

Southwest Region University Transportation Center

**The Calibration of PRIOR, A Computer System
for the Simulation of Port Operations Considering Priorities**

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16. Abstract <p>As part of the research conducted at the University of Texas at Austin on the implementation of priority systems at container ports, a simulation system was developed. This simulation system, PRIOR, has the unique capability of performing micro-simulations of port operations considering different operational schemes depending on the container's priority. This report focuses on describing the calibration process followed by the research team to ensure an adequate representation of the test case.</p> <p>Two different approaches to calibration were followed in this research, combined models and empirical service time distributions. In the former case, the models estimate service time as a function of the tasks' attributes (e.g., distance traveled by the yard crane), the mathematical expression of the service process, and the set of parameters obtained empirically. This approach allows specific consideration of both systematic (i.e., explained by the independent variables) and random components of the service time. The parameters of the models representing the systematic component of the service time were estimated using multiple regression. On the other hand, empirical distributions were used when the process' characteristics were not suitable for analytical modeling, such as gate processes.</p>					
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**THE CALIBRATION OF PRIOR, A COMPUTER SYSTEM
FOR THE SIMULATION OF PORT OPERATIONS
CONSIDERING PRIORITIES**

by

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Research Report SWUTC/96/721928-1

**Southwest Region University Transportation Center
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EXECUTIVE SUMMARY

As part of the research conducted at The University of Texas at Austin on the implementation of priority systems at container ports, a simulation system was developed. This simulation system, PRIOR, has the unique capability of performing micro-simulation of port operations considering different operational schemes depending on the container's priority.

Two separate reports are dedicated to the simulation system. The report entitled "Prior, a Computer System for the Simulation of Port Operations Considering Priorities" provides a glimpse into the general characteristics of PRIOR. This report focuses on describing the calibration process followed by the research team to ensure an adequate representation of the test case. Other reports focus on the role of information technology, optimal yard allocation and performance analysis of the different systems.

The service time models described in this report focus on the following processes:

- a) service time of the yard cranes,
- b) yard crane movements along the storage yard,
- c) service time of the gantry cranes, and
- d) gate processes.

The data set was obtained from video tapes taken at yard crane operations at the Barbours Cut Terminal and gantry crane operations at the Sea Land terminal, both in the Port of Houston.

Two different approaches to calibration were followed in this research, combined models and empirical service time distributions. In the former case, the models estimate service time as a function of the tasks' attributes (e.g., distance travelled by the yard crane), the mathematical expression of the service process, and the set of parameters obtained empirically. This approach allows specific consideration of both systematic (i.e., explained by the independent variables) and random components of the service time. The parameters of the models representing the systematic component of the service time were estimated using multiple regression. On the other hand, empirical distributions were used when the process' characteristics were not suitable for analytical modelling, such as gate processes.

ABSTRACT

As part of the research conducted at The University of Texas at Austin on the implementation of priority systems at container ports, a simulation system was developed. This simulation system, PRIOR, has the unique capability of performing micro-simulations of port operations considering different operational schemes depending on the container's priority. This report focuses on describing the calibration process followed by the research team to ensure an adequate representation of the test case.

Two different approaches to calibration were followed in this research, combined models and empirical service time distributions. In the former case, the models estimate service time as a function of the tasks' attributes (e.g., distance travelled by the yard crane), the mathematical expression of the service process, and the set of parameters obtained empirically. This approach allows specific consideration of both systematic (i.e., explained by the independent variables) and random components of the service time. The parameters of the models representing the systematic component of the service time were estimated using multiple regression. On the other hand, empirical distributions were used when the process' characteristics were not suitable for analytical modelling, such as gate processes.

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INTRODUCTION

As part of the research conducted at The University of Texas at Austin on the implementation of priority systems at container ports, a simulation system was developed. The simulation system, PRIOR, has the unique capability of performing micro-simulations of port operations considering different operational schemes depending on the container's priority.

Two separate reports are dedicated to the simulation system. The report entitled "PRIOR, A Computer System for the Simulation of Port Operations Considering Priorities" provides a glimpse into the general characteristics of PRIOR. This report focuses on describing the calibration process followed by the research team to ensure an adequate representation of the test case.

The calibration of the simulation system required the use of two distinct approaches, the development of analytical expressions relating service time to the task's characteristics and the estimation of service time empirical distributions. The former approach was used to estimate analytical models for gantry crane operations, yard crane operations and yard crane movements. The latter approach was used in the cases in which the characteristics of the service process were not suitable for analytical modelling (e.g., yard gate operations).

The simulation system developed in this research estimates the service time for different service processes as a function of corresponding equipment micromovements. Microsimulation (i.e., the detailed depiction of the micromovements) is needed because some of the operational schemes analyzed in this research have not been implemented in practice and, consequently, there is no data about their service characteristics.

