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May 2002

Final Report
Application of SIMAN ARENA Discrete Event Simulation Tool in the Operational Planning of a Rail System

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May 31, 2001

Abstract:

Application of SIMAN ARENA Discrete Event Simulation Tool in the Operational Planning of a Rail System

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The Tren Urbano Project is expected to start operating in the 2003 under a private turnkey contract. One important feature of Tren Urbano is that it is the first time that a private company operates a heavy rail in the United States. In order to study the operation of this system from the user perspective it's important to have a model that allows us the examination of possible operational strategies that could be used by the operator.

This research project describes the design and application of a SIMAN-ARENA – model of the Tren Urbano system. The model includes an animation of the traffic process that allow us to visualize the system performance. The simulation model gives the capability to use a realistic model of the rail network including a group of four consecutive stations (Sagrado Corazón, Nuevo Centro, Roosevelt and Domenech) simulate the vehicle operating and compute special system performance parameters such as waiting time in platforms and on time performance. In addition, a simulation will allow us to analyze the track layout, operation strategies, modal coordination, on-time performance and compare schedule operation and headway operation of the system

The simulation model developed under this research project is expected to be used in the future as a building block of their entire Tren Urbano network to explore several operation strategies.

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1 Introduction

1.1 Motivation

Transit systems always are subject to disruption, this problem cause grater waiting time, and inefficient operation of the rail system. This study is analyzing the operational strategies necessary to recuperate the system from a disruption.

The problem under study is how the Tren Urbano system will perform under specified conditions according to the expectations of executives and the government involved in the Tren Urbano Project. The scope of this project is to evaluate four stations (Domenech, Roosevelt, Nuevo Centro and Sagrado Corazón) and evaluate how the passengers will interact in the system as well as how the train as an entities and resource will serve the system. Our goal is to evaluate overall performance in order to visualize if the system meets the requirements established earlier and evaluate the system while changing several parameters in the simulation model.

1.2 The Tren Urbano

1.2.1 The Transportation Problem in the San Juan Metropolitan Area

The San Juan Metropolitan Area has several traffic congestion problems and is constantly increasing. In 1999, 50% of all inbound peak direction lane was congested. [(1)] This problem result from the following conditions:

- Concentrated population and employment density
- High and increasing travel demand
- Limited capacity of the highway network in the San Juan Metropolitan Area
- Inadequate public transportation systems
- Lack of intermodal connections

In 1994, the government of Puerto Rico decided to build the Tren Urbano to improve in mobility in the San Juan Metropolitan Area.

