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The Performance Analysis of Priority Systems

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16. Abstract

This report summarized the research conducted at the University of Texas on the performance analysis of priority systems for containers. The performance analysis focused on a selected group of possible priority systems that differ in the extent in which service by priority is implemented. The systems analyzed are: a) base case, i.e., no service differentiation; b) "hot hatch" programs; c) service differentiation at the storage yard; d) service differentiation at the yard gate and e) combinations of systems b), c), d). The performance analysis was conducted using a simulation system specially designed to simulate priority systems. The performance of these systems is assessed for different combinations of the relevant experimental factors, namely: a) operational scheme, b) proportion of high priority containers, and c) number of incoming containers. Using the resulting performance measures, the impacts on the different segments of users are assessed for each of the systems. Finally, the policy implications are analyzed and conclusions are drawn.

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THE PERFORMANCE ANALYSIS OF PRIORITY SYSTEMS

by

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Research Report SWUTC/97/467304-1

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DISCLAIMER

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EXECUTIVE SUMMARY

This report summarizes the research conducted at The University of Texas at Austin on the performance analysis of priority systems for containers. First, the elements comprising the experiment design are defined. The performance analysis focused on a selected group of possible priority systems that differ in the extent in which service differentiation by priority is implemented. The systems analyzed are: (a) base case, in which high priority containers and low priority containers are randomly located on the ship and the service characteristics are the same, regardless of priority; (b) the existing "hot hatch programs," in which high priority containers are located on the hatches to be unloaded first; (c) service differentiation at the storage yard, in which high priority containers are sent to a special section of the storage yard where they receive a faster service; (d) service differentiation at the yard gate, in which the trucks that come to pick up high priority containers receive expedited treatment; and (e) combinations of systems (b), (c) and (d). The performance analysis was conducted using a simulation system specially designed to simulate the different versions of priority systems. Two different levels of priority were considered, namely, high and low. The simulation system was written in FORTRAN and it is comprised of more than 16,000 lines of code and more than 150 subroutines. Since most of the priority systems under analysis have not yet been implemented in practice, there is no empirical data with which to estimate the statistical distributions needed for the standard simulation approach, e.g., service time distributions. For that reason, the model simulates the micromovements of the handling equipment at the container terminal to estimate the service times for the different service stages. The performance of these systems is assessed for a number of different combinations of the relevant factors in terms of waiting times, operating costs and user costs. The computation experiment uses three different experiment factors, namely: (a) operational scheme, (b) proportion of high priority containers, and (c) number of incoming containers. Using the resulting performance measures, the impacts on the different segments of users are assessed for each of the systems. Finally, the policy implications are analyzed and conclusions are drawn.

ABSTRACT

This report summarizes the research conducted at The University of Texas at Austin on the performance analysis of priority systems for containers. The performance analysis focused on a selected group of possible priority systems that differ in the extent in which service by priority is implemented. The systems analyzed are: (a) base case, i.e., no service differentiation; (b) "hot hatch programs; (c) service differentiation at the storage yard; (d) service differentiation at the yard gate; and (e) combinations of systems (b), (c) and (d). The performance analysis was conducted using a simulation system specially designed to simulate priority systems. The performance of these systems is assessed for different combinations of the relevant experimental factors, namely: (a) operational scheme, (b) proportion of high priority containers, and (c) number of incoming containers. Using the resulting performance measures, the impacts on the different segments of users are assessed for each of the systems. Finally, the policy implications are analyzed and conclusions are drawn.

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INTRODUCTION

The success of containerization is due to the benefits associated with reducing a potentially infinite number of shapes and sizes of cargoes into a much smaller set of standard units, containers. By unitizing containers, operators are able to take advantage of scale economies in a number of ways. First, the container is used as a consolidation unit that accommodates a batch of cargoes in one move. Second, and more importantly, since all containers can be handled in a similar manner, as boxes, operators can make efficient use of loading equipment and storage space. Without a doubt, the "container-as-boxes" approach has worked, but there are signs that indicate that this approach does not fit the needs of some segments of users. This is a fairly new situation, brought about by changes in the international economy that, among other impacts, have stressed the importance of dimensions previously considered non-relevant. The cargo value provides a good example of such a case.

Cargo value can be subdivided in two separate components: the intrinsic value of the cargo (determined by market value and replacement costs) and the logistic value of the cargo (a dynamic component that is a function of the importance of the cargo in the production system at particular times and at particular inventory levels).

In the last twenty years, developments in electronics and computer control have increasingly allowed production of goods with higher added value, smaller unit size and relatively low volume. In addition, globalization of the world economy has stressed the role of transportation and logistics as the key factors in reducing inventory costs. Concurrently, the growing popularity of Just-in-Time (JIT) production systems has increased the importance of the logistic value of cargoes. As a consequence, there is an increased need to expedite the flow of high-valued goods.

On the other hand, the advent of intermodalism has provided container carriers with the opportunity to target non-traditional markets. As part of these efforts, container carriers are trying to attract low-valued cargoes as a way to reduce the number of empty movements, e.g., cotton movements from Texas to the West Coast. If these attempts to attract low-valued cargoes succeed, container carriers and intermodal terminals may be handling, in the near future, a potentially high number of containers carrying low-valued cargoes.

The combined effect of the aforementioned trends is to increase the relative importance of both ends of the cargo value distribution. In this situation, an operational policy that does not distinguish containers according to cargo value is likely to penalize the segments of users located at both extremes of the cargo value distribution, i.e., the low-valued cargoes may be charged for a service that they do not need and the high-valued cargoes may receive a quality of service below their needs. Container carriers have responded to this new challenge by implementing simple versions of priority systems. In most of the cases, these priority systems consist of one or two ship hatches, known as "hot hatches," defined as the hatches that will be unloaded first. So far, most of the "hot hatches" programs have been implemented for only Asia-US East Coast routes. However, it is expected that their use will be extended to other routes as soon as market conditions indicate prioritization needs.

Another issue is overall system optimality. Increasing cargo values implies increasing user costs. In this context, decisions based on operating costs will yield sub-optimal operations because the alternatives that minimize operating costs do not necessarily minimize system costs (user + operator costs).

In view of all these issues, the implementation of priority systems will help expedite the flow of high-valued cargoes. However, this implementation is not straightforward. There are operational and technological constraints that need to be analyzed. These constraints may be technical, e.g., equipment size and type or physical, e.g., land availability. They are likely to be important in determining the feasibility of priority systems and the tradeoffs between the decision criteria, e.g., operator costs, user costs, and risk of non-compliance.

Priority systems can be implemented at the network level, i.e., by routing high priority containers through the fastest routes or by using the fastest modes within a given transportation network, and at the port level, i.e., by using alternative operational schemes. The relative importance of each of these levels will depend on the particular conditions of the problem.

The purpose of this research is to analyze the technological and economic feasibility of the implementation of priority handling systems for containers at the port level.

The aim of such systems would be to expedite the flow of high-valued cargoes, thereby reducing user inventory costs. This "prime service" could be implemented through a combination of handling equipment, electronic data interchange technology, and innovative operational rules.

There are a number of issues that need to be studied. Among them, we must highlight the requirement of designing a system that does not penalize the efficiency of port operators in terms of operating costs, loading productivity and land requirements. Considering the impact on terminal operators is a crucial element of this research because of the importance of terminal costs.

The possible priority systems range from the current "hot hatch" programs, in which service differentiation only occurs at the unloading stage, to more complex systems in which service differentiation is done at all the stages, i.e., movement to storage yard, storing yard operations, gate processing in/out of the storage yard and container retrieval.

The analysis of the envisioned systems requires the examination of different aspects of the problem, including the definition and performance analysis of operational rules, pricing rules, and the corresponding information systems and information technology (IS/IT).

This report presents the results corresponding to the performance analysis of the envisioned systems. The report has eight chapters. The first chapter describes the experiment design and the experimental factor for the computation experiment. Chapters II to VII focus on presenting the results corresponding to each of the systems. In chapter VIII the results are summarized.

Other reports that have been published as part of this research project are:

(a) "A Categorized and Annotated Bibliography to the Performance Analysis of Port Operations,"

(b) "Prior, a Computer System for the Simulation of Port Operations Considering Priorities,"

(c) "The Calibration of Prior, a Computer System for the Simulation of Port Operations Considering Priorities,"

(d) "The Role of Information Technology on the Implementation of Priority Systems and the State of the practice of Information Technology on Marine Container Terminals,"

(e) "On the Performance Analysis of Priority Systems,"

(f) "Range of Applicability of Priority Systems."

CHAPTER I. EXPERIMENT DESIGN

QUESTIONS ADDRESSED AND PERFORMANCE MEASURES

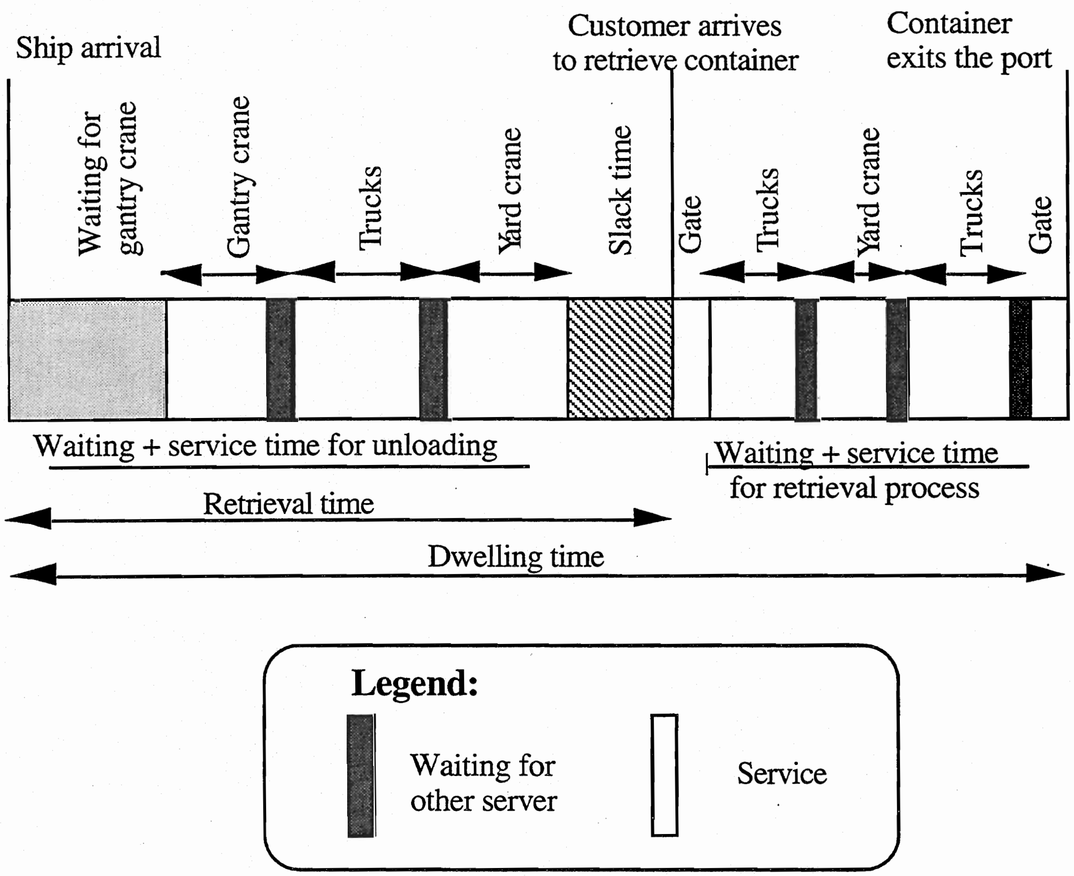
The questions addressed by this research revolved around a basic one: What are the technological and economic implications of implementing priority systems at the port level?. Answering this question required the implementation of a simulation system that provided estimates of the performance measures more directly related to the operator's decision criteria. In addition, the simulation system provided information about the quality of the service, i.e., the customer's perspective, because one of the basic assumptions of this research is that the operators are sensitive to the customer's perspective of the problem.

From the operator standpoint, the most relevant decision criteria are: (a) operating costs and profitability which are highly determined by the level of equipment utilization and efficiency and (b) risk of non-compliance, which is determined by service reliability. From the customer standpoint, the most important criterion is reliability, i.e., the probability that their containers are ready to be retrieved when scheduled.

Both aspects were assessed by using three set of performance measures: (a) waiting and service times for the different service stages, which provided the basic input for the cost calculations; (b) equipment utilization indicators, e.g., percentage of time being idle; and, (c) the probability the containers are ready to be retrieved when the customers needs them, i.e., the customer side of the problem.

Figure 1.1 shows a conceptual representation of the timeline for both high and low priority containers (HPC and LPC). As can be seen, there are three important events, i.e., ship arrival, customer arrival and container exiting the port, that define some important relationships.

Figure 1.1: Expected timelines



Before discussing these relationships, some operational definitions need to be made:

Total time at unloading (T_u) is equal to the summation of the waiting times (including the waiting time on the ship and the time waiting for another server) and the service time for all the service stages. Similarly, the total time at retrieval (T_r) equals the summation of the waiting times plus the service times of all the related service stages.

Retrieval time (R_t) will be defined as the time elapsed since the ship arrival to the moment in which the customers arrives to pick up the containers. Slack time (S_t) is the time that passes since the end of the unloading process until customer arrival. Dwelling time (Dt) will be the time elapsed since ship arrival to the container exit to the port.

As can be seen in Figure 1.1, the following relationships hold:

$$R_t = T_u + S_t \qquad (1)$$

$$D_t = T_u + S_t + T_r \qquad (2)$$

Thus, the slack time is equal to:

$$S_t = R_t - T_u \qquad (3)$$

The simulation system calculated the slack time for each container. At the end, mean slack times and the corresponding standard deviation were calculated. The output analysis is performend using a set of summarizing indicators, that are described in the following paragraphs.

Service time at unloading (S_u) is equal to the summation of the service times of all the stages comprising the unloading process.

Waiting time at unloading (W_u) is equal to the summation of the waiting times of all the stages comprising the unloading process.

Service time at retrieval (S_r), same as S_u for retrieval.

Waiting time at retrieval (W_r), same as W_u for retrieval.

Mean slack times, equal to the average slack time.

Reliability (R'), equal to the probability that the containers were ready at the moment of retrieval.

Total unit cost, equal to the operational cost associated to handling the containers.

EXPERIMENTAL FACTORS

Three different factors were considered in the numerical experiments. The experimental factors can be classified as:

a) Operational factors:

Operational policy (six different policies)

b) Demand factors:

Proportion of high priority containers (25% and 50%)

Total demand (1,000 containers/week and 2,000 containers/week)

The operational policy defines the extent to which service differentiation by priority is implemented. A number of different operational policies were considered. The systems differ in the extent to which service differentiation by priority is implemented. Figure 1.2 shows the summary of the characteristics of the different operational policies.