At least two different approaches can be used to estimate the service times in a microsimulation approach. The first one describes the technological characteristics of the equipment (e.g., speed, capacity) by using a mathematical model to describe the equipment's activities. By making some assumptions about the equipment performance (e.g., the yard crane speed is 85% of the maximum design speed) the service times can be calculated. A major drawback of this approach is that it does not consider how the equipment is actually operated, which may be significantly different than the way it is expressed in the model. In addition, since the models are essentially deterministic, this approach does not consider the inherent variability of port operations.

A second approach, the one used in this research, relies on the use of empirically calibrated service time models. These models estimate service time as a function of the tasks' attributes (e.g., distance travelled by the yard crane), the mathematical expression of the service process, and the set of parameters obtained empirically. This approach allows specific

consideration of both systematic (i.e., explained by the independent variables) and random components of the service time.

The parameters of the models representing the systematic component of the service time were estimated using multiple regression. The criteria used to select the final models are conceptual validity of the structural equation of the model and its parameters, and statistical significance. After choosing the final models, the residuals were analyzed to determine which statistical distribution can be used to describe them.

In the simulation system, both components (i.e., systematic and random) are used to estimate the service time. The task's characteristics (e.g., distance travelled, type of container) are inputs to the regression models (i.e., representing the systematic component). The statistical distributions representing the random component of the service times are used to generate random numbers that are added to the systematic component to obtain the service time.

The service time models described in this report focus on the following processes:

- a) service time of the yard cranes,
- b) yard crane movements along the storage yard,
- c) service time of the gantry cranes, and
- d) gate processes.

The data set was obtained from video tapes taken at yard crane operations at the Barbours Cut Terminal and gantry crane operations at the Sea Land terminal, both in the Port of Houston.

The analysis of the data set indicated that some observations have atypically high service times, the behavior of which is not entirely understood. At first, the atypical observations were included in the estimation of the systematic component of the service times. A binary variable (i.e., ATYPICAL) was used to differentiate both groups.¹ It became evident that the atypical observations were affecting the quality of the models and a new course of action was taken.

The basic assumption of the new approach is that both groups (i.e., typical and atypical observations) share the same systematic component, while having two distinct random components. After estimating the systematic component, using exclusively typical observations, the random components for both groups were determined, as well as the probabilities associated with each group.

Once the best models for each of the service processes mentioned above were selected, they were integrated into the simulation system as FORTRAN functions that are called by the corresponding subroutines as needed. In this way, the calibration process was simplified significantly.

¹ Only significant and robust models are presented in this section.

CHAPTER 1. YARD CRANE OPERATION SUBMODEL

The objective of this model is to estimate the time required to move the spreader from one position to another as a function of both the distance travelled and the characteristics of the movement (i.e., empty/loaded, to pick a container/to reposition the spreader). After excluding the atypical observations, the data set was comprised of 62 observations.²

The variables used are:

Time: time required to move the spreader (in seconds);

D_x : distance along the horizontal axis (in ms);

D_y : distance along the vertical axis (in ms);

D_{total} : $D_x + D_y$ (in ms);

D_{hyp} : hypotenuse of the right triangle formed by D_x and D_y (in ms);

Empty: dummy variable equal to 1 if the spreader is empty and equal to 0, otherwise.

Picking: dummy variable equal to 1 when the spreader is going to pick up a container and equal to 0, otherwise.

Model 1: This model postulates a linear relationship between service time and the independent variables.³

$$Time = 0.079 + 4.414D_{hyp} + 27.333Picking - 28.877Empty$$

(0.004) (3.744) (2.283) (-4.200)

$$F = 10.313$$

$$\text{Adjusted } R^2 = 0.311$$

As shown, all variables except the intercept are significant.

² The most common case of an "atypical" operation is when the yard crane picks a container, but its corresponding truck has not arrived yet. Sometimes the yard cranes hold the container for several minutes before placing it in its final destination.

³ The characteristics of the service processes modelled in this section make them suitable to linear formulations. In a linear formulation of service time as a function of distance and a set of dummy variables, the coefficient of distance has a dimension of seconds/ms and the coefficient of the dummy variables can be interpreted as marginal service times.

Model 2: It is a variation of Model 1, in which there is no intercept. The results are:

$$Time = 4.418D_{hyp} + 27.376Picking - 28.872Empty$$

(5.652) (3.777) (-4.278)

Adjusted R² = 0.322

Since the parameters of this model are conceptually valid and statistically significant, this model will be accepted as final. As can be seen, there is a significant difference between the movements in which the operator is trying to pick up a container (PICKING = 1) with respect to those reposition movements (PICKING = 0). In addition, an empty spreader (EMPTY = 1) moves faster than a loaded one (EMPTY = 0).

Since heteroscedasticity may be present in the model (i.e., due to longer distances inducing higher variability to the model), the homoscedasticity assumption was tested. The test consisted in determining the existence of relationships between the squared residuals (as the dependent variable), and the variables used in the model. In all tests, heteroscedasticity was not significant.

ANALYSIS OF THE RESIDUALS OF THE FINAL MODEL

Table 1.1 shows the main characteristics of the residuals' distribution. As shown in Table 1.1, the distributions of the residuals for typical observations are significantly different from the distribution of the residuals for atypical observations.

	Typical observations		Atypical observations	
Probability of each case	83.78%		16.22%	
	Time	Residuals	Time	Residuals
Average time	48.73	-2.17	153.63	86.58
Standard deviation	22.84	19.44	89.82	93.49
Minimum value		-48.17		-18.97
Maximum value		52.75		276.90

The mean of the residuals for typical observations is slightly different than zero (i.e., -2.17 secs). The corresponding standard deviation is 19.439 secs. Since the mean is not zero due to the small sample size, the residuals are set to a mean of zero.

To assure that the service times generated from both systematic and random components are within the practical range of values, the random component will be generated using truncated normal distributions with parameters (0.00, 19.44)⁴ and (86.58,93.49) for typical and atypical observations, respectively. In general, the truncation limits for the typical observations

⁴ Mean and standard deviation.

are a function of the systematic component, while for the atypical observations are in between zero and the maximum residual. Figures 1.1 and 1.2 show the plot of residuals for both, typical and atypical observations.

Figure 1.1: Plot of residuals
Yard crane operations. Typical observations

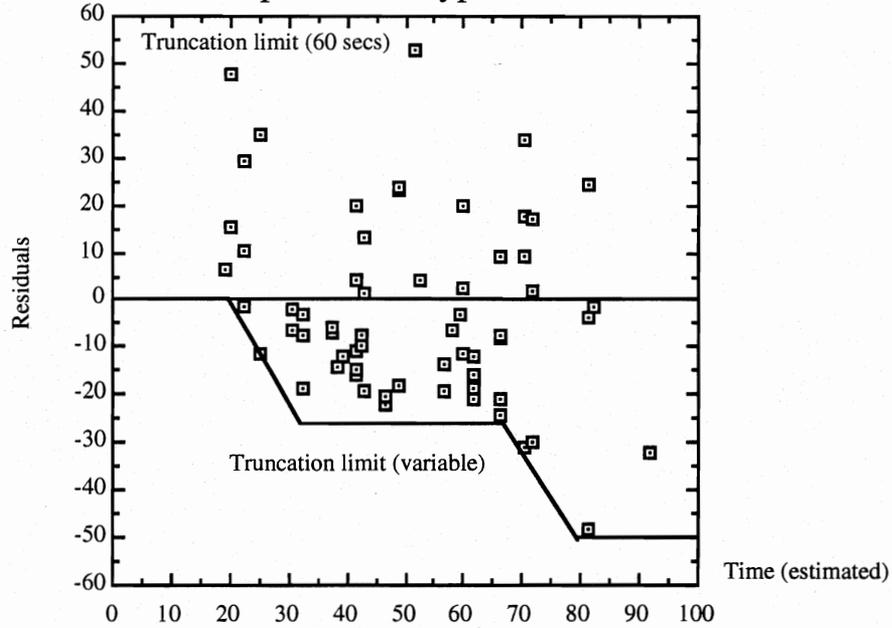
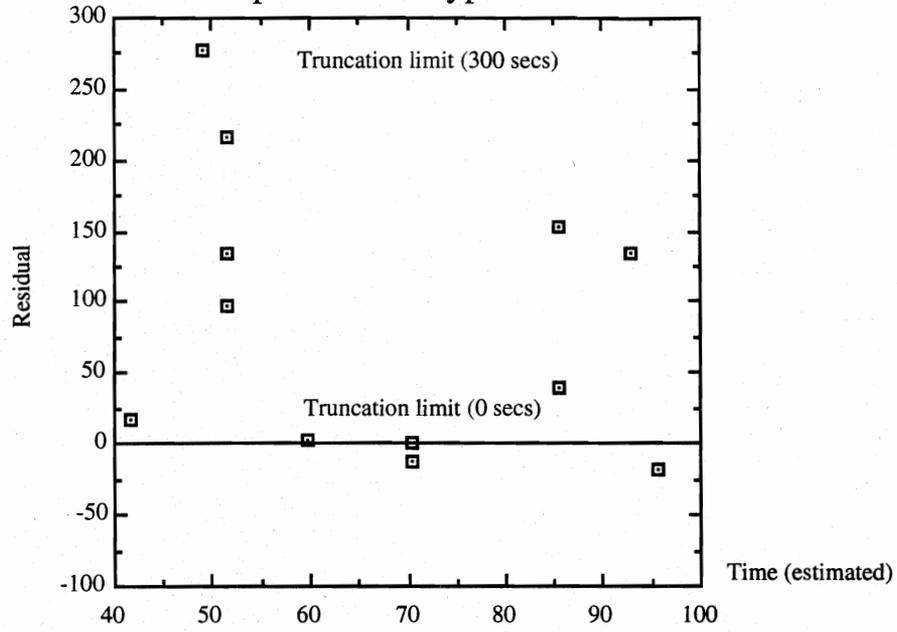


Figure 1.2: Plot of residuals
Yard crane operations. Atypical observations



CHAPTER 2. YARD CRANE MOVEMENT SUBMODEL

The models obtained in this chapter are intended to estimate the time required by the yard crane to move from one container lot to another as a function of the movement's characteristics. The data set was comprised of 24 observations.⁵ The variables used were the following:

Time: travel time from one lot to another (in seconds);

Distance: total distance travelled (in mts);

Stop: dummy variable equal to 1 if the crane stops and equal to 0, otherwise;⁶

Turning: dummy variable equal to 1 if the crane had to turn its wheels (for a perpendicular movement) and 0 otherwise;

Model 1: It postulates a linear relationship between service time and its independent variables.

$$Time = 6.216 + 0.527Distance + 16.79Stop + 133.656Turning$$

(0.772) (4.437) (2.754) (15.65)

$$F = 105.593$$

$$\text{Adjusted } R^2 = 0.929$$

Leaving out the atypical observations increased the model's significance. The intercept is not significant.

Model 2: This model has a structure similar to Model 1, but no intercept. The resulting parameters are:

$$Time = 0.606Distance + 19.974Stop + 133.218Turning$$

(9.929) (4.490) (15.779)

$$\text{Adjusted } R^2 = 0.930$$

All the parameters have the expected sign and correct order of magnitude, yet remained statistically significant. For that reason, this model will be accepted as final.

The assumption of homoscedasticity was tested. The results indicated that the squared residuals are uncorrelated to variables used in the model; consequently the homoscedasticity assumption is valid.

⁵ Some of the yard cranes, while moving from one container lot to another, exhibited a strange behavior. The typical case is a yard crane moving 20 mts in one direction, then stopping and then finally resuming its original direction. In an extreme case while moving from lot #8 to lot #5, one crane repeated this maneuver three or four times taking it 500 seconds to complete the trip.

⁶ The need for this variable arises from the data collection process. The data was retrieved from videos taken using stationary video cameras. In some cases, yard cranes entered one side of the screen and exited the other side without making a stop. Using STOP, these observations, otherwise useless, were included in the data set.

ANALYSIS OF THE RESIDUALS OF THE FINAL MODEL

Table 2.1 shows the characteristics of the residuals' distribution for both typical and atypical observations. As expected, the mean residual is approximately equal to zero (i.e., 0.66) and the standard deviation is equal to 12.24 secs, for the typical observations.

Table 2.1: Distribution of residuals. Yard crane movements				
Probability of each case	Typical observations		Atypical observations	
	67.57%		32.43%	
	Time	Residuals	Time	Residuals
Average time	57.12	0.66	105.16	58.90
Standard deviation	48.49	12.24	122.45	79.16
Minimum value		-23.92		-6.87
Maximum value		41.45		300.51

As in the yard operation model, the mean residual and the standard deviation for atypical observation are larger than their counterparts for typical observations (i.e., 58.90 secs and 79.16 secs).

Similarly as before, truncated normal distributions will be used to ensure that the random component is generated within the practical range of values. Figures 2.1 and 2.2 show the plot of residuals for typical and atypical observations and their corresponding truncation limits.

Figure 2.1: Plot of residuals
Yard crane movements. Typical observations

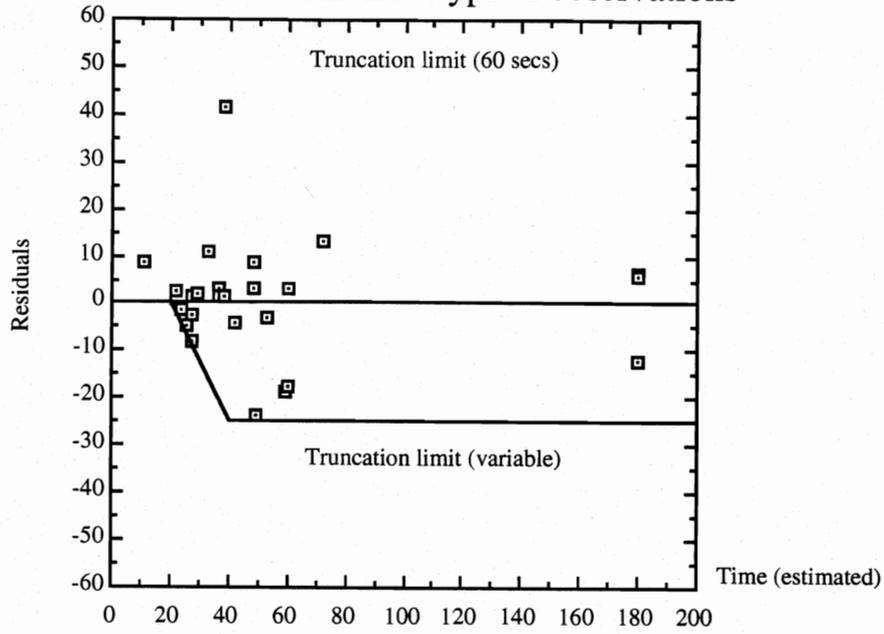
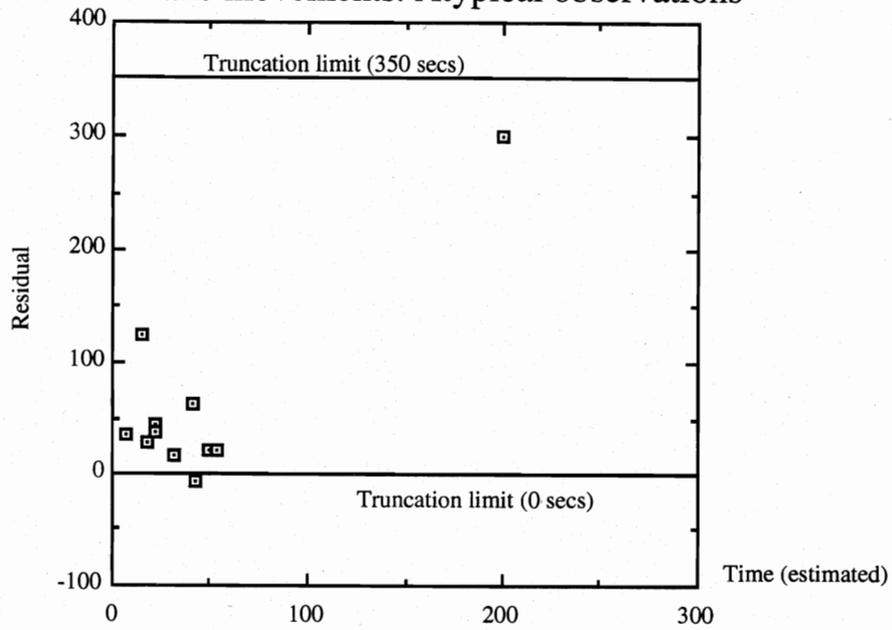


Figure 2.2: Plot of residuals
Yard crane movements. Atypical observations



CHAPTER 3. GANTRY CRANE OPERATIONS

The gantry crane operation model is intended to estimate the gantry crane's service time as a function of the container position on the ship. The data set had 140 observations.⁷ The variables used are:

Time: time required by the crane to move the spreader (in seconds);

Dx: horizontal distance of the movement (in mts)

Dy: vertical distance of the movement (in mts);

Empty: dummy variable equal to 1 if spreader is empty and equal to 0, otherwise

On deck: dummy variable equal to 1 if container is on the deck and equal to 0 if container is in the hatch.⁸

At first, four different linear models were estimated, each having different specifications (shown in the appendix). Then, the best model of the group was tested for heteroscedasticity. The test indicated that the model is heteroscedastic.⁹

Since the presence of heteroscedasticity makes the regression coefficients non-efficient, the t-test for the coefficients has little value.¹⁰ For that reason, the remedial measures for heteroscedasticity will include the full set of variables, although some of them were rejected in the first four models.

3.1 REMEDIAL MEASURES FOR HETEROSCEDASTICITY

1st trial: Using the natural logarithms of the variables (Models 1 and 2)

This approach relies on using natural logarithms of the variables instead of the original variables. The basic assumption is that logarithms reduce heteroscedasticity by means of reducing the relative differences between different observations (e.g., a difference of 10 is reduced to a difference of 2).

⁷ In some cases, similar to yard crane operations, the gantry cranes stopped operations (without any apparent reasons). In others, the gantry crane could not pick up a container; this difficulty required a trip back to the berth to get a special attachment that allows the crane to pick up containers in difficult positions. As with yard cranes, these cases were recorded.

⁸ It is important to make a distinction between containers on deck and containers in the ship hatch, because the ship from which the data was taken is a cellular ship. In cellular ships the hatches are provided with rails to guide the spreader picking up containers (which increased the gantry crane productivity). On the other hand, deck operations do not have such rails, and its operations are affected by elements such as wind and ship oscillations.

⁹ The test also indicated that the variable introducing heteroscedasticity is Dx.

¹⁰ The increased variance of the estimates may lead to the rejection of variables that are, indeed, significant.

Model 1: It includes all the independent variables.

$$\ln(\text{Time}) = 2.243 + 0.179 \ln(D_x) + 0.376 \ln(D_y)$$

$$(4.382) \quad (1.825)$$

$$-0.317 \ln(\text{Empty} + 1) - 0.351 \ln(\text{OnDeck} + 1)$$

$$(7.845) \quad (1.333)$$

$$F = 98.111$$

$$\text{Adjusted } R^2 = 0.735$$

As can be seen, the coefficient of ONDECK is not significant. For that reason, it will be taken out of the model.

Model 2: It results from leaving ONDECK out of Model 1.

$$\ln(\text{Time}) = 1.294 + 0.182 \ln(D_x) + 0.647 \ln(D_y) - 0.316 \ln(\text{Empty} + 1)$$

$$(4.433) \quad (18.302) \quad (7.79)$$

$$F = 129.487$$

$$\text{Adjusted } R^2 = 0.734$$

Since all parameters have the correct sign,¹¹ this model is tested for heteroscedasticity. The analysis indicates that this model is heteroscedastic (all of its variables have significant correlation with the squared residuals).

2nd trial: Transformed model dividing all variables by D_x

This model relies on the assumption that the variance of the error term is proportional to the square of the variable introducing heteroscedasticity in the model (i.e., D_x). It has been proven that by dividing all the variables by D_x , the resulting parameters are efficient (i.e., minimum variance).¹²

In mathematical terms:

$$E(u_i^2) = \sigma^2 D_x^2$$

¹¹ This formulation makes it difficult to determine whether or not the parameters have the correct order of magnitude, because they are not associated with natural variables (as in the linear formulation). In this case, the parameters represent elasticities of service time with respect to the different independent variables.

¹² For a proof of this assumption as well as the others used in this section see: "Basic econometrics"; Gujarati, Damodar; 2 edition; MacGraw Hill, 1988.

Model 3: It includes all independent variables.

$$\frac{Time}{D_x} = 0.232 + 1.724 \frac{D_y}{D_x} - 10.759 \frac{Empty}{D_x} + 7.414 \frac{OnDeck}{D_x}$$

(25.734) (7.165) (3.488)

$$F = 278.957$$

$$\text{Adjusted } R^2 = 0.856$$

Since the parameters have the correct signs and order of magnitude, this model is tested for heteroscedasticity. The tests indicate that the model is still heteroscedastic.

3rd trial: Transformed model dividing all variables by the square root of D_x

This model relies on the assumption that the variance of the error term is directly proportional to the variable introducing heteroscedasticity in the model (i.e., D_x).

In mathematical terms:

$$E(u_i^2) = \sigma^2 D_x$$

Model 4: It includes all the independent variables.

$$\frac{Time}{\sqrt{D_x}} = 0.368\sqrt{D_x} + 1.559 \frac{D_y}{\sqrt{D_x}} - 7.465 \frac{Empty}{\sqrt{D_x}} + 6.120 \frac{OnDeck}{\sqrt{D_x}}$$

(4.525) (22.241) (5.514) (3.585)

$$\text{Adjusted } R^2 = 0.057$$

The parameters have the correct signs and order of magnitude. The analysis of the residuals indicates that this model is still heteroscedastic.

4th trial: Transformed model dividing all variables by Time (estimated)

This model relies on the assumption that the variance of the error term is proportional to the square of the expected value of the dependent variable (i.e., service time). The use of this assumption requires a two stage estimation process. In the first stage, the parameters of the model with the original variables are estimated. Using the resulting parameters, a new set of variables are calculated (i.e., dividing the original variables by the time estimated by the model). In the second stage, the new variables are used to estimate the new set of parameters.

In mathematical terms:

$$E(u_i^2) = \sigma^2 [E(Y_i)]^2$$

Model 5: It includes all the independent variables.

$$\frac{Time}{\widehat{Time}} = 0.294 \frac{D_x}{\widehat{Time}} + 1.689 \frac{D_y}{\widehat{Time}} - 11.187 \frac{Empty}{\widehat{Time}} + 6.481 \frac{OnDeck}{\widehat{Time}}$$

(3.259) (25.639) (-7.861) (3.231)

$$\text{Adjusted } R^2 = 0.769$$

All the parameters have the correct sign and order of magnitude. In spite of the transformations, the model is still heteroscedastic.

5th trial: Application of Weighted Least Squares (WLS)

WLS is a statistical technique that uses weighed variables, instead of the original ones. By weighing the variables according to their variance, heteroscedasticity can be eliminated, in most of the cases. WLS requires information about the variance of the observations for the different values of the independent variables.

To estimate the variances to be used in WLS, the data set was sorted according to the values of the different independent variables. The variances of service times are calculated for the observations with the same values of the independent variables. These variances are used to weigh the different variables.

The resulting model is as follows:

Model 6: It includes all independent variables.

$$\frac{Time_i}{\sigma_i^2} = 0.381 \frac{1}{\sigma_i^2} + 1.501 \frac{D_y}{\sigma_i^2} - 1.088 \frac{Empty}{\sigma_i^2} + 4.927 \frac{OnDeck}{\sigma_i^2}$$

(4.299) (21.273) (-1.514) (1.812)

Adjusted R² = 0.984

All the parameters have the correct signs. The order of magnitude of the parameters, except the coefficient of Empty, which is significantly underestimated, appear to be correct. This model is homoscedastic.

3.2 SELECTION OF THE FINAL MODEL

In this case, there is not single model that can be clearly chosen as the best one. Different models can be selected depending on the weight assigned to conceptual validity and statistical significance.

The following conclusions can be drawn:

a) Models 1 and 2 (i.e., using the natural logarithms of the variables) may not be appropriate for modelling a phenomenon in which a linear equation is expected (i.e., a consequence of uniform movement). For that reason, Models 1 and 2 are no longer considered as good candidates.

b) The parameters of Model 4 have the expected signs and correct order of magnitude, though the coefficient of EMPTY seems to be underestimated.¹³ In addition, the low correlation

¹³ The statistical analysis of the data set indicates that for the same distance, the difference between the travel time of a loaded spreader with respect to the empty spreader has an average of 10.762 seconds, with a standard deviation of 9.6 seconds.

coefficient (i.e., 0.057) seems to indicate that the model is not appropriate for descriptive modelling. For that reasons, Model 4 is rejected.

c) Model 6 is the only homoscedastic model of the group. It also has the highest correlation coefficient (i.e., 0.984). However, the coefficient of EMPTY (i.e., 1.088) is significantly underestimated; thus, Model 6 is rejected.

d) Although heteroscedastic, the best models seem to be Model 3 and Model 5. Their parameters have the correct sign and order of magnitude. The analysis of heteroscedasticity for Model 3 indicates that only the transformed variables Dy/Dx and $OnDeck/Dx$ are correlated to the squared residuals. On the other hand, all of the transformed variables used in Model 5 have significant correlation with the squared residuals. In addition, Model 3 has a higher correlation coefficient than Model 5. For these reasons, Model 3 is selected as the final model.

3.3 ANALYSIS OF THE RESIDUALS OF MODEL 3

The statistical analysis of the residuals indicated that they have a mean equal to 0.16 seconds and a standard deviation of 7.81 seconds, while the atypical observations have a mean of 84.37 secs and a standard deviation equal to 58.56 secs.

Truncated normal distributions are used to ensure that the random component, and consequently the total service time, is within the practical range. Figures 3.1 and 3.2 show the plot of residuals for both groups, as well as the truncation limits used in the simulation system. Table 3.1 shows the characteristics of the distribution of residuals.

Table 3.1: Distribution of residuals. Gantry crane operations				
Probability of each case	Typical observations		Atypical observations	
	95.92%		4.08%	
	Time	Residuals	Time	Residuals
Average time	49.64	0.16	126.51	84.37
Standard deviation	14.57	7.78	52.97	58.54
Minimum value		-14.45		13.44
Maximum value		27.24		198.52

Figure 3.1: Plot of residuals
Gantry crane operations. Typical observations

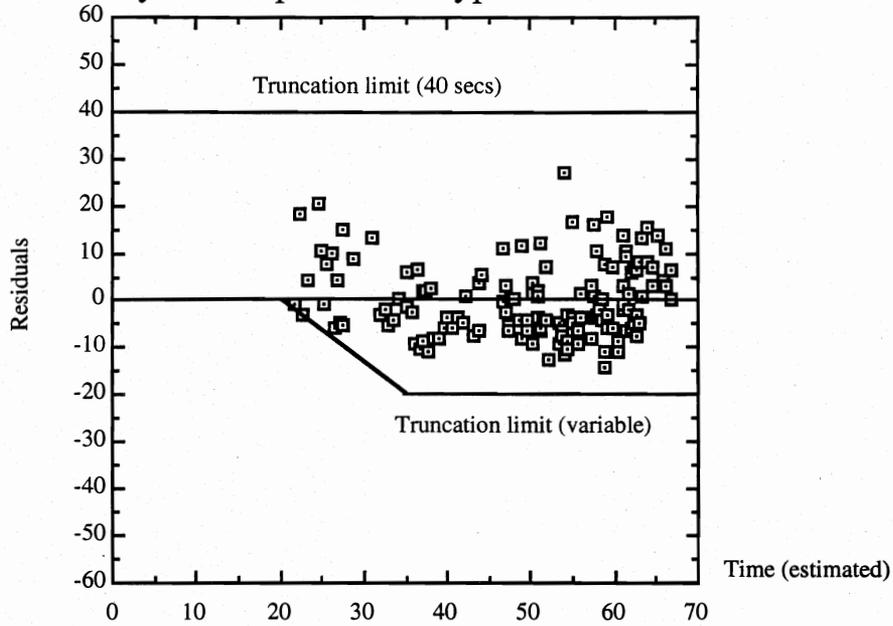


Figure 3.2: Plot of residuals
Gantry crane operations. Atypical observations

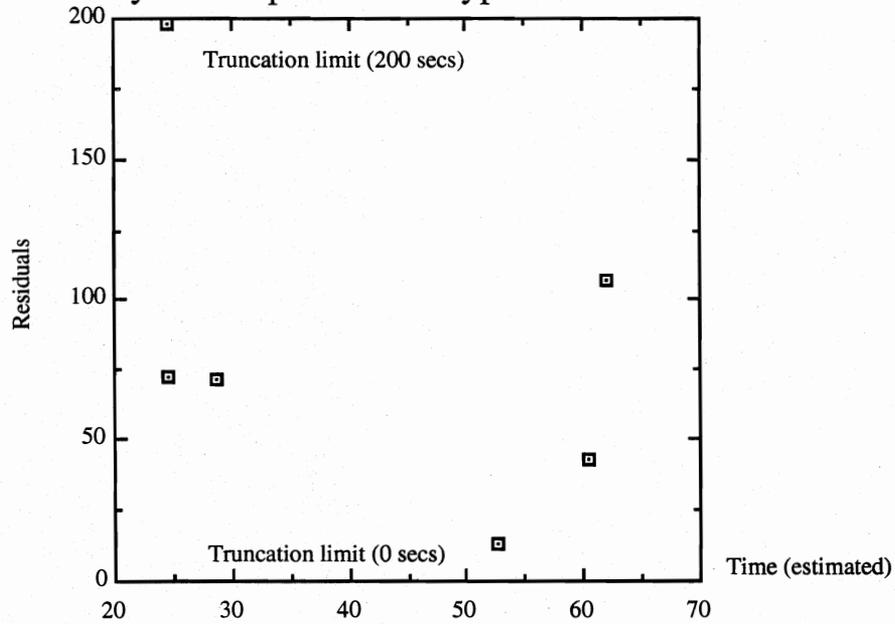
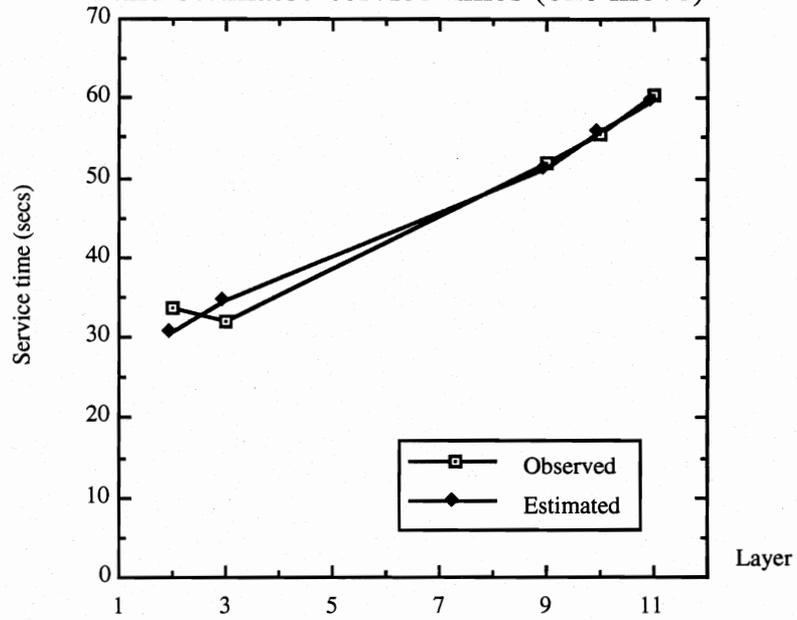


Figure 3.3 shows a comparison between the observed average service time per layer and the average service time per layer calculated by the model. As can be seen, there is a good agreement.

Figure 3.3: Comparison between observed and estimated service times (one move)



CHAPTER 4. SERVICE TIME EMPIRICAL DISTRIBUTIONS

Throughout this research, special emphasis has been given to modelling the equipment's micro-movements. The previous section showed the service time models obtained for gantry crane operations, yard crane operations, and yard crane movements. The calibration of these models was possible because the independent variables were readily identified and quantified (e.g., distance travelled by the spreader).

In contrast, some other service processes (i.e., gate operations) exhibit a different situation. In gate operations, for instance, there are not any quantitative independent variables that can be easily related to service time (most of the service time is spent checking the paperwork and other related activities).

For that reason, it was decided to model these processes using empirical distributions of service times. For the base case, the empirical distributions correspond to actual service times. For the case in which priority systems are implemented at the gates, the empirical distributions were assumed to be uniformly distributed. The interval of the uniform distribution was estimated from data provided by AMTECH for gate processing systems using Automatic Equipment Identification (AEI). The parameters corresponding to the base case were taken from EASLEY94. The parameters of the empirical distributions used are shown in Table 4.1

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

REFERENCES

EASLEY94.- Easley, Richard (1994); "Gate Operations at Barbours Cut Terminal: A Case Analysis"; Master's Thesis presented at The University of Texas at Austin, August, 1994.