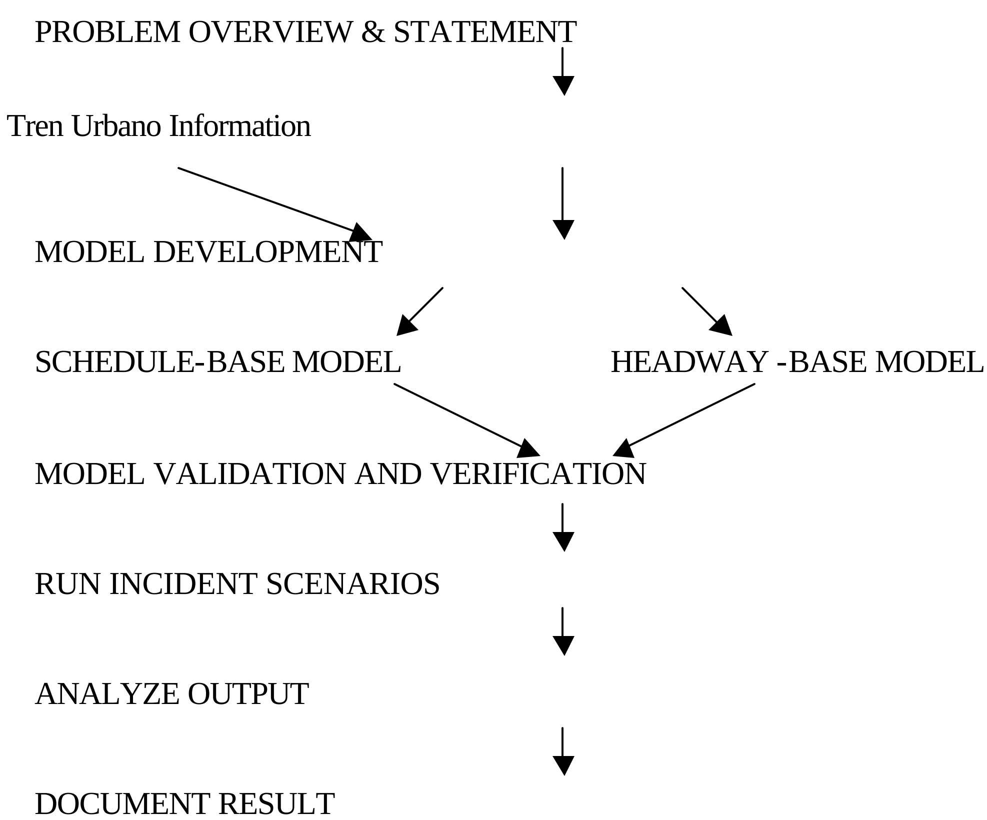
1.3 Study Methodology

In order to study the operation of the Tren Urbano system from the user perspective, it is important to have a model that allows the examination of possible operational strategies that could be used by the operator.

1.3.1 Methodology

This research project describes the design process of a simulation model and the application SIMAN/Arena simulation tool to model the Tren Urbano system. This model includes an animation of the traffic process that allow us to visualize the systems performance. Use simulation model because this is and complex model with multiple interaction and not exist mathematical relationship which include the most important interaction. The Figure 1.1 present the methodology used in this project

Figure 1.1: Methodology Flowchart



The model describe in this research is based in literary review of previous related research and the Tren Urbano projection data. They are two models used to analyze the system one model simulates the vehicle operation based on headway operation and the other model simulate the schedule. Both models compute special system performance parameters such as waiting time in platforms and on time performance measure.

The model is verified and validated using Queuing Theory and Random Incidence theory.

Minor incident scenarios are simulated in order to analyze the performance of the Schedule Based and Headway Based system operation mode. The analyzed incident are divided in two group according to the disruption caused.

1.3.2 Stations to be modeled

The simulation model gives the capability to use a realistic model of the real network including a group of four consecutive stations. The four Tren Urbano stations to be modeled are: Sagrado Corazon, Hato Rey, Roosevelt, and Domenech. These four stations are located in the most important area of San Juan because this region has the highest concentration of the most important work facilities. The Sagrado Corazon station is located in the gateway to Santurce; this is a significant intermodal connection point. The Domenech station is located close to the Milla de Oro, where are all the banks that are considered the backbone of the puertorrican economy.

1.4 Benefit

The primary target of this research is to generate a model that gives us the capability to use a realistic model of the rail system and its interactions between the user and the system. The benefits of this research project are to:

- Develop a realistic model of the Tren Urbano system
- Visualize the traffic in the system
- Analyze the train schedule

- Compare operation strategies (Headway base, Schedule base)
- Punctuality deviation of the train in each station
- The number of people missing a train
- Equipment utilization rate
- Platform waiting time

1.5 Disadvantages

The major disadvantage of this research project is that the Tren Urbano is not currently in operation. For this reason I do not have historical data about the operation and performance of the system. This disadvantage can introduce errors to the model and affect the results. In addition, the verification and validation processes are more difficult, because they depend on the available data of expected values or similar systems available.

2 Literature Review

2.1 Description and operating system of Tren Urbano

2.1.1 Systems Description

The Tren Urbano is expected to start operating during 2003 under a private turnkey contract. This is the first rapid transit system to be constructed in Puerto Rico. The first phase of the system, consists in 17.2 km of dual track heavy rail.

The Tren Urbano alignments have grade sections, elevated sections, and underground sections at Rio Piedras. The system has 16 stations across the whole route from Bayamón to Sagrado Corazon. The yard and the control center building are located between the station Martínez Nadal and Las Lomas.