Base case: No priority system implemented. High and low priority containers are located randomly on the ship. The unloading process does not consider service differentiation by priority.

Priority system I -Service differentiation at the unloading from the ship- (PS-I): The location of the containers on the ship is priority dependent. The gantry cranes unload the high priority containers first. Though there might be a number of possible variations for this type of system the most important to be considered, from a practical standpoint, is the "hot hatch" system. In this case all high priority containers are located on the priority hatches allowing the gantry cranes to unload them with a minimum number of lateral movements.

Priority system II -Service differentiation at the storage yard- (PS-II): The high priority containers are sent to special lots where they receive a faster service. There are a number of different alternative systems that could have been analyzed. Some of the possible variations were: (a) storing the high priority containers on chassis (wheeled operations, stacking height equal to one) and (b) assigning more yard cranes to service the lots where the high priority containers are stored (stacking height greater than one). Since the basic postulate of this research is that high priority containers demand a level of service significantly different than the one provided to low priority containers, the analysis focused on alternative (a) because it provided a maximum level of service differentiation. In all cases low priority containers are stacked three or four high, to compensate for the additional space required by the storing of high priority containers.

Priority system III -Service differentiation at the yard gate- (PS-III): The trucks arriving to pick up high priority containers receive a faster service at the gate. Currently, there are a number of implementations of electronic data interchange technology (EDI), information technology (IT) that can be adapted to this purpose. Some of these implementations use cameras to retrieve information about the truck identification, electronic transponders to verify the identification of the containers and computers to do the paper work.

Priority system I-II (PS-I-II): Combination of PS-I and PS-II, as defined above.

Priority system I-II-III (PS-I-II-III): Combination of PS-I, PS-II and PS-I-II-III as above.

Figure 1.2: Description of operational policies

	Location of HPCs	Yard crane operations	Yard gate operations
Base case	Random	No priority service HPC stacked as other containers	No priority service
Priority system I	Hot hatches	No priority service HPC stacked as other containers	No priority service
Priority system II	Random	HPC are wheeled	No priority service
Priority system III	Random	No priority service HPC stacked as other containers	HPC receive preferential service
Priority system IV (I + II)	Hot hatches	HPC are wheeled	No priority service
Priority system V (I+II+III)	Hot hatches	HPC are wheeled	HPC receive preferential service

The yard crane allocation scheme defines the way in which the work at the storage yard is distributed among the yard cranes. Two cases were implemented in the simulation system, namely, static and dynamic. In the static allocation scheme, at the beginning of the simulation, the yard lots are distributed among the yard cranes. The allocation does not change during the simulation and, regardless of the queues, yard cranes are not allowed to cooperate with each other. On the other hand, when dynamic allocation is used, the allocation is revised at a time interval specified by the user. Yard cranes collaborate with each other to tackle the longest queue. Since in practice static allocation is hardly used, all the runs were performed using dynamic allocation.

Two priority classes were considered, high and low. The former represented containers carrying high valued cargoes, i.e., from the user's perspective. Conversely, the latter represented containers carrying low-valued cargoes.

Two different proportions of high priority containers were used, 25% and 50%. These values were selected for practical, and probably arbitrary, reasons. First, it was considered that if the majority of the containers handled at a given port are "high priority containers," then it is very likely that the current definition of "high priority" is not appropriate. If the majority of containers requires the special treatment reserved for high priority containers, then this treatment can not be considered "special." For that reason, 50% was selected as the upper bound. 25% was selected because it is the mid-value between 0% and 50%.

The second demand factor considered is the total demand. Two values were considered: 1,000 containers/week and 2,000 containers/week. The latter was estimated as the capacity of the terminal being simulated.

CHAPTER II. BASE CASE

The simulation system provides a multidimensional output that includes: (a) detailed information about individual servers, e.g., mean and standard deviations of service, waiting, breakdown and repositioning times; (b) server statistics, e.g., percentage of total time being idle, busy, repositioning, broken or waiting; and (c) cross statistics, e.g., matrices of mean waiting times of gantry cranes waiting for yard trucks.

A printout of the full output produced by the simulation system requires, on average, thirty (30) pages per ship. Since the number of observations (ships) have been set to twenty (20), the output file for one case would have 600 pages. Thus, the analysis of the 24 different cases considered in the experiment design would require to print an output 14,400 pages long.

For obvious reasons, it is required to find a way to collapse the output into a small set of summarizing performance indicators for which the analysis can be reduced to a manageable size. In order to provide an adequate description of system performance, the selected indicators must be able to distinguish: (a) between service and waiting times and (b) between unloading and retrieval process. Thus, it was decided that the following performance indicators would be used:[1]

(a) Service times at unloading, equal to the summation of the average service times of the different stages comprising the unloading process, namely, unloading from the ship, movement to the storage yard and unloading at the yard.

(b) Waiting times at unloading, same as (a) for waiting times.

(c) Service times at retrieval, equal to the summation of the average service times of the different stages comprising the retrieval process, namely, service at the "in" gate, movement to the yard, loading at the yard, movement to the gate, and service at the "out" gate.

(d) Waiting times at retrieval, same as (d) for waiting times.

In addition to the performance indicators defined above, which are mainly related to system performance, there are two important aspects to be considered: service reliability and operating costs. The former is important for port users while the latter is for port managers. The performance indicators that will be used to capture these aspects are:

(e) Mean slack times that are equal to the time elapsed between the moment in which the container is ready to be picked up and the time in which the corresponding external truck arrives to retrieve it.

(f) Reliability, equal to the probability of having positive slack times.

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[1] The underlining represents the name assigned to each performance indicator.

(g) Operating costs which are an estimate of the amount of resources used. The operating costs are the output of the program in charge of post-processing the simulation system's output.

Before discussing the results, it is important to highlight the scope and limitations of the simulation system. First, the objective of this modelling effort is to simulate a typical operation, rather than to simulate the operation of a specific terminal. For that reason, the results provided here have no relation to the different terminals that, generously, provided data for this research.

Second, port operations involves a dynamic decision making process in which the terminal manager continuously monitors system performance and takes decisions accordingly. By virtue of this process, the terminal manager tries to optimize their operations at each level of demand. The way in which the goal of optimizing operations is achieved is highly dependent on the experience of the terminal manager, and on the practices and tradition of the company. Since modelling this decision making process is beyond the scope of this research, the different systems were simulated with a fixed combination of equipment. In this context, the simulation results will only provide an indication of relative performance.

Third, the interaction between supply and demand was not considered. Specifically, dwelling times are likely to be determined by the total demand and the storage pricing policy. In this context, a growing demand may require the implementation of storage charges so that the storage yard will not be overfilled. External trucks arriving to retrieve containers are likely to take into consideration the level of service they perceive. If the waiting times are high, for instance, some truck drivers are going to change their arrivals to avoid peak periods of congestion at the terminal. Since the distributions of container dwelling times were assumed to be the same, regardless of the level of demand, waiting times are likely to be overestimated. This limitation must be understood as the consequence of having neither adequate theory nor data to model this problem.

DESCRIPTION OF THE BASE CASE SCENARIO

The base case scenario is the one used as the baseline to compare the performance of the alternative systems. The base case represents the typical operational scheme implemented in US ports in which priorities are not considered.

The general characteristics of the base case are as follows:

(a) Containers on ship: high and low priority containers are randomly located on the ship. Two different ship sizes were considered, namely 1,000 and 2,000 containers. The ship's frequency was assumed to be one per week. Thus, the total demand was 1,000 containers/week and 2,000 containers/week respectively.

(b) Gantry crane operations: high and low priority containers are unloaded from top of the hatch to bottom, regardless of their priority. Three gantry cranes unload the ships.

(c) Yard truck operations: yard truck operations are the same for both priorities. When the container is unloaded from the ship, the destination lot is determined as a function of the hatch number. Twenty four yard trucks move the containers from the ship to the storage yard.

(d) Gate operations (in and out): all external trucks are treated in the same way and, consequently, the service time distributions for both priorities are the same. Eight inbound lanes and eight outbound lanes serve the trucks.

(e) External truck operations (gate-to-yard lot and yard lot-to-gate): the external trucks have the same operational characteristics for both priorities. The only difference between the two groups is their arrival time at the terminal. [2]

(f) Yard operations: stacked operations are assumed for all containers, regardless of priority level. No special treatment is given to high priority containers. The storage yard is comprised of twenty four yard lots. Each lot is capable of storing two hundred and forty containers (10x6x4). The lots are served by six yard cranes.

MAIN RESULTS OF THE SIMULATION

To identify the different runs produced by the simulation system, file name extensions were used to distinguish the output files. The extensions have four characters. The first character refers to the operational policy (B for base case). The second character refers to the yard crane allocation scheme used (S for static, D for dynamic).[3] The third character identifies the file containing the string of ships and percentages of high priority containers (1 for SHIPS.DAT1, 2 for SHIPS.DAT2).[4] The fourth character represents the file containing the number of containers on board the ship (1 for BADATA.DAT1, 2 for BADATA.DAT2).

Table 2.1 shows the file naming convention, the input files used and its corresponding figures. The four cases presented in Table 2.1 were simulated. Tables 2.2 to 2.5 show the

[2] Trucks arriving to retrieve high priority containers have scheduled arrivals between six and ten hours after ship arrival. On the other hand, trucks retrieving low priority containers have scheduled arrivals in the interval between two and seven days after ship arrival.

[3] The results corresponding to static yard crane allocation are not presented because, in practice, static allocation is hardly used.

[4] The percentage of high priority containers will be represented by its acronym, % HPC.

summary of service and waiting times for the unloading and retrieval processes.[5] Tables 2.6 and 2.7 show the mean slack times and reliabilities for high and low priority containers.

Table 2.1: File naming convention and input files		
% of High priority containers	1,000 cont/week File: BADATA.DAT1	2,000 cont/week File: BADATA.DAT2
25% File: SHIPS.DAT1	BD11	BD12
50% File: SHIPS.DAT2	BD21	BD22

Table 2.2: Summary of service times (secs) -Unloading-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	Average	257.28	260.00
	Std Dev	7.41	2.81
50% HPC, 1000 cont/week (BD21)	Average	260.33	260.72
	Std Dev	5.11	2.60
25% HPC, 2000 cont/week (BD12)	Average	264.11	264.83
	Std Dev	4.25	2.87
50% HPC, 2000 cont/week (BD22)	Average	265.61	264.83
	Std Dev	4.11	4.31

Table 2.3: Summary of waiting times (secs) -Unloading-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	Average	15626.89	15622.22
	Std Dev	750.38	527.43
50% HPC, 1000 cont/week (BD21)	Average	15832.28	15864.78
	Std Dev	722.99	439.44
25% HPC, 2000 cont/week (BD12)	Average	31896.67	31946.78
	Std Dev	1482.34	1191.02
50% HPC, 2000 cont/week (BD22)	Average	31951.00	31945.28
	Std Dev	1303.33	1388.45

Table 2.4: Summary of service times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	Average	789.06	787.11
	Std Dev	9.16	8.24
50% HPC, 1000 cont/week (BD21)	Average	789.39	785.94
	Std Dev	5.84	9.28
25% HPC, 2000 cont/week (BD12)	Average	789.72	789.06
	Std Dev	8.57	4.25
50% HPC, 2000 cont/week (BD22)	Average	786.89	787.39
	Std Dev	7.67	10.18

[5] Priority 1 refers to high priority containers, while priority 2 refers to low priority containers.

Table 2.5: Summary of waiting times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	Average	9715.89	289.06
	Std Dev	1111.53	11.51
50% HPC, 1000 cont/week (BD21)	Average	18018.39	264.94
	Std Dev	1259.94	11.71
25% HPC, 2000 cont/week (BD12)	Average	33083.67	347.78
	Std Dev	2131.61	49.23
50% HPC, 2000 cont/week (BD22)	Average	53880.56	288.83
	Std Dev	3018.93	9.23

Table 2.6: Mean slack times (secs)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	Average	13026.00	372580.67
	Std Dev	849.25	4077.60
50% HPC, 1000 cont/week (BD21)	Average	12951.89	374912.06
	Std Dev	767.78	7415.47
25% HPC, 2000 cont/week (BD12)	Average	-3040.39	357045.11
	Std Dev	1471.09	2986.79
50% HPC, 2000 cont/week (BD22)	Average	3253.39	357472.00
	Std Dev	1360.83	3235.91

Table 2.7: Reliabilities			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	Average	0.90	1.00
	Std Dev	0.02	0.00
50% HPC, 1000 cont/week (BD21)	Average	0.90	1.00
	Std Dev	0.02	0.00
25% HPC, 2000 cont/week (BD12)	Average	0.44	1.00
	Std Dev	0.03	0.00
50% HPC, 2000 cont/week (BD22)	Average	0.56	1.00
	Std Dev	0.03	0.00

As can be seen in Table 2.2, no significant difference exist between the service times at unloading for low and high priority containers. The service times at retrieval, shown in Table 2.4, also show similar behavior. Since the fundamental characteristic of the base case is that both priorities receive the same service, these results should not be surprising.

Table 2.3 shows that waiting times at unloading are virtually unaffected by the percentage of high priority containers. Since both priorities receive essentially the same service, this result was expected because the level of service depends only on the total demand.

In order to assess the sensitivity of waiting times with respect to total demand, arc elasticities were calculated. The resulting elasticities are shown in Table 2.8. As can be seen, waiting times at unloading are slightly sensitive to total demand; the elasticities for all the cases are slightly greater than 1.00.

Table 2.8: Elasticities of waiting times -Unloading-		
Case:	Priority 1	Priority 2
25% HPC	1.027	1.030
50% HPC	1.012	1.009
Average for all cases	1.020	1.019

Table 2.9 shows the coefficient of variation for the different cases.

Table 2.9: Coefficients of variation -Unloading-		
Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	0.048	0.034
50% HPC, 1000 cont/week (BD21)	0.046	0.028
25% HPC, 2000 cont/week (BD12)	0.046	0.037
50% HPC, 2000 cont/week (BD22)	0.041	0.043
Average for all cases	0.045	0.036

Table 2.5 shows the summary of waiting times at retrieval. As can be seen, there is a significant difference between the waiting times for each priority. In general, the waiting times for low priority containers are much lower than the waiting times for high priority containers. External trucks retrieving high priority containers wait longer because their arrivals are clustered in a very short time interval.[6] On the other hand, waiting times for low priority containers are relatively small because the arrival of the corresponding external trucks are spread over a longer period of time. [7]

As a consequence of the relatively short interval for scheduled retrievals, waiting times at retrieval of high priority containers are very sensitive to the total demand. As can be seen in Table 2.10, the elasticities are greater than 1.496. On the other hand, waiting times for retrieval of low priority containers are inelastic to total demand. In all cases, the elasticities are no greater than 0.30.

Table 2.10: Elasticities of waiting times -Retrieval-		
Case:	Priority 1	Priority 2
25% HPC	1.638	0.277
50% HPC	1.496	0.129
Average for all cases	1.567	0.203

[6] Between six to ten hours after ship arrival.
[7] Usually between 2 and 7 days after ship arrival.

Table 2.11 shows the coefficient of variation for the different cases.

Table 2.11: Coefficients of variation -Retrieval-		
Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	0.114	0.040
50% HPC, 1000 cont/week (BD21)	0.070	0.044
25% HPC, 2000 cont/week (BD12)	0.064	0.142
50% HPC, 2000 cont/week (BD22)	0.056	0.032
Average for all cases	0.076	0.064

Tables 2.6 and 2.7 summarizes the results corresponding to mean slack times and reliabilities for each priority.[8] These results indicate that the system reliability drops quickly when the demand increases.

Table 2.12 shows the corresponding averages and standard deviations of the unit costs calculated by ECON. Since the estimates provided by ECON consider only labour and equipment costs, one must add the corresponding land costs. The unit land costs are calculated using the framework proposed by Hatzitheodorou (HATZI83). In this framework the unit land cost is calculated as a function of the average dwelling time, area required and land cost.[9] In mathematical terms,

$$C_L^u = D_t A C_L$$

Where:

C_L^u = Unit land cost ($/container)

D_t = Average dwelling time (days)

A = Area occupied by the container (square meters/container)

C_L = Anual land cost ($/square meter/year)

Table 2.13 shows the values used and the resulting unit land costs for high and low priority containers. An average stack height equal to three was used in the calculations summarized in Table 2.13.

[8] Slack time, as defined in chapter 1, is the time elapsed since the container is ready for retrieval and the moment in which the external truck arrives to pick it up. A negative value indicates that the external truck arrived before the container was ready, positive values means the opposite. The reliability is defined as the probability that the containers are ready for retrieval, namely, the probability of having slack times greater than zero.

[9] If the terminal operator is leasing the land, the land cost is equal to the lease. If the terminal operator owns the land, the land cost is equal to the fixed cost of the land.

Table 2.12: Labour and equipment unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	Average	234.572	231.472
	Standard Dev	8.229	6.116
50% HPC, 1000 cont/week (BD21)	Average	239.739	234.228
	Standard Dev	9.777	9.620
25% HPC, 2000 cont/week (BD12)	Average	239.906	232.872
	Standard Dev	9.557	8.021
50% HPC, 2000 cont/week (BD22)	Average	241.039	236.078
	Standard Dev	10.432	10.954

Table 2.13: Input data and resulting unit land costs			
Parameter:		Priority 1	Priority 2
Average dwelling time (days)		0.333	4.500
Area required (mt^2/container)	Height: 2	43.660	43.660
	Height: 3	29.260	29.260
	Height: 4	21.830	21.830
Land cost ($/mt^2/year)		20.000	20.000
Unit land cost ($/container)		0.534	7.215

As seen in Table 2.13, in spite of providing the same treatment at the storage yard to both priorities, the resulting unit land costs for high priority containers are much lower than the unit land costs corresponding to low priority containers. This is a consequence of having shorter dwelling times.

Table 2.14: Total unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (BD11)	Average	235.106	238.687
	Standard Dev	8.229	6.116
50% HPC, 1000 cont/week (BD21)	Average	240.273	241.443
	Standard Dev	9.777	9.620
25% HPC, 2000 cont/week (BD12)	Average	240.440	240.087
	Standard Dev	9.557	8.021
50% HPC, 2000 cont/week (BD22)	Average	241.573	243.293
	Standard Dev	10.432	10.954

As can be seen in Figure 2.14, the total unit costs varies between $235 and $243 per container. In general, both priorities have similar unit costs. As expected, the unit cost increases as the total demand increases. [10] Figures 2.25 to 2.28 show the total unit cost for the different scenarios considered.

[10] The resulting unit costs are consistent with the findings of the research conducted for the Maritime

REFERENCES

HATZI83.- Hatzitheodoru, George Ch. (1983); "Cost comparison of container handling techniques"; Journal of Waterways, Port, Coastal and Ocean Engineering, Vol. 109, No. , February 1983.

PRC93.- PRC, Inc.; "Assessment of Cargo Handling Technology"; Vol. I and II, report no. MA-RD-840-93004; written for the Maritime Administration; 1993.

Administration (see PRC93), in which unit cost were calculated for a variety of new systems. The total unit costs range between $191 and $239 per container.

CHAPTER III. HOT HATCHES (PS-I)

DESCRIPTION OF THE HOT HATCH SCENARIO

The "hot hatch" program (PS-I) is the most widely implemented priority system at US ports. In this system, high priority containers are located on the hatches, i.e., "hot hatches," that will be unloaded first at the destination port. It has been implemented mostly in US-Asia routes.

The general characteristics of the hot hatches are as follows:

(a) Containers on ship: high priority containers are located on the hot hatches.

(b) Gantry crane operations: all containers are unloaded from top of the hatch to bottom, regardless of their priority. Three gantry cranes are used to unload the ships (same as the base case).

(c) Yard truck operations: yard truck operations are the same for both priorities. Twenty four yard trucks move the containers from the ship to the storage yard (same as the base case).

(d) Gate operations (in and out): all external trucks receive the same service. As in the base case, eight inbound lanes and eight outbound lanes serve the trucks (same as the base case).

(e) External truck operations (gate-to-storage yard and storage yard lot-to-gate): the external trucks have the same operational characteristics for both priorities (same as the base case).

(f) Yard operations: stacked operations are assumed for all containers, regardless of priority level. The storage yard is comprised of twenty four yard lots. The lots are served by six yard cranes (same as the base case).

As can be seen, the only difference between the base case and the hot hatch system is the location of containers on the ship. In the former, high priority containers are randomly located; in the latter, they are located on the hot hatches.

MAIN RESULTS OF THE SIMULATION

As in the base case, file name extensions were used to distinguish the output files and to make it easier to reference a particular simulation. The first two characters refers to the operational policy (HH for hot hatch). The third character refers to the yard allocation scheme used (S for static, D for dynamic).[11] The fourth character identifies the file containing the string of ships and percentages of high priority containers (1 for SHIPS.DAT1, 2 for SHIPS.DAT2).[12] The

[11] As stated before, the results corresponding to static yard crane allocation are not presented.
[12] The percentage of high priority containers will be represented by its acronym, % HPC.

fifth character represents the file containing the number of containers on board the ship (1 for BADATA.DAT1, 2 for BADATA.DAT2).

Table 3.1 shows the naming convention, the input files used and the figures displaying the results. Tables 3.2 to 3.5 show the summary of service and waiting times for both, unloading and retrieval. Mean slack times and reliabilities are shown in Tables 3.6 and 3.7.

Table 3.1: File naming convention and input files

% of High priority containers	1,000 cont/week File: BADATA.DAT1	2,000 cont/week File: BADATA.DAT2
25% File: SHIPS.DAT1	HHD11	HHD12
50% File: SHIPS.DAT2	HHD21	HHD22

Table 3.2: Summary of service times (secs) -Unloading-

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	Average	248.28	265.06
	Std Dev	11.36	4.58
50% HPC, 1000 cont/week (HHD21)	Average	251.44	267.94
	Std Dev	6.12	6.32
25% HPC, 2000 cont/week (HHD12)	Average	258.06	269.28
	Std Dev	9.08	4.29
50% HPC, 2000 cont/week (HHD22)	Average	258.44	272.06
	Std Dev	6.83	5.35

Table 3.3: Summary of waiting times (secs) -Unloading-

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	Average	11669.33	17173.17
	Std Dev	569.88	660.54
50% HPC, 1000 cont/week (HHD21)	Average	13967.22	18163.50
	Std Dev	1031.99	606.26
25% HPC, 2000 cont/week (HHD12)	Average	23389.06	34567.39
	Std Dev	553.22	891.41
50% HPC, 2000 cont/week (HHD22)	Average	27538.11	36261.33
	Std Dev	881.23	1091.99

Table 3.4: Summary of service times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	Average	792.50	786.44
	Std Dev	15.32	10.10
50% HPC, 1000 cont/week (HHD21)	Average	791.89	786.11
	Std Dev	12.91	11.03
25% HPC, 2000 cont/week (HHD12)	Average	780.89	792.06
	Std Dev	13.86	9.77
50% HPC, 2000 cont/week (HHD22)	Average	790.44	786.89
	Std Dev	9.36	9.88

Table 3.5: Summary of waiting times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	Average	10802.94	328.00
	Std Dev	1295.02	12.84
50% HPC, 1000 cont/week (HHD21)	Average	18311.72	320.94
	Std Dev	1776.79	10.76
25% HPC, 2000 cont/week (HHD12)	Average	39584.83	391.78
	Std Dev	2071.86	16.07
50% HPC, 2000 cont/week (HHD22)	Average	55377.11	379.00
	Std Dev	2231.54	18.41

Table 3.6: Mean slack times (secs)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	Average	16961.94	373432.56
	Std Dev	733.20	3879.72
50% HPC, 1000 cont/week (HHD21)	Average	14909.56	370473.22
	Std Dev	993.89	4337.13
25% HPC, 2000 cont/week (HHD12)	Average	5427.28	353735.17
	Std Dev	607.80	3219.76
50% HPC, 2000 cont/week (HHD22)	Average	7684.39	351964.00
	Std Dev	869.29	4690.03

Table 3.7: Reliabilities			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	Average	0.99	1.00
	Std Dev	0.00	0.00
50% HPC, 1000 cont/week (HHD21)	Average	0.92	1.00
	Std Dev	0.03	0.00
25% HPC, 2000 cont/week (HHD12)	Average	0.65	1.00
	Std Dev	0.02	0.00
50% HPC, 2000 cont/week (HHD22)	Average	0.64	1.00
	Std Dev	0.02	0.00

As can be seen in Table 3.2, service times at unloading for both priorities are similar. Service times for low priority containers are slightly higher for low priority containers because of the way the simulation system creates containers on the ship. When a hatch is not fully occupied by high priority containers, the simulation system place them on top of the hatch, and low priority containers at the bottom. Since the gantry crane service time model takes into consideration the container location, the extra vertical distance produces slightly greater service times.

Waiting times at unloading, shown in Table 3.3, are significantly different for each priority. As can be seen, hot hatches significantly reduce waiting times for high priority containers and consequently improve the corresponding service reliability. Average waiting times at unloading for high priority containers are approximately 60% of the waiting times corresponding to low priority containers.

As expected, the reduction in waiting times for high priority containers is higher when the percentage of high priority containers is small. When the percentage of high priority containers increases, the saving in waiting times for high priority containers decreases. For the case with 25% of high priority containers, the waiting times for high priority containers are 33%-40% smaller than the waiting times corresponding to low priority containers. However, for the case with 50% of high priority containers, the reduction in waiting times for high priority containers is only 25%.

Tables 3.4 and 3.5 show the results corresponding to service and waiting times at retrieval that, as can be seen, are not significantly different to their counterparts in the base case. Since the implementation of hot hatches affects only the unloading process, this result is consistent.

Tables 3.6 and 3.7 show mean slack time and reliabilities for hot hatches. As can be seen the mean slack time for high priority containers increases significantly with respect to the base case. In addition, it can be seen that the impact of hot hatches is more noticeable when the percentage of high priority containers is small. For 25% HPC and 1000 containers/week (cases BD11 and HHD11), the difference in the corresponding mean slack times is, approximately, 3,900 secs, i.e., 65 minutes. However, for 50% HPC and the same total input (cases BD12 and HHD12), the difference between the mean slack times drops to 1,950 secs, i.e., 32.5 minutes.

The reliability for high priority containers increases with respect to the base case. This increase is more noticeable in the high end of total input rates (2,000 containers/week) where the reliability increases to 0.65 from 0.44, and 0.64 from 0.56 in the base case.

Additionally, as can be seen in Table 3.8, waiting times at unloading increase proportionally to the total demand (unit demand) indicating that the effect of the hot hatches is to reduce the elasticity of waiting times.

Table 3.8: Elasticities of waiting times -Unloading-		
Case:	Priority 1	Priority 2
25% HPC	1.003	1.009
50% HPC	0.981	0.998
Average for all cases	0.992	1.003

Table 3.9 shows that the coefficient of variations for the different test cases. As can be seen, there is no significant difference between theses cases and the base case.

Table 3.9: Coefficients of variation -Unloading-		
Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	0.049	0.038
50% HPC, 1000 cont/week (HHD21)	0.074	0.033
25% HPC, 2000 cont/week (HHD12)	0.024	0.026
50% HPC, 2000 cont/week (HHD22)	0.032	0.030
Average for all cases	0.045	0.032

Tables 3.10 to 3.11 show the statistics corresponding to retrieval. As can be seen in Table 3.10, the hot hatches increase the elasticity of waiting times at retrieval for high priority containers (in the base case, the corresponding elasticities were 1.638 and 1.496). On the other hand, the effect of hot hatches on the elasticities for low priority containers is not conclusive. For 25% of high priority containers, the elasticities decreased from 0.277 in the base case to 0.266; while for 50% high priority containers, the elasticity increased from 0.129 in the base case to 0.249.

Table 3.10: Elasticities of waiting times -Retrieval-		
Case:	Priority 1	Priority 2
25% HPC	1.714	0.266
50% HPC	1.509	0.249
Average for all cases	1.611	0.257

Table 3.11 shows the coefficient of variation for the different test cases, which are the same order of magnitude as the ones observed in the base case.

Table 3.11: Coefficients of variation -Retrieval-		
Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	0.120	0.039
50% HPC, 1000 cont/week (HHD21)	0.097	0.034
25% HPC, 2000 cont/week (HHD12)	0.052	0.041
50% HPC, 2000 cont/week (HHD22)	0.040	0.049
Average for all cases	0.077	0.041

Reliabilities, shown in Table 3.7, improved significantly when compared to the base case. In the base case, the reliability for high priority containers was in the range of 44% to 90%. Implementing hot hatches, however, increased the reliability to 64% - 99%.

Table 3.12 shows the unit costs calculated by ECON which are associated to labour and equipment. As explained in Chapter 6, these estimates must be corrected by adding the unit land costs. The unit land costs and the resulting total unit costs are shown in Tables 3.13 and 3.14.[13]

Table 3.12: Labour and equipment unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	Average	227.750	235.594
	Standard Dev	10.904	10.341
50% HPC, 1000 cont/week (HHD21)	Average	233.228	243.917
	Standard Dev	9.494	12.960
25% HPC, 2000 cont/week (HHD12)	Average	229.889	236.422
	Standard Dev	7.978	10.679
50% HPC, 2000 cont/week (HHD22)	Average	230.889	243.106
	Standard Dev	9.036	11.275

As shown in Table 3.13, the unit land costs are equal to the ones calculated in the previous cahpter because the service characteristics at the storage yard are essentially the same in both systems.

[13] It must be highlighted that the extra cost associated to loading high priority containers on the hot hatches was not quantified. For that reason these cost estimates must be interpreted as lower bounds. A second stage of this research will quantify this cost component.

Table 3.13: Input data and resulting unit land costs			
Parameter:		Priority 1	Priority 2
Average dwelling time (days)		0.333	4.500
Area required (mt^2/container)	Height: 2	43.660	43.660
	Height: 3	29.260	29.260
	Height: 4	21.830	21.830
Land cost ($/mt^2/year)		20.000	20.000
Unit land cost ($/container)		0.534	7.215

As can be seen in Table 3.14, the total unit cost for high priority containers decreased with respect to the base case, a consequence of having smaller waiting times for unloading. On the other hand, total unit costs for low priority containers increased with respect to the base case, for the opposite reason.

Table 3.14: Total unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (HHD11)	Average	228.284	242.809
	Standard Dev	10.904	10.341
50% HPC, 1000 cont/week (HHD21)	Average	233.762	251.132
	Standard Dev	9.494	12.960
25% HPC, 2000 cont/week (HHD12)	Average	230.423	243.637
	Standard Dev	7.978	10.679
50% HPC, 2000 cont/week (HHD22)	Average	231.423	250.321
	Standard Dev	9.036	11.275

CHAPTER IV. PRIORITIES AT THE STORAGE YARD (PS-II)

DESCRIPTION OF THE SYSTEM

As stated before, priority systems can also be implemented at the storage yard. Although there is a number of possible versions that may be analyzed: (a) dedicated yard cranes serving high priority containers; (b) stacking high priority containers on "priority lots" with small stack height; and (c) storing high priority containers on chassis (wheeled operations), only (c) was simulated because it is the one that provides the maximum degree of service differentiation. This system, termed "Priority System II" (PS-II), has the following general characteristics:

(a) Containers on ship: high and low priority containers are randomly located on the ship, as in the base case.

(b) Gantry crane operations: high and low priority containers are unloaded from top of the hatch to bottom, as in the base case.

(c) Yard truck operations: yard truck operations are the same for both priorities, same as the base case.

(d) Gate operations (in and out): all external trucks receive the same service.

(e) External truck operations (gate-to-yard lot and yard lot-to-gate): external trucks have the same operational characteristics, as before.

(f) Yard operations: low priority containers are stacked on the yard, while high priority containers are stored on chassis. An important issue is determining the yard allocation[14] to be used in the simulations. Optimal yard allocation, as discussed in Chapter 4, is a function of the demand for each priority and their economic characteristics. However, lack of information about the economic characteristics for each priority level prevented the use of the formulations derived in Chapter 4. Thus, a simplified approach was used which consisted in using the yard allocation that approximately matches the corresponding demand.

As before, low priority lots are capable of storing two hundred and forty containers (10x6x4), while high priority lots store 80 containers (40x2). Table 4.0 shows the storage yard capacity for various combinations of high and low priority lots. In all runs, except 2000 containers/week with 50% HPC (which required 13 high priority lots and 11 low priority lots), 8 high priority lots and 16 low priority lots were used. The distribution of yard lots is shown in Figure 4.0.

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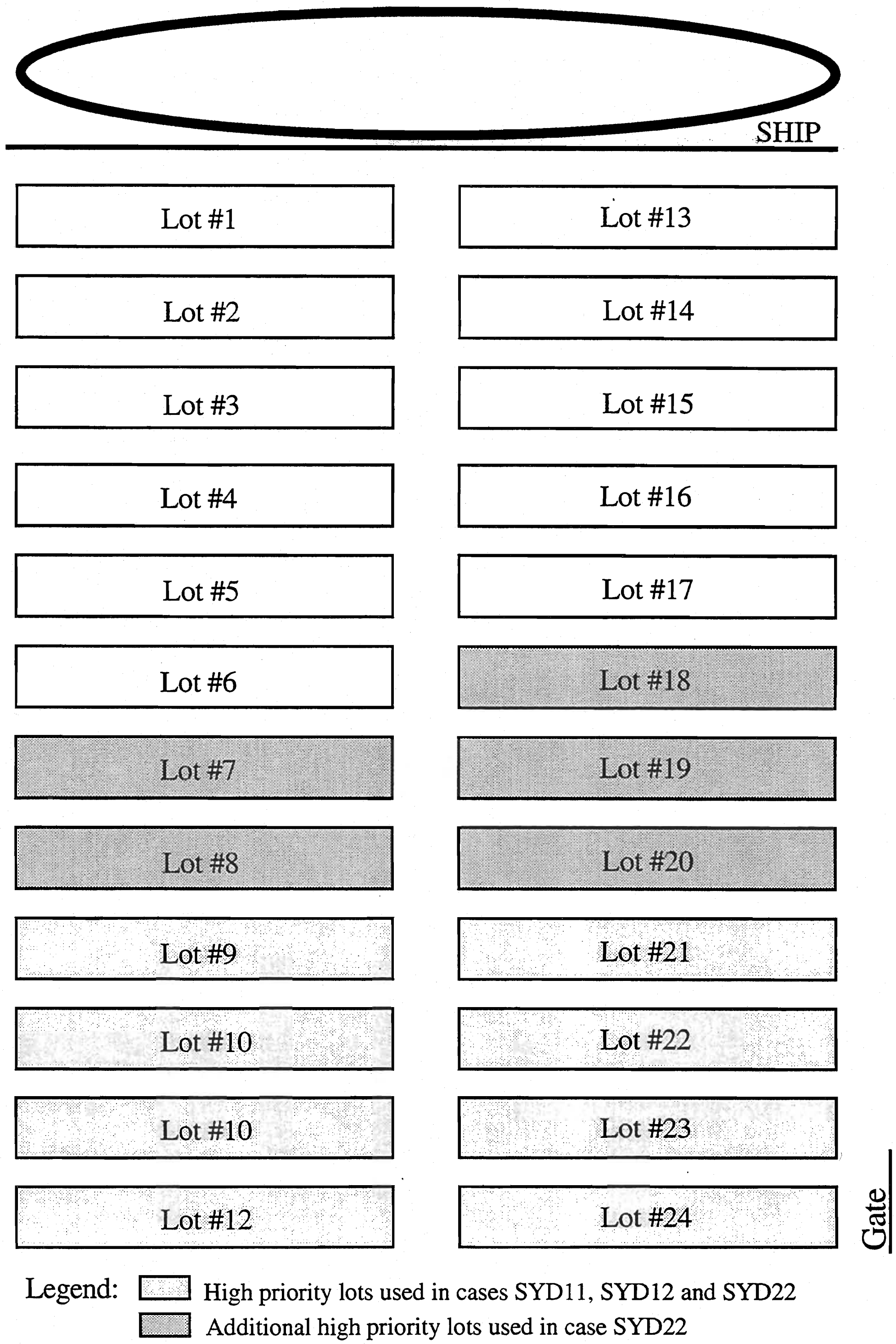
[14] The distribution of the available spaces between the different priorities.

Table 4.0: Storage yard capacity for different yard configurations				
High priority lots		Low priority lots		
Number of lots	Capacity	Number of lots	Capacity	Total capacity
0	0	24	5760	5760
2	160	22	5280	5440
4	320	20	4800	5120
6	480	18	4320	4800
8	640	16	3840	4480
10	800	14	3360	4160
12	960	12	2880	3840
13	1040	11	2640	3680
14	1120	10	2400	3520
16	1280	8	1920	3200
18	1440	6	1440	2880
20	1600	4	960	2560
22	1760	2	480	2240
24	1920	0	0	1920

Note: The shading indicates the yard allocations used.

Figure 4.0: Yard configurations used



MAIN RESULTS OF THE SIMULATION

As in the previous chapters, file name extentions were used to identify the output files. In general, the naming convention follows the principles outlined previously, the only difference being that the first two characters (SY) indicate priority at the storage yard.

Table 4.1 shows the file naming convention, the input files used and the numbers of figures displaying the results. Tables 4.2 to 4.5 show the summary of service and waiting times for the unloading and retrieval processes. Tables 4.6 and 4.7 show the mean slack times and reliabilities for high and low priority containers.

Table 4.1: File naming convention and input files

% of High priority containers	1,000 cont/week File: BADATA.DAT1	2,000 cont/week File: BADATA.DAT2
25% File: SHIPS.DAT1	SYD11	SYD12
50% File: SHIPS.DAT2	SYD21	SYD22

Table 4.2: Summary of service times (secs) -Unloading-

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	Average	138.11	250.06
	Std Dev	1.63	3.22
50% HPC, 1000 cont/week (SYD21)	Average	142.39	250.22
	Std Dev	1.57	3.57
25% HPC, 2000 cont/week (SYD12)	Average	136.28	259.44
	Std Dev	1.59	2.89
50% HPC, 2000 cont/week (SYD22)	Average	133.72	252.39
	Std Dev	0.93	2.65

Table 4.3: Summary of waiting times (secs) -Unloading-

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	Average	14326.50	14727.33
	Std Dev	648.42	291.88
50% HPC, 1000 cont/week (SYD21)	Average	14092.78	14689.39
	Std Dev	435.82	512.74
25% HPC, 2000 cont/week (SYD12)	Average	29381.06	29925.78
	Std Dev	713.51	608.05
50% HPC, 2000 cont/week (SYD22)	Average	28999.56	29490.72
	Std Dev	456.19	716.24

Table 4.4: Summary of service times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	Average	768.56	808.44
	Std Dev	15.25	7.16
50% HPC, 1000 cont/week (SYD21)	Average	765.89	808.67
	Std Dev	8.50	9.58
25% HPC, 2000 cont/week (SYD12)	Average	767.00	807.50
	Std Dev	9.20	5.62
50% HPC, 2000 cont/week (SYD22)	Average	775.67	816.11
	Std Dev	5.36	6.21

Table 4.5: Summary of waiting times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	Average	937.17	320.28
	Std Dev	274.30	15.43
50% HPC, 1000 cont/week (SYD21)	Average	7943.00	302.83
	Std Dev	520.12	9.64
25% HPC, 2000 cont/week (SYD12)	Average	2384.39	388.44
	Std Dev	464.07	46.21
50% HPC, 2000 cont/week (SYD22)	Average	18636.17	354.50
	Std Dev	919.84	23.63

Table 4.6: Mean slack times (secs)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	Average	14316.06	373854.22
	Std Dev	819.91	4619.79
50% HPC, 1000 cont/week (SYD21)	Average	14795.28	374536.00
	Std Dev	364.10	5168.98
25% HPC, 2000 cont/week (SYD12)	Average	-449.00	359010.17
	Std Dev	732.23	3096.80
50% HPC, 2000 cont/week (SYD22)	Average	6218.17	360053.00
	Std Dev	452.68	4154.15

Table 4.7: Reliabilities			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	Average	0.93	1.00
	Std Dev	0.01	0.00
50% HPC, 1000 cont/week (SYD21)	Average	0.94	1.00
	Std Dev	0.01	0.00
25% HPC, 2000 cont/week (SYD12)	Average	0.49	1.00
	Std Dev	0.02	0.00
50% HPC, 2000 cont/week (SYD22)	Average	0.63	1.00
	Std Dev	0.01	0.00

As can be seen in Table 4.2, wheeling high priority containers significantly reduces the service time at unloading. The reduction is, approximately, 110 seconds with respect to the base case. The service times at unloading for low priority containers are slightly smaller than the base case, which is a consequence of the proximity of low priority lots to the ship side (see Figure 4.0).

Waiting times at unloading, shown in Table 4.3, indicates a 10% reduction with respect to the base case, which is caused by the increased productivity of the yard trucks.[15] As expected, waiting times at unloading are approximately the same for both priorities.

Table 4.4 shows the service times at retrieval for both priorities. As can be seen, the service times corresponding to high priority containers experience a slight reduction, approximately 20 seconds, with respect to the base case. On the other hand, the service times for low priority containers increase by approximately the same amount, 20 seconds, due to the increased congestion on the priority lots.

The waiting times at retrieval, shown in Table 4.5, indicate that the waiting times for high priority containers experience a significant reduction with respect to the base case.

Tables 4.6 and 4.7 show mean slack times and reliabilities, respectively. As can be seen, mean slack times increase due to shorter service times at retrieval. The system reliability increases accordingly, though the increase is not as significant as the one generated by the implementation of hot hatches.

Arc elasticities of waiting times at unloading for high priority containers, shown in Table 4.8, indicate a slight increase with respect to the base case; while the arc elasticities for low priority containers exhibits a slight decrease wiht respect to the base case.

The coefficients of variation, shown in Table 4.9, indicate a reduction on the variability of waiting times from 0.045 and 0.036 in the base case to 0.029 and 0.025 in PS-II.

Table 4.8: Elasticities of waiting times -Unloading-

Case:	Priority 1	Priority 2
25% HPC	1.033	1.021
50% HPC	1.038	1.005
Average for all cases	1.036	1.013

Table 4.9: Coefficients of variation -Unloading-

Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	0.045	0.020
50% HPC, 1000 cont/week (SYD21)	0.031	0.035
25% HPC, 2000 cont/week (SYD12)	0.024	0.020
50% HPC, 2000 cont/week (SYD22)	0.016	0.024
Average for all cases	0.029	0.025

[15] Yard trucks do not have to wait for yard cranes to be unloaded

Arc elasticities of waiting times at retrieval with respect to total demand are shown in Table 4.10. As a consequence of the ease of retrieving high priority containers, the waiting times at retrieval become more inelastic to total demand. In the base case, the arc elasticities were 1.638 and 1.496; dropping to 1.307 and 1.207 for 25% in PS-II.

On the other hand, low priority containers experience the opposite effect, an increase in the sensitivity of waiting times to total demand. In the base case, the corresponding elasticities were 0.277 and 0.129. This increase in the elasticity of waiting times is the consequence of the extra number of moves needed to retrieve low priority containers.

Table 4.11 shows the coefficients of variation for waiting times at retrieval. As can be seen, the coefficient of variations increased with respect to the base case, though the standard deviations of waiting times (shown in Table 4.5) are smaller than in the base case.

Table 4.10: Elasticities of waiting times -Retrieval-

Case:	Priority 1	Priority 2
25% HPC	1.307	0.289
50% HPC	1.207	0.236
Average for all cases	1.257	0.262

Table 4.11: Coefficients of variation -Retrieval-

Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	0.293	0.048
50% HPC, 1000 cont/week (SYD21)	0.065	0.032
25% HPC, 2000 cont/week (SYD12)	0.195	0.119
50% HPC, 2000 cont/week (SYD22)	0.049	0.067
Average for all cases	0.151	0.066

Table 4.12 shows the labour and equipment costs estimated by ECON. Table 4.13 presents the estimates of unit land costs for the different priorities. As can be seen in Table 4.14, the total unit costs for high priority containers experience a reduction that amount to $80 per container, approximately.

Low priority containers also benefit from the increase productivity of yard trucks. The corresponding total unit costs experience a reduction of approximately $20 per container.

Table 4.12: Labour and equipment unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	Average	152.583	214.483
	Standard Dev	3.281	9.036
50% HPC, 1000 cont/week (SYD21)	Average	153.350	201.106
	Standard Dev	1.661	5.294
25% HPC, 2000 cont/week (SYD12)	Average	156.317	213.033
	Standard Dev	2.613	6.462
50% HPC, 2000 cont/week (SYD22)	Average	153.894	202.439
	Standard Dev	1.059	6.725

As shown in Table 4.13, storing high priority containers on chassis increase the corresponding unit land cost from $0.53 to $1.45. Although it is a significant increase, the relatively short dwelling times keep the unit land cost below the corresponding values to low priority containers, $7.21.

Table 4.13: Input data and resulting unit land costs			
Parameter:		Priority 1	Priority 2
Average dwelling time (days)		0.333	4.500
Area required (mt^2/container)	Height: 1	79.430	n.a.
	Height: 2	n.a.	43.660
	Height: 3	n.a.	29.260
	Height: 4	n.a.	21.830
Land cost ($/mt^2/year)		20.000	20.000
Unit land cost ($/container)		1.449	7.215

Table 4.14: Total unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (SYD11)	Average	154.032	221.698
	Standard Dev	3.281	9.036
50% HPC, 1000 cont/week (SYD21)	Average	154.799	208.321
	Standard Dev	1.661	5.294
25% HPC, 2000 cont/week (SYD12)	Average	157.766	220.248
	Standard Dev	2.613	6.462
50% HPC, 2000 cont/week (SYD22)	Average	155.343	209.654
	Standard Dev	1.059	6.725

CHAPTER V. PRIORITIES AT THE GATES (PS-III)

DESCRIPTION OF THE SYSTEM

Priority system III (PS-III) represents the operational scheme in which service differentiation occurs only at the yard gates. In such a system, the external trucks arriving to retrieve high priority containers receive preferential treatment at the gate. The system that is examined here involves the use of electronic tags for automatic equipment identification (AEI). The service parameters corresponding to such systems have been provided by AMTECH, the leading manufacturer of electronic tags for intermodal equipment. According to AMTECH's estimates, processing time at the gates can be cut down from an average of 220 seconds to an average of 17.5 seconds, with a range between 15 seconds and 25 seconds.

In addition to the use of AEI technology, it is assumed that the related paperwork is reduced, or even eliminated, by using Electronic Data Interchange (EDI). Request and transmittal of clearances is performed by EDI means. [16]

In general terms, PS-III has the following characteristics:

(a) Containers on ship: high and low priority containers are randomly located on the ship.

(b) Gantry crane operations: high and low priority containers are unloaded from top of the hatch to bottom.

(c) Yard truck operations: yard truck operations are the same for both priorities.

(d) Gate operations (in and out): external trucks retrieving high priority containers are processed at the gates using AEI devices. While external trucks retrieving low priority containers receive the same treatment as the base case. Table 5.0 shows the parameters and statistical distributions used.

Table 5.0: Parameters used in the empirical service time distributions (secs)

Service Process:	Average	Standard Deviation	Lower Bound	Upper Bound	Distribution
Gate_In_Base	220.13	43.08	95.00	393.00	Truncated normal
Gate_In_Prior	17.50	2.89	15.00	25.00	Uniform
Gate_Out_Base	415.50	227.85	197.00	1043.00	Truncated normal
Gate_Out_Prior	17.50	2.89	15.00	25.00	Uniform

[16] A selected number of terminals have such systems in operation. See Chapter 5 for a review of the state of the practice of information technology on U.S. ports.

(e) External truck operations (gate-to-yard lot and yard lot-to-gate): external trucks have the same operational characteristics for both priorities.

(f) Yard operations: all containers are stacked on the yard, regardless of priority level.

MAIN RESULTS OF THE SIMULATION

As in the previous chapters, file name extensions were used to distinguish the different runs. The file name extensions follow the principles described previously. In this case, the first two characteres identify the operational policy (TG for priority operation at Terminal Gates).

Table 5.1 shows the file name extensions and the numbers of the figures displaying the results. Tables 5.2 to 5.5 show the results corresponding to service and wating times for the unloading and retrieval process. Tables 5.6 and 5.7 show mean slack times and reliabilities.

Table 5.1: File naming convention and input files

% of High priority containers	1,000 cont/week File: BADATA.DAT1	2,000 cont/week File: BADATA.DAT2
25% File: SHIPS.DAT1	TGD11	TGD12
50% File: SHIPS.DAT2	TGD21	TGD22

Table 5.2: Summary of service times (secs) -Unloading-

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	Average	261.00	260.56
	Std Dev	5.27	3.62
50% HPC, 1000 cont/week (TGD21)	Average	260.78	260.72
	Std Dev	4.84	4.83
25% HPC, 2000 cont/week (TGD12)	Average	267.06	266.17
	Std Dev	5.33	2.63
50% HPC, 2000 cont/week (TGD22)	Average	266.83	264.33
	Std Dev	2.77	2.79

Table 5.3: Summary of waiting times (secs) -Unloading-

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	Average	15815.67	15780.72
	Std Dev	1031.82	407.85
50% HPC, 1000 cont/week (TGD21)	Average	16233.33	16090.22
	Std Dev	1127.28	946.52
25% HPC, 2000 cont/week (TGD12)	Average	31817.22	31977.72
	Std Dev	1043.96	1136.21
50% HPC, 2000 cont/week (TGD22)	Average	31931.11	31825.78
	Std Dev	915.85	541.43

Table 5.4: Summary of service times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	Average	123.78	789.83
	Std Dev	3.44	8.13
50% HPC, 1000 cont/week (TGD21)	Average	125.72	788.78
	Std Dev	3.43	7.39
25% HPC, 2000 cont/week (TGD12)	Average	124.61	786.33
	Std Dev	3.48	7.48
50% HPC, 2000 cont/week (TGD22)	Average	125.28	790.06
	Std Dev	3.46	6.14

Table 5.5: Summary of waiting times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	Average	10517.17	301.67
	Std Dev	978.67	40.01
50% HPC, 1000 cont/week (TGD21)	Average	18158.39	269.61
	Std Dev	1420.30	9.35
25% HPC, 2000 cont/week (TGD12)	Average	34030.72	337.00
	Std Dev	2514.39	33.53
50% HPC, 2000 cont/week (TGD22)	Average	49708.00	288.00
	Std Dev	2678.77	7.90

Table 5.6: Mean slack times (secs)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	Average	12971.00	373029.06
	Std Dev	887.35	4725.94
50% HPC, 1000 cont/week (TGD21)	Average	12547.50	373785.67
	Std Dev	894.85	4876.44
25% HPC, 2000 cont/week (TGD12)	Average	-3136.28	357103.22
	Std Dev	958.47	2631.61
50% HPC, 2000 cont/week (TGD22)	Average	-3233.56	357450.00
	Std Dev	876.76	4925.01

Table 5.7: Reliabilities			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	Average	0.89	1.00
	Std Dev	0.02	0.00
50% HPC, 1000 cont/week (TGD21)	Average	0.88	1.00
	Std Dev	0.03	0.00
25% HPC, 2000 cont/week (TGD12)	Average	0.44	1.00
	Std Dev	0.02	0.00
50% HPC, 2000 cont/week (TGD22)	Average	0.43	1.00
	Std Dev	0.02	0.00

As can be seen in Table 5.2, the service times at unloading are approximately the same for both priorities. As expected, the service times at unloading are approximately equal to the base case (see Table 2.2). Since the implementation of priority operations at the gate does not affect the unloading process, the results described above are consistent.

The waiting times at unloading (see Table 5.3) show the same pattern as the service times at unloading. Low and high priority containers experience similar waiting times that , as expected, are similar to those in the base case.

Service times at retrieval (shown in Table 5.4) indicate a significant difference between high and low priority containers. The former have service times in the vicinity of 125 seconds, while the service times for the latter are approximately 785 seconds.

The waiting times at retrieval, shown in Table 5.5, indicate that there is no significant difference with respect to the base case. Similarly, mean slack times and reliabilities, shown in Table 5.6 and 5.7, show no significant difference with respect to the base case.

Table 5.8 shows the arc elasticities of waiting times with respect to total demand. As can be seen, the waiting times have unit elasticity, meaning that the waiting times will increase in the same proportion as the total demand. Table 5.9 shows the corresponding coefficients of variation, which are approximately the same as in the base case.

Table 5.8: Elasticities of waiting times -Unloading-

Case:	Priority 1	Priority 2
25% HPC	1.008	1.017
50% HPC	0.978	0.985
Average for all cases	0.993	1.001

Table 5.9: Coefficients of variation -Unloading-

Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	0.065	0.026
50% HPC, 1000 cont/week (TGD21)	0.069	0.059
25% HPC, 2000 cont/week (TGD12)	0.033	0.036
50% HPC, 2000 cont/week (TGD22)	0.029	0.017
Average for all cases	0.049	0.034

Table 5.10 shows the arc elasticities of waiting times at retrieval. As can be seen, the waiting times are elastic with respect to the total demand, though less elastic than in the base case.

The coefficients of variation (see Table 5.11) show no significant difference with respect to the base case.

Table 5.10: Elasticities of waiting times -Retrieval-		
Case:	Priority 1	Priority 2
25% HPC	1.583	0.166
50% HPC	1.395	0.099
Average for all cases	1.489	0.132

Table 5.11: Coefficients of variation -Retrieval-		
Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	0.093	0.133
50% HPC, 1000 cont/week (TGD21)	0.078	0.035
25% HPC, 2000 cont/week (TGD12)	0.074	0.099
50% HPC, 2000 cont/week (TGD22)	0.054	0.027
Average for all cases	0.075	0.074

Table 5.12 shows the labour and equipment unit costs. As can be seen, significant savings in labour costs can be obtained by using electronic tags. Table 5.13 shows the unit land costs and Table 5.14 shows the unit fixed costs associated to the initial investment in Automatic Equipment Identification (AEI) technology. It was assumed that all lanes, in and out, will be equipped with AEI readers.

Table 5.12: Labour and equipment unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	Average	188.444	237.239
	Standard Dev	11.343	10.206
50% HPC, 1000 cont/week (TGD21)	Average	189.444	237.617
	Standard Dev	10.311	10.034
25% HPC, 2000 cont/week (TGD12)	Average	187.817	236.939
	Standard Dev	8.498	8.589
50% HPC, 2000 cont/week (TGD22)	Average	186.900	235.739
	Standard Dev	7.629	9.350

Table 5.13: Input data and resulting unit land costs			
Parameter:		Priority 1	Priority 2
Average dwelling time (days)		0.333	4.500
Area required (mt^2/container)	Height: 2	43.660	43.660
	Height: 3	29.260	29.260
	Height: 4	21.830	21.830
Land cost ($/mt^2/year)		20.000	20.000
Unit land cost ($/container)		0.534	7.215

Table 5.14: Input data and resulting unit costs associated to AEI equipment					
			Electronic tags:		
Parameter:		AEI readers	Truck	Container	Total
Initial investment ($)		208,000.00	40.00	20.00	
Lifespan (years)		8	8	8	
Interest rate (%)		8%	8%	8%	
Equivalent annuity ($/year)		36,195.32	6.96	3.48	
Number of moves per year		n.a.	35.00	8.33	
Unit cost ($/move) for electronic tags		n.a.	0.20	0.42	
Unit cost for AEI readers	Moves/year: 13,000	2.78	0.20	0.42	3.40
	Moves/year: 26,000	1.39	0.20	0.42	2.01
	Moves/year: 52,000	0.70	0.20	0.42	1.31

Table 5.15: Total unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (TGD11)	Average	191.834	237.239
	Standard Dev	11.343	10.206
50% HPC, 1000 cont/week (TGD21)	Average	191.444	237.617
	Standard Dev	10.311	10.034
25% HPC, 2000 cont/week (TGD12)	Average	189.817	236.939
	Standard Dev	8.498	8.589
50% HPC, 2000 cont/week (TGD22)	Average	188.210	235.739
	Standard Dev	7.629	9.350

The total unit costs for high priority containers drops to approximately $188/container, while the corresponding total unit cost for low priority containers is in the vicinity of $236/container.

CHAPTER VI. PRIORITY SYSTEM IV (PS-IV)

DESCRIPTION OF THE SYSTEM

Priority system IV is a combination of PS-I (hot hatches) and PS-II (wheeled operations). In such a system, high priority containers are located on the hot hatches from where they are sent to storage on chassis.

The general characteristics of PS-IV are:

(a) Containers on ship: high priority containers are located on hot hatches.

(b) Gantry crane operations: high and low priority containers are unloaded from top of hatch to bottom.

(c) Yard truck operations: yard truck operations are the same for both priorities.

(d) Gate operations (in and out): all external trucks receive the same service.

(e) External truck operations (gate-to-yard lot and yard lot-to-gate): external trucks have the same operational characteristics, as before.

(f) Yard operations: low priority containers are stacked on the yard, while high priority containers are stored on chassis. The yard allocation follows the rules described in Chapter 8.

MAIN RESULTS OF THE SIMULATION

Table 6.1 shows the file name extensions used to distinguish the different runs and the numbers of figures displaying the main results. The characters IV identify the runs as belonging to priority system IV (PS-IV). Tables 6.2 to 6.5 presents the results corresponding to service and waiting times for the unloading and retrieval processes. Tables 6.6 and 6.7 shows the corresponding mean slack times and reliabilities.

Table 6.1: File naming convention and input files

% of High priority containers	1,000 cont/week File: BADATA.DAT1	2,000 cont/week File: BADATA.DAT2
25% File: SHIPS.DAT1	IVD11	IVD12
50% File: SHIPS.DAT2	IVD21	IVD22

Table 6.2: Summary of service times (secs) -Unloading-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	Average	131.11	259.67
	Std Dev	1.37	3.87
50% HPC, 1000 cont/week (IVD21)	Average	138.67	262.28
	Std Dev	1.05	5.16
25% HPC, 2000 cont/week (IVD12)	Average	130.72	264.39
	Std Dev	1.15	2.41
50% HPC, 2000 cont/week (IVD22)	Average	131.33	260.00
	Std Dev	0.88	2.73

Table 6.3: Summary of waiting times (secs) -Unloading-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	Average	10412.56	15813.28
	Std Dev	232.43	207.38
50% HPC, 1000 cont/week (IVD21)	Average	12087.72	16474.78
	Std Dev	196.96	216.16
25% HPC, 2000 cont/week (IVD12)	Average	21791.72	32258.94
	Std Dev	769.42	574.75
50% HPC, 2000 cont/week (IVD22)	Average	24998.22	33286.33
	Std Dev	361.50	627.68

Table 6.4: Summary of service times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	Average	762.28	807.06
	Std Dev	10.81	7.31
50% HPC, 1000 cont/week (IVD21)	Average	765.50	806.67
	Std Dev	6.59	7.52
25% HPC, 2000 cont/week (IVD12)	Average	764.17	808.89
	Std Dev	8.60	8.11
50% HPC, 2000 cont/week (IVD22)	Average	773.11	815.89
	Std Dev	4.77	5.69

Table 6.5: Summary of waiting times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	Average	649.89	348.61
	Std Dev	157.97	27.40
50% HPC, 1000 cont/week (IVD21)	Average	7918.28	310.50
	Std Dev	325.24	10.49
25% HPC, 2000 cont/week (IVD12)	Average	5433.94	386.78
	Std Dev	412.02	21.97
50% HPC, 2000 cont/week (IVD22)	Average	18866.61	363.17
	Std Dev	330.81	26.22

Table 6.6: Mean slack times (secs)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	Average	18286.06	373797.78
	Std Dev	373.14	4872.97
50% HPC, 1000 cont/week (IVD21)	Average	16772.11	372696.17
	Std Dev	356.61	3723.28
25% HPC, 2000 cont/week (IVD12)	Average	7104.11	356933.22
	Std Dev	823.58	3366.33
50% HPC, 2000 cont/week (IVD22)	Average	10281.61	354825.44
	Std Dev	356.58	4273.23

Table 6.7: Reliabilities			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	Average	0.99	1.00
	Std Dev	0.00	0.00
50% HPC, 1000 cont/week (IVD21)	Average	0.96	1.00
	Std Dev	0.00	0.00
25% HPC, 2000 cont/week (IVD12)	Average	0.70	1.00
	Std Dev	0.02	0.00
50% HPC, 2000 cont/week (IVD22)	Average	0.70	1.00
	Std Dev	0.01	0.00

The service times at unloading, shown in Table 6.2, indicate a significant reduction with respect to the base case. Service times in PS-IV are approximately 50% of the service times in the base case.

Table 6.3 shows the waiting times at unloading. As can be seen, the waiting times corresponding to high priority containers are, on average, 70% of the ones corresponding to low priority containers.

Table 6.4 shows the tradeoff between the service times corresponding to high and low priority containers. The service time for high priority containers decreases by approximately 20-25 seconds, while the service time for low priority containers increases by the same amount.

Waiting times at retrieval for high priority containers (see Table 6.5) experience a significant reduction with respect to the base case. The waiting times for low priority containers increase by an amount of, approximately, 50 to 80 seconds, as a consequence of the extra handling.

The implementation of PS-IV causes a significant increment in mean slack times for high priority containers, as a consequence of which system reliability also improves. Mean slack times and system reliability are shown in Tables 6.6 and 6.7.

Waiting times at unloading are slighly more elastic to total demand than in the base case. The average arc elasticity in the base case was 1.020, while for PS-IV increased to 1.052, as shown in Table 6.8.

The variability of waiting times decreased with the implementation of PS-IV. In the base case, the coefficients of variation were in the range of 0.041 to 0.048; while in PS-IV the range is from 0.016 to 0.035, as shown in Table 6.9.

Table 6.8: Elasticities of waiting times -Unloading-

Case:	Priority 1	Priority 2
25% HPC	1.060	1.026
50% HPC	1.044	1.014
Average for all cases	1.052	1.020

Table 6.9: Coefficients of variation -Unloading-

Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	0.022	0.013
50% HPC, 1000 cont/week (IVD21)	0.016	0.013
25% HPC, 2000 cont/week (IVD12)	0.035	0.018
50% HPC, 2000 cont/week (IVD22)	0.014	0.019
Average for all cases	0.022	0.016

Tables 6.10 and 6.11 show the elasticites of waiting times at retrieval and the coefficients of variation, respectively. As can be seen, waiting times at retrieval for high priority containers are elastic to total demand. The percentage of high priority containers seems to affect the elasticity of waiting times; the lower this percentage is, the more elastic the waiting times are.

On the other hand, coefficients of variation for high priority contaiers are higher than the base case (0.094 vs. 0.076). Low priority containers have, approximately, the same variability.

Table 6.10: Elasticities of waiting times -Retrieval-

Case:	Priority 1	Priority 2
25% HPC	2.359	0.156
50% HPC	1.226	0.235
Average for all cases	1.793	0.195

Table 6.11: Coefficients of variation -Retrieval-

Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	0.243	0.079
50% HPC, 1000 cont/week (IVD21)	0.041	0.034
25% HPC, 2000 cont/week (IVD12)	0.076	0.057
50% HPC, 2000 cont/week (IVD22)	0.018	0.072
Average for all cases	0.094	0.060

Table 6.12 shows the equipment and labour costs estimated by ECON. As before, these estimates do not include land costs; consequently, they are corrected by adding the unit land costs shown in Table 6.13.

The total unit costs for high priority containers, shown in Table 6.14, drop significantly with respect to the base case. This drop amounts to, approximately, $80 per container. On the other hand, as in PS-II, low priority containers also benefit from the increased productivity of yard trucks and experience a reduction in total unit costs amounting to $30 per container, approximately.

Table 6.12: Labour and equipment unit cost ($/container)

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	Average	150.872	210.089
	Standard Dev	1.878	8.233
50% HPC, 1000 cont/week (IVD21)	Average	152.933	201.589
	Standard Dev	1.150	6.385
25% HPC, 2000 cont/week (IVD12)	Average	155.456	208.900
	Standard Dev	1.204	9.010
50% HPC, 2000 cont/week (IVD22)	Average	153.744	195.239
	Standard Dev	1.017	5.267

Table 6.13: Input data and resulting unit land costs

Parameter:		Priority 1	Priority 2
Average dwelling time (days)		0.333	4.500
Area required (mt^2/container)	Height: 1	79.430	n.a.
	Height: 2	n.a.	43.660
	Height: 3	n.a.	29.260
	Height: 4	n.a.	21.830
Land cost ($/mt^2/year)		20.000	20.000
Unit land cost ($/container)		1.449	7.215

Table 6.14: Total unit cost ($/container)

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (IVD11)	Average	152.321	217.304
	Standard Dev	1.878	8.233
50% HPC, 1000 cont/week (IVD21)	Average	154.382	208.804
	Standard Dev	1.150	6.385
25% HPC, 2000 cont/week (IVD12)	Average	156.905	216.115
	Standard Dev	1.204	9.010
50% HPC, 2000 cont/week (IVD22)	Average	155.193	202.454
	Standard Dev	1.017	5.267

CHAPTER VII. PRIORITY SYSTEM V (PS-V)

DESCRIPTION OF THE SYSTEM

In priority system V (PS-V) service diferentiation is implemented at all stages. In such a system, high priority containers are located on hot hatches, from where they are sent to storage on chassis. At the gates, the external trucks arriving to retrieve high priority containers are processed using Automatic Equipment Identification (AEI).

In summary, the characteristics of PS-V are:

(a) Containers on ship: high priority containers are located on hot hatches.

(b) Gantry crane operations: high and low priority containers are unloaded from top of the hatch to bottom.

(c) Yard truck operations: yard truck operations are the same for both priorities.

(d) Gate operations (in and out): external trucks retrieving high priority containers are processed using AEI.

(e) External truck operations (gate-to-yard and yard-to-gate): external trucks have the same operational characteristics.

(f) Yard operations: low priority containers are stacked on the yard, while high priority containers are stored on chassis. The yard allocation used in the simulations follows the same rules described in Chapter 8.

MAIN RESULTS OF THE SIMULATION

Table 7.1 shows the file naming convention and the number of the figures displaying the final results. The characters VD refer to priority system V and dynamic yard crane allocation.

Tables 7.2 to 7.5 show service and waiting times for the unloading and retrieval of containers. Tables 7.6 and 7.7 show mean slack time and reliabilites, while Tables 7.8 and 7.9 show the elasticities of waiting times to total demand.

Table 7.1: File naming convention and input files

% of High priority containers	1,000 cont/week File: BADATA.DAT1	2,000 cont/week File: BADATA.DAT2
25% File: SHIPS.DAT1	VD11	VD12
50% File: SHIPS.DAT2	VD21	VD22

Table 7.2: Summary of service times (secs) -Unloading-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	Average	131.17	259.06
	Std Dev	2.03	3.17
50% HPC, 1000 cont/week (VD21)	Average	138.67	263.67
	Std Dev	1.41	4.88
25% HPC, 2000 cont/week (VD12)	Average	129.72	265.00
	Std Dev	1.15	3.53
50% HPC, 2000 cont/week (VD22)	Average	129.94	259.78
	Std Dev	0.97	2.62

Table 7.3: Summary of waiting times (secs) -Unloading-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	Average	10435.94	15918.61
	Std Dev	367.92	233.19
50% HPC, 1000 cont/week (VD21)	Average	12301.33	16468.44
	Std Dev	493.23	288.70
25% HPC, 2000 cont/week (VD12)	Average	21267.56	32292.00
	Std Dev	412.19	466.82
50% HPC, 2000 cont/week (VD22)	Average	25362.94	33283.56
	Std Dev	1223.36	420.32

Table 7.4: Summary of service times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	Average	98.22	805.94
	Std Dev	0.71	8.22
50% HPC, 1000 cont/week (VD21)	Average	99.94	803.83
	Std Dev	0.52	11.78
25% HPC, 2000 cont/week (VD12)	Average	101.33	807.83
	Std Dev	0.47	8.25
50% HPC, 2000 cont/week (VD22)	Average	111.28	813.89
	Std Dev	0.45	5.69

Table 7.5: Summary of waiting times (secs) -Retrieval-			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	Average	0.00	333.78
	Std Dev	0.00	23.20
50% HPC, 1000 cont/week (VD21)	Average	0.00	307.78
	Std Dev	0.00	14.54
25% HPC, 2000 cont/week (VD12)	Average	0.00	386.78
	Std Dev	0.00	19.25
50% HPC, 2000 cont/week (VD22)	Average	0.06	361.33
	Std Dev	0.23	29.32

Table 7.6: Mean slack times (secs)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	Average	18334.67	373938.72
	Std Dev	483.31	4194.80
50% HPC, 1000 cont/week (VD21)	Average	16337.44	373094.39
	Std Dev	553.52	5813.03
25% HPC, 2000 cont/week (VD12)	Average	7477.67	356207.61
	Std Dev	475.41	2951.39
50% HPC, 2000 cont/week (VD22)	Average	3389.50	355053.00
	Std Dev	1213.54	3512.26

Table 7.7: Reliabilities			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	Average	0.99	1.00
	Std Dev	0.00	0.00
50% HPC, 1000 cont/week (VD21)	Average	0.95	1.00
	Std Dev	0.01	0.00
25% HPC, 2000 cont/week (VD12)	Average	0.71	1.00
	Std Dev	0.01	0.00
50% HPC, 2000 cont/week (VD22)	Average	0.57	1.00
	Std Dev	0.03	0.00

As can be seen in Table 7.2, the implementation of PS-V produces service times at unloading similar to those of PS-IV which are, approximately, 50% of the service time corresponding to the base case. From Table 7.3, it can be seen that waiting times at unloading remain at the same level, as in PS-IV.

The biggest impact of PS-V is on the service and waiting times corresponding to the retrieval process. As can be seen in Tables 7.4 and 7.5, service times at retrieval for high priority containers are reduced significantly, a consequence of the interaction effects among the service differentiated processes at each stage. Waiting times at retrieval for high priority containers practically disappear.

Having such an improvement on the performance measures associated to the retrieval process increases the mean slack times and, consequently, the system reliability. As can be seen in Tables 7.6 and 7.7, when the total demand is 1,000 containers/week or less, the system reliability is above 90%. Reliability deteriorates rather quickly as the demand increases. In case VD12 (i.e., 25% HPC and 2,000 containers/week), it drops to 71%; while in case VD22 (i.e., 50% HPC and 2,000 containers/week), the drop is even sharper, to 57%.

As can be seen in Table 7.8, arc elasticities at unloading for both high and low priority containers experience a slight reduction with respect to the base case. Similarly, the coefficients of variation also decrease with respect to the base case, which is a consequence of the service differentiation.

Table 7.8: Elasticities of waiting times -Unloading-		
Case:	Priority 1	Priority 2
25% HPC	1.025	1.019
50% HPC	1.040	1.014
Average for all cases	1.033	1.016

Table 7.9: Coefficients of variation -Unloading-		
Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	0.035	0.015
50% HPC, 1000 cont/week (VD21)	0.040	0.018
25% HPC, 2000 cont/week (VD12)	0.019	0.014
50% HPC, 2000 cont/week (VD22)	0.048	0.013
Average for all cases	0.036	0.015

As can be seen in Table 7.10, arc elasticities at retrieval for high priority containers are, for the most part, indeterminate; which is a consequences of having zero waiting times at retrieval. On the other hand, arc elasticities for low priority containers experience a slight reduction with respect to the base case.

The coefficients of variation, shown in Table 7.11, remain in the same range as in the base case.

Table 7.10: Elasticities of waiting times -Retrieval-		
Case:	Priority 1	Priority 2
25% HPC	n/a	0.221
50% HPC	3.000	0.240
Average for all cases	3.000	0.230

Table 7.11: Coefficients of variation -Retrieval-		
Case:	Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	n/a	0.070
50% HPC, 1000 cont/week (VD21)	n/a	0.047
25% HPC, 2000 cont/week (VD12)	n/a	0.050
50% HPC, 2000 cont/week (VD22)	4.123	0.081
Average for all cases	4.123	0.062

Table 7.12 shows the labour and equipment unit costs estimated by ECON. As can be seen, equipment and labour costs drop significantly, a consequence of having less labour

intensive operations at the storage yard and the gates. As in system PS-IV, discussed in Chapter 10, low priority containers also experience a reduction in labour and equipment costs.

Tables 7.13 and 7.14 shows the unit fixed costs corresponding to land costs and the initial investment in AEI technology respectively. As explained in the previous chapters, ECON does not consider these items in its calculations of operating costs. Table 7.15 shows the total unit costs for the different scenarios.

Table 7.12: Labour and equipment unit cost ($/container)

Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	Average	98.683	211.494
	Standard Dev	2.482	8.424
50% HPC, 1000 cont/week (VD21)	Average	99.022	202.772
	Standard Dev	1.521	8.209
25% HPC, 2000 cont/week (VD12)	Average	100.267	211.828
	Standard Dev	1.152	7.778
50% HPC, 2000 cont/week (VD22)	Average	99.728	195.650
	Standard Dev	0.865	6.453

Table 7.13: Input data and resulting unit land costs

Parameter:		Priority 1	Priority 2
Average dwelling time (days)		0.333	4.500
Area required (mt^2/container)	Height: 1	79.430	n.a.
	Height: 2	n.a.	43.660
	Height: 3	n.a.	29.260
	Height: 4	n.a.	21.830
Land cost ($/mt^2/year)		20.000	20.000
Unit land cost ($/container)		1.449	7.215

Table 7.14: Input data and resulting unit costs associated to AEI equipment

			Electronic tags:		
Parameter:		AEI readers	Truck	Container	Total
Initial investment ($)		208,000.00	40.00	20.00	
Lifespan (years)		8	8	8	
Interest rate (%)		8%	8%	8%	
Equivalent annuity ($/year)		36,195.32	6.96	3.48	
Number of moves per year		n.a.	35.00	8.33	
Unit cost ($/move) for electronic tags		n.a.	0.20	0.42	
Unit cost for AEI readers	Moves/year: 13,000	2.78	0.20	0.42	3.40
	Moves/year: 26,000	1.39	0.20	0.42	2.01
	Moves/year: 52,000	0.70	0.20	0.42	1.31

Table 7.15: Total unit cost ($/container)			
Case:		Priority 1	Priority 2
25% HPC, 1000 cont/week (VD11)	Average	103.522	218.704
	Standard Dev	2.482	8.424
50% HPC, 1000 cont/week (VD21)	Average	102.472	209.982
	Standard Dev	1.521	8.209
25% HPC, 2000 cont/week (VD12)	Average	103.717	219.038
	Standard Dev	1.152	7.778
50% HPC, 2000 cont/week (VD22)	Average	102.488	202.860
	Standard Dev	0.865	6.453

The estimates shown in Table 7.15 indicate that the total unit costs (an indication of the amount of resources consumed) is less than the total unit cost associated to the previous systems.

CHAPTER VIII. SUMMARY OF RESULTS AND CONCLUSIONS

This chapter focuses on summarizing and comparing the results corresponding to the different test cases. To facilitate the analysis and interpretation of results, the performance measures presented in the previous chapters were normalized, dividing them by the corresponding maximum value. It was also decided to use the complement of "System reliability" i.e., "Probability of non-compliance," instead of "System reliability," in order to have decreasing monotonic preferences in all the decision variables, i.e., the lower the more preferred the alternative is. The results are presented, case by case, in Figures 8.1 to 8.8, which have the following legend:

S_un_p1 (p2): Service time at unloading for priority 1 (2)
W_un_p1 (p2): Waiting time at unloading for priority 1 (2)
S_re_p1 (p2): Service time at retrieval for priority 1 (2)
W_re_p1 (p2): Waiting time at retrieval for priority 1 (2)
F1' (F2'): Probability of non compliance for priority 1 (2)
Cost_p1 (p2): Total unit cost for priority 1 (2)

The results shown in Figures 8.1 to 8.4, corresponding to high priority containers, reveals some general characteristics:

1. The implementation of priority systems, as expected, impact most significantly the performance measures associated to high priority containers. In some cases, these performance measures drop to less than 10% of the values corresponding to the base case. For instance, waiting times at retrieval (W_re_p1) for priority system IV (PS-IV), shown in Figure 8.1, dropped to 6% of the base case value.

2. Overall, the systems that articulate service differentiation at various stages,[17] i.e., PS-IV and PS-V, produced the largest impact on the performance of high priority containers, by modifying several performance measures at the time. This seems to suggest the existence of strong interaction effects among the different service processes.

3. On the other hand, the priority systems in which service differentiation is implemented at only one stage, [18] i.e., "Hot hatch," "Priority at the storage yard" and "Priority at the gates," tend to have a more narrower impact on the performance measures. At most, two performance

[17] From now on, these systems will be referred to as "Articulated."
[18] From now on, these systems will be referred to as "Single-stage."

measures are significantly modified each time. The impact of the implementation of each of the single-stage systems can be summarized as follows:

Hot hatch: It affects most significantly waiting times at unloading and probability of non-compliance. The former drops to 74%-86% of the base case values, and the latter to 14%-63% of the base case values.

Priority at the storage yard: It affects waiting times at retrieval and service time at unloading. Waiting time at retrieval drops to 9%-34% of the base case values, while service time at unloading becomes, approximately, 50% of the base case value.

Priority at the gates: It is the single most important factor in reducing service time at retrieval, which becomes 16% of the base case value. An unfortunate consequence of the increased efficiency at the gates [19] is that the probability of non-compliance increases. This phenomenon, explained and analyzed in Chapter V, stresses the importance of articulating service differentiation at various stages.

4. The performance measures associated with high priority containers tend to deteriorate as the number of incoming high priority containers increases, which is due to the increased workload at the servers handling high priority containers.

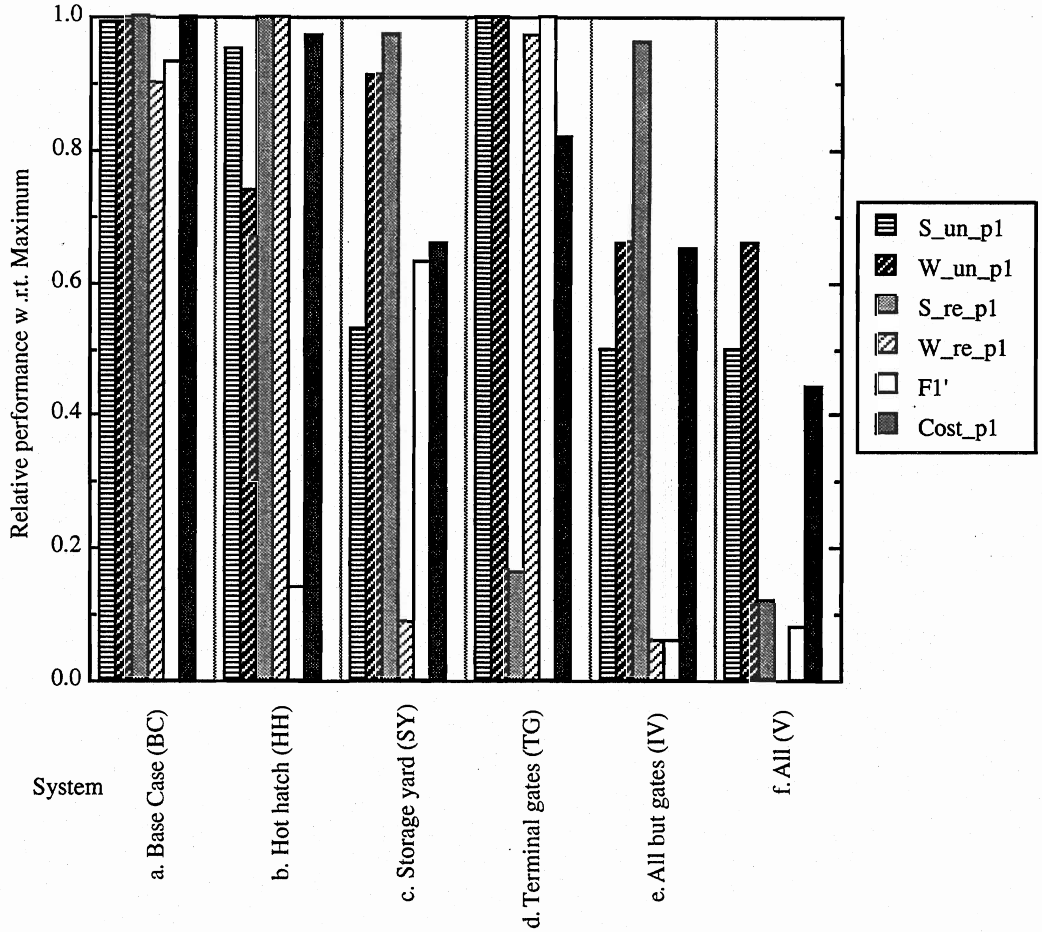
On the other hand, Figures 8.5 to 8.8, corresponding to low priority containers, have the following general characteristics:

1. The implementation of "hot hatch" systems slightly deteriorates the performance of low priority containers. The most significant impact being on waiting times at unloading that increase, on average, 10%.

2. The performance measures associated to low priority containers improve as the number of incoming high priority containers increases. Since the total number of incoming containers has been assumed to be constant, an increased flow of high priority containers implies a reduced flow of low priority containers. This reduction, in turn, improves the corresponding performance measures.

[19] Attributed to the use of of Automatic Equipment Identification (AEI) devices.

Figure 8.1: Relative performance
25% HPC and 1,000 containers/week
High priority containers



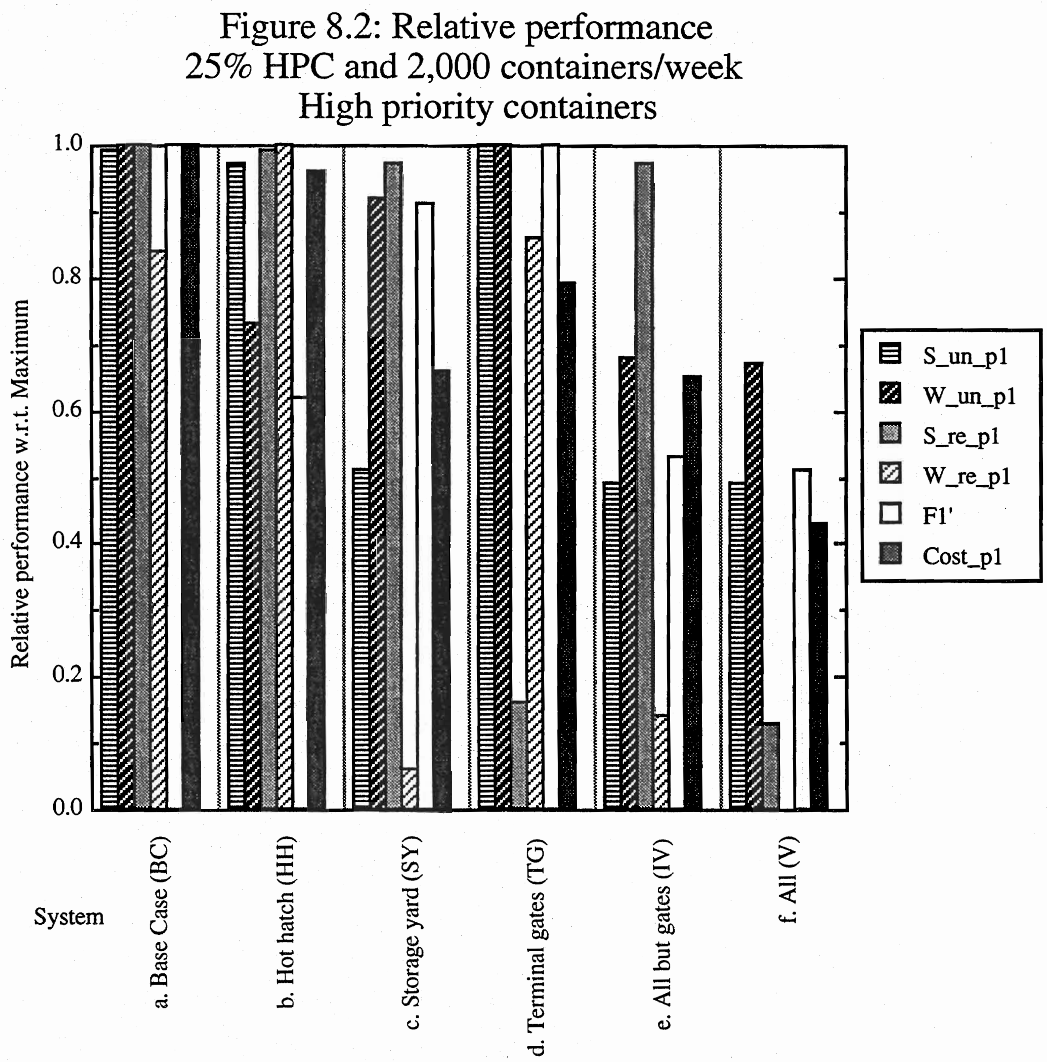


Figure 8.2: Relative performance
25% HPC and 2,000 containers/week
High priority containers
1.0
0.8
0.6
0.4
0.2
0.0
Relative performance w.r.t. Maximum
S_un_p1
W_un_p1
S_re_p1
W_re_p1
F1'
Cost_p1
System
a. Base Case (BC)
b. Hot hatch (HH)
c. Storage yard (SY)
d. Terminal gates (TG)
e. All but gates (IV)
f. All (V)

Figure 8.3: Relative performance
50% HPC and 1,000 containers/week
High priority containers

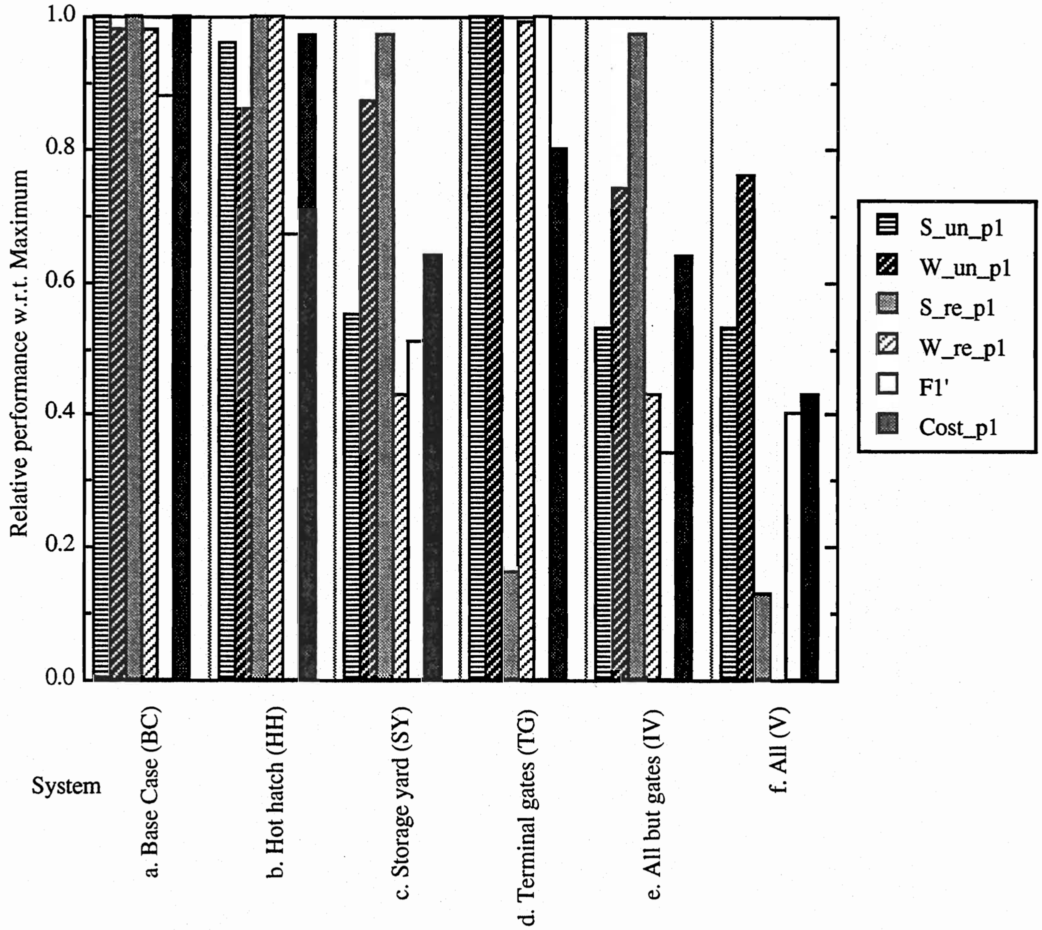


Figure 8.4: Relative performance
50% HPC and 2,000 containers/week
High priority containers

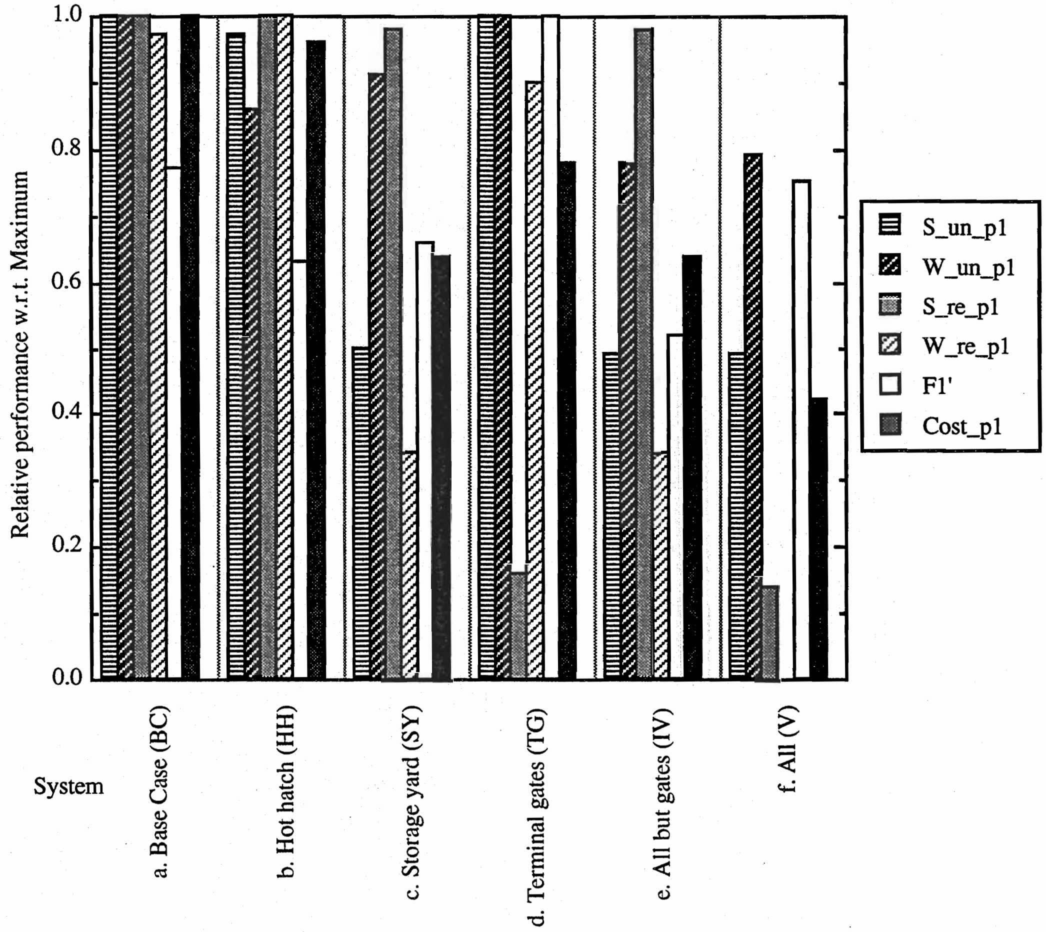
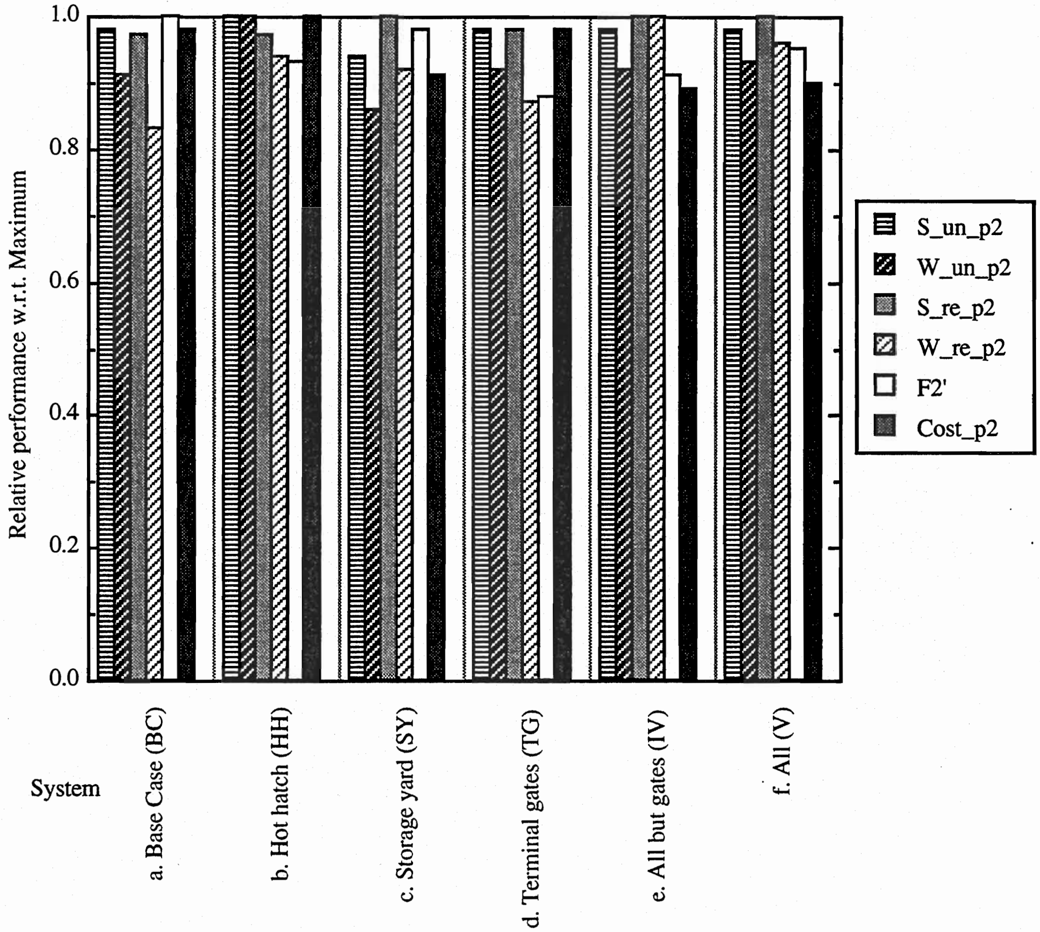


Figure 8.5: Relative performance
25% HPC and 1,000 containers/week
Low priority containers



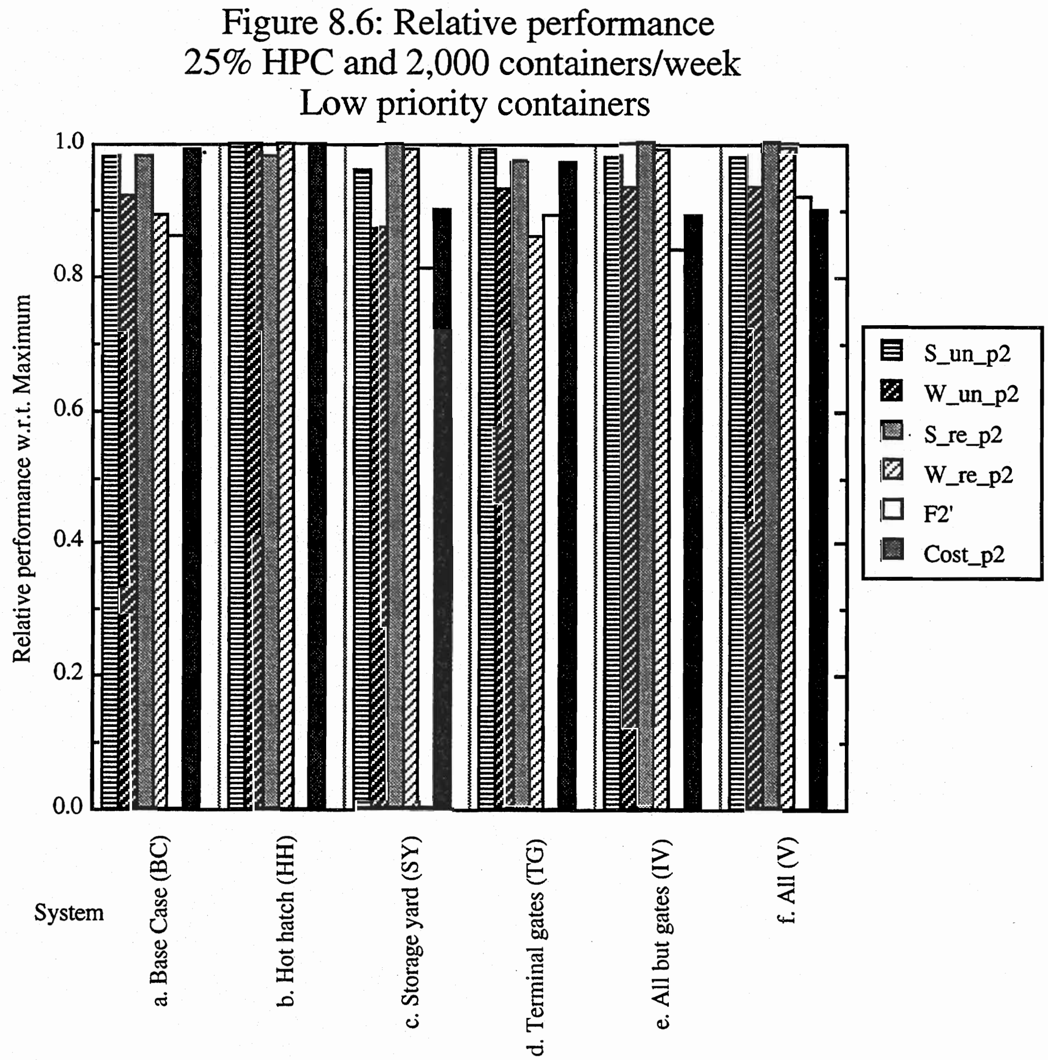


Figure 8.6: Relative performance
25% HPC and 2,000 containers/week
Low priority containers
1.0
0.8
0.6
0.4
0.2
0.0
Relative performance w.r.t. Maximum
System
a. Base Case (BC)
b. Hot hatch (HH)
c. Storage yard (SY)
d. Terminal gates (TG)
e. All but gates (IV)
f. All (V)
S_un_p2
W_un_p2
S_re_p2
W_re_p2
F2'
Cost_p2

Figure 8.7: Relative performance
50% HPC and 1,000 containers/week
Low priority containers

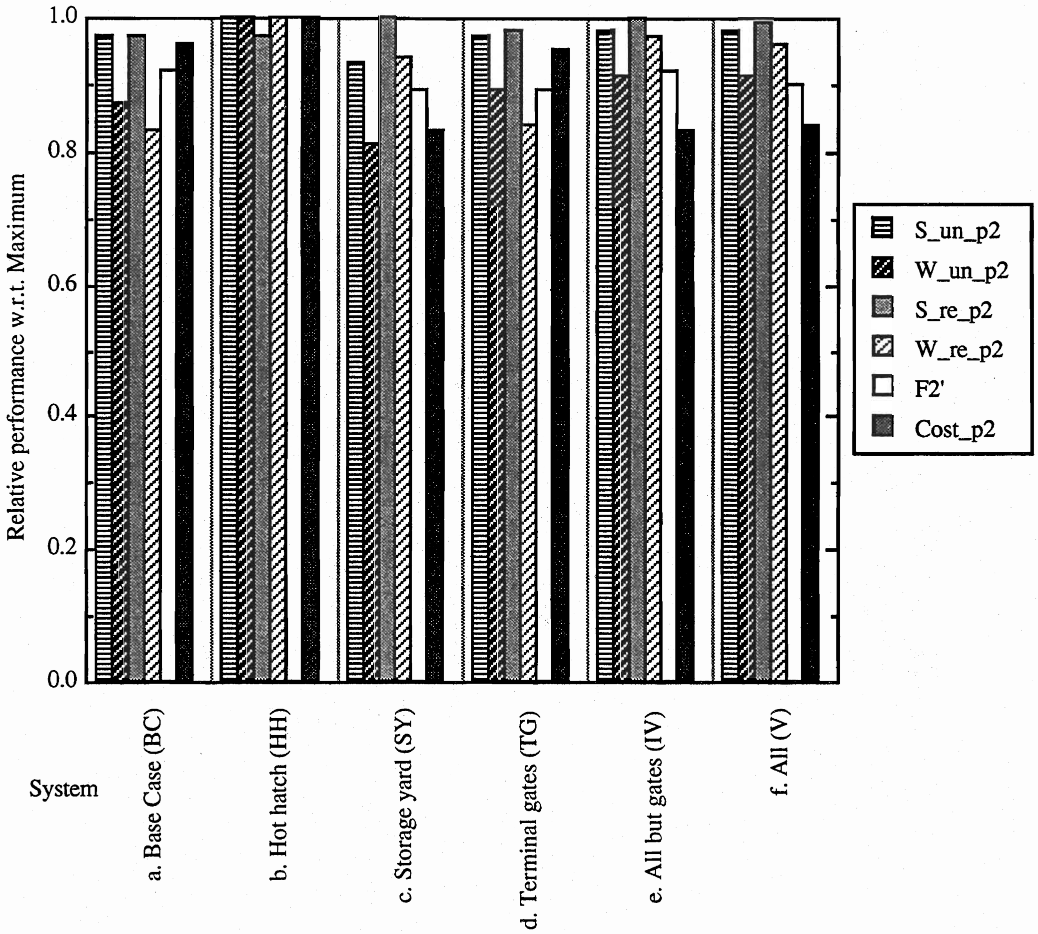


Figure 8.8: Relative performance
50% HPC and 2,000 containers/week
Low priority containers