.

Bruzzone, A. and Signorile, R., "Simulation and Genetic Algorithms for Ship Planning and Shipyard Layout", *Simulation*, Vol.71, 1998, pp.74 83.

Bruzzone, A., "Harbour and Maritime Simulation : Guest Editorial," *Simulation*, Vol.71, 1998, pp.72 73.

Banks, J., *Handbook of Simulation*, EMP, 1998.

Cargo Systems, *The Future of Container Handling Technology*, 1997.

Cargo Systems, *Developments in Container Handling Technology*, 1999.

Cargo Systems, *Recent Development in Information Technology for Container Terminals*, 1997.

Daganzo, C.F., "The Crane Scheduling Problem", *Transportation Research-B*, Vol.24B, 1989, pp.159 172.

De Castilho, B. and Daganzo, C.F., "Handling Strategies for Import Containers at Marine terminals", *Transportation Research-A*, Vol.27B, 1993, pp.15 1 166.

Gambardella, L.M., Rizzili, A.E., and Zaffalon, M., "Simulation and Planning

of an Intermodal Container Terminal," *Simulation,* Vol.71, 1998, pp.107 116.

Harrell, C. and Tumay, K., *Simulation Made Easy*, EMP, 1995.

Hayakawa, K. et al., "Port of Kawasaki Automated Container Terminal," *NKK,* No.155, 1996, pp.25 30.

Hedrick, R. L. et al., "Simulation Modeling of Marine Terminal Facilities and Their Operation," *Naval Architects and Marine Engineers,* Spring Meeting/STAR Symposium, New Orleans, April 12 15, 1989.

Jeffery, K., "Recent developments in information technology for container terminals", *Cargo Systems*, 1999.

Kim, K. H. and Bae, J. W., "A Dispatching Method for Automated Guided Vehicles to Minimize Delays of Containership Operation", *International Journal of Management Science,* Vol.5, 1999, pp.1 25.

Kim, K. H. et al., "Development of Decision Support System for the Yard Assignment Planning of the Import and Export Containers", *Korean Management Science Review,* Vol.12, 1995, pp.1 12.

Kozan, E. and Preston, P., "Genetic Algorithms to Schedule Container Transfers at Multimodal Terminals", *International Transactions in Operational Research,* Vol.6, 1999, pp.311 329.

Kim, D. J. and Park, Y. T., "A Planning Based Slot Assignment System for Containers", *Journal of the Korean Institute of Intelligent Information Systems,* Vol.5, 1996, pp.145 166.

Kim, K. H. and Kim, D. Y., "Group Storage Methods at Container Port Terminals", *The Material Handling Engineering Division 75th Anniversary Commemorative Volume ASME 1994,* MH-Vol.2, 1994.

Kim, H. B., *Operational Policies for Import Container Yard in the Port Container Terminal* (Ph. D. Thesis), Pusan National University, 1999.

Kim, K. H., Park, Y. M., and Ryu, K. R., "Deriving Decision Rules to

Locate Export Containers in Container Yard", *European Journal of Operational Research,* Vol.124, 2000, pp.89 101.

Kim, K. H., "Evaluation of the Number of Rehandles in Container Yards", *Computers and Industrial Engineering,* Vol.32, 1997, pp.701 711.

Kim, K. H. and Park, K. T., "A Dynamic Space Allocation Method for Outbound Containers in Carrier-direct Systems", *Proceedings of The 3rd Annual International Conference on Industrial Engineering Theories, Applications and Practice,* HongKong, Dec. 28 31, 1998.

Kim, K. H. and Bae, J. W., "Remarshaling Export Containers in Port Container Terminals", *Computers and Industrial Engineering,* Vol.35, 1998, pp.655 658.

Kim, K. H. and Kim, K. Y., "An Optimal Routing Algorithm for a Transfer Crane in Port Container Terminals", *Transportation Science,* Vol.33, 1999, pp.17 33.

Kim, K. H. and Kim, H. B., "Segregating Space Allocation Models for Container Inventories in Port Container Terminals", *International Journal of Production Economics,* Vol.59, 1999, pp.415 423.

Koh, P. H. et al. "Using Simulation to Preview Plans of a Container Port Operations", *Proceedings of the 1994 Winter Simulation Conference,* Seila, 1994.

Lee, K. M., *Sequencing Delivery and Receiving Operations for Transfer Cranes*(Master Thesis), Pusan National University, 2000.

Lee, H. G. and Lee, C. Y., "A Heuristic Algorithm of Berth Assignment Planning in a Container Terminal", *Journal of the Korea Institute of Port Research,* Vol.8, 1995, pp.1 8.

Lim, A., "The berth planning problem", *Operation Research Letters,* Vol.22, 1988, pp.105 110.

Lai, K. K. and Shih, K., "A Study of Container Berth Allocation.", *Journal*

of Advanced Transportation, Vol.26, 1992, pp.45 60.

Lai, K. K., and Lam, K., "A Study of Container Yard Equipment Allocation Strategy in Hong Kong", *International Journal of Modeling and Simulation,* Vol.14, 1994, pp.134 138.

Lin, G. Y., *A Distributed Production for Intelligent Manufacturing Systems* (Ph. D. Thesis), Purdue University, 1993.

Leva, A., Bartolini, A., and Maffezzoni, C., "A Process Simulation Environment Based on Visual Programming and Dynamic Decoupling", *Simulation,* Vol.71, 1998, pp.183 193.

Li, C. et al., "Scheduling with Multiple-job-on-one processor Pattern", *IIE Transactions,* Vol.30, 1998, pp.433 445.

Merkuryev, Y., et al., "A Modeling and Simulation Methodology for Managing the Riga Harbour Container Terminal", *Simulation,* Vol.71, 1998, pp.84 95.

MPA & ACES, *Seminar on Port Design and Operation Technology,* Nov. 4 5, 1999.

Nevins, M. R., "A Discrete-Event Simulation Model for Seaport Operations", *Simulation,* Vol.70, 1998, pp.213 223.

Okawa, T. et al., "Shift Operation Planning for Container Terminals", *NKK,* No.156, 1996, pp.34 38.

Park, K. T., *A Space Allocation Method for Export Containers in Port Container Terminals Considering Liability to Model Change* (Master Thesis), Pusan National University, 1997.

Powell, W. B. and Carvalho, T. A., "Real-Time Optimization of Containers and Flatcars for Intermodal Operations", *Transportation Science,* Vol.32, 1998, pp.110 126.

Peterkofsky, R. I. and Daganzo, C. F., "A Branch and Bound Solution Method for the Crane Scheduling Problem", *Transportation Research-B,* Vol.24B,

1990, pp.159 172.

Ryu, M., *A Study on the Container Handling Time in Port Container Terminals* (Master Thesis), Pusan National University, 1998.

Revins, M. R. et al., "Simulation, Animation and Visulation of Seaport Operations", *Simulation*, Vol.71, 1998, pp.96 106.

Shin, J. Y. and Nam, K. C., "Intelligent Decision Support System for Containership Auto-stowage Planning", *Journal of the Korea Institute of Port Research*, Vol.9, 1995, pp.19 32.

Taleb-Ibrahimi, M., De Castilho, B., and Daganzo, C. F., "Storage Space vs Handling Work in Container Terminals", *Transportation Research-B*, Vol.27B, 1993, pp.13 32.

Taleb-Ibrahimi, M., De Castilho, B., and Daganzo, C. F., "Storage Space vs. Handling Work in Container Terminals", *Transportation Research-B*, Vol.27B, 1993, pp.13 32.

Tao, Chen et al., "Empirical studies on yard operations Part 2 : Quantifying unproductive moves under taken in quay transfer operations", *Maritime Policy & Management*, Vol.27, No.2, 2000, pp.191 207.

Thiers, G. F. and Janssens, G. K., "A Port Simulation Model as a Permanent Decision Instrument", *Simulation*, Vol.71, 1998, pp.117 125.

Thomas, B. J. *Port Productivity and costs with Particular Reference to the Handling of Iron and Steel Products* (Ph. D Thesis), University of Wales, 1980.

Wang, K. H., *A Distributed Operation System for Container Handling Equipments in Port Container Terminals* (Master Thesis), Pusan National University, 1998.

Ward, T. A., *Simulation in Marine Terminals - Technique and Technology*, IIR Training Materials, JWD, 1999.

Ward, T. A. and Woodman, R. A., "Gate Congestion at Howard Terminal

Applied Simulation", *Facilities Engineering Seminar*, AAPA, Savannah, Georgia, 1993, April 14 16.

Ward, T. A. and Johansen, R., "Simulation Analysis in Terminal Planning, Pier 300 Marine Terminal Port of Los Angeles", *Planning and Research Seminar*, AAPA, Tempa, Florida, April 24 26, 1996.

Watanabe, I., "Innobated Operation Systems of Container Terminal", *MES Technical Report*, Vol.17, 1980, pp.89 98.

Watanabe, I., "An Approach to the Automated Container Terminals", *Seminar on Automated Container Terminals*, Korean Institute of Machinery and Materials, 1996.

Wijno1st, N., Scholtens, M., and Waals, F. A. J., *Malacca-Max : The Ultimate Container Carrirer*, Delft University Press, 1999.

Wilson, D. and Roach, P. A., "Principles of Combinatorial Optimization Applied to Container-Ship Stowage Planning", *Journal of Heuristics*, Vol.5, 1999, pp.403 418.

Yang, C. H. et al., *Feasibility Study for Automated Container Terminal in Korea*, Korea Maritime Institute, 1998.

Yang, C. H., "Examining the impact of next generation ships on terminal operations and how terminals are adapting quay side operations to service the Vessels", *Container Handling Automation & Technology*, Cargo Systems, Feb. 2000.

Yang, C. H., Kim, J. H., "Automated Handling system for Container Maritime Terminal in Korea : Development Necessity and Prospects," *Maritime Policy and the Korean Economy : Key issues and Opportunities*, The First Annual Korea-U.S. Marine Policy Forum, KMI, Oct. 1998.

A Study on the System Design and Operations of the Automated Container Terminal

2000年 12月 26日 印刷
2000年 12月 30日 發行

編輯兼發行人 李 廷 旭

發行處 韓國海洋水産開發院
서울특별시 송파구 신천동 11-6
전 화 2105-2700 FAX : 2105-2800
등 록 1984년 8월 6일 제16-80호

組版·印刷/ (株) 精 印 社 3486-6791 4 정가 25,000원

판매 및 보급 : 정부간행물판매센터
Tel : 394-0337, 734-6818