2.1.2 *Expected ridership:*

The expected ridership of the system is based on the study done for the Final Environmental Impact Statement for the Tren Urbano Project in 1995. Based on the 1990 traffic mode data projected to 2010, the expected ridership of Tren Urbano is 113,266 trips per day [(2)]. The expected ridership of each station is presented in the following table:

Table 2.1: Projected 2010 Daily Boarding and Access Mode by Station (2)

STATION	WALK TO STATION	DRIVE TO STATION	TRANSFER AT STATION	TOTAL BOARDING	PERCENT OF TOTAL
Bayamón	5823	788	16587	23198	20.5%
Deportivo	638	1030	2890	4558	4.0%
Jardines	1660	659	205	2524	2.2%
Torrimar	1115	233	378	1726	1.5%
Martínez Nadal	1699	915	3069	5683	5.0%
Las Lomas	1183	198	524	1905	1.7%
San Francisco	1333	1061	1480	3874	3.4%
Centro Medico	3732	160	6112	10400	8.8%
Cupey	3193	629	2402	6224	5.5%
Río Piedras	6498	215	5254	11967	10.6%
Universidad	1433	47	1159	2639	2.3%
Piñero	2990	20	1052	4062	3.6%
Doménech	1875	13	660	2548	2.2%
Roosevelt	5335	95	1358	6788	6.0%
Hato Rey	4684	293	6734	11711	10.3%
Sagrado Corazón	3588	111	10156	13855	12.2%
Total	46779	6467	60020	113266	100.0%
Percentage of Total by Mode	41.3%	5.7%	53.0%	100%	

As shown in Table 2.1 the stations with more expected ridership is Bayamón, Río Piedras, Roosevelt and Sagrado Corazón. When the system expands an increase in ridership is expected.

2.1.3 Hours of Operation and Service schedule:

The system is planed to operate 20 daily hours from 5:00AM to 1:00 AM. The planned off-peak hour headway is 12 minutes during the morning, midday, night and weekend. During thirty minutes before the peak hour and half hour after the peak hour the headway is 8 minutes. During peak hour, (6:30AM-8: 30AM and 3:30-6:30) the planned headway is 4 minutes.

2.1.4 *Travel Times:*

The travel time presented in the Operation and Maintenance plan are computed in some simulations realized by Siemens. The travel time from Bayamón to Sagrado Corazón and vice versa is 28 minutes. In addition, the time between the Yard and Bayamón is 8 minutes and the time between Sagrado Corazón and the Yard is 15 minutes (without stopping at any station). Table 2.2 presents the distance and travel time between stations.

Table 2.2: Tren Urbano Distance and Travel Time between Stations [2]

STATION	TRAVEL TIME (SEC)	DWELL TIME (SEC.)	TOTAL TIME (SEC.)	TIME MINUTE	ACUM. TIME
Bay. Centro	0	240	240	4	4
Bay. Depart.	93	30	113	1.883333	5.88333
Jardines	159.6	20	179.6	2.993333	8.87667
Torrimar	64.7	20	84.7	1.411667	10.2883
Martínez Nadal	102.8	20	122.8	2.046667	12.335
Las Lomas	63.3	20	83.3	1.388333	13.7233
San Francisco	77.1	20	97.1	1.618333	15.3417
Centro Medico	84.8	20	104.8	1.746667	17.0883
Cupey	94.2	20	114.2	1.903333	18.9917
Río Piedras	108.2	25	133.2	2.22	21.2117
Universidad	57.7	25	82.7	1.378333	22.59
Piñero	79.4	25	104.4	1.74	24.33

Domenech	63.2	25	88.2	1.47	25.8
Roosevelt	71.8	25	96.8	1.613333	27.4133
Hato Rey	58.9	25	83.9	1.398333	28.8117
Sagrado Corazón	74	25	99	1.65	30.4617

2.1.5 Vehicles Characteristic

Siemens manufacture the Tren Urbano vehicles. The model is a steel wheeled vehicle designed to run on steel rails on high platform boarding station. The vehicle has Ac propulsion (IGBT) regeneration capability. Some Feature of the vehicles is:

- Maximum Speed: 100:km/hr
- Maximum Acceleration: 1.35 m/s^2
- Maximum deceleration: -1.35 m/s^2
- Passenger Capacity: 72 seated, 181 total

2.2 TRITAPT Software Performance Measure

2.2.1 What is TRITAPT?

TRITAPT is a software package for analyzing public transport performance [(3)]. This program provides:

- Quality indicator such as speed and punctuality
- Operational characteristic, such as running time and delay
- Time table optimization information
- Passenger load information

This program work in two stage the first stage generate the Trips database and the second stage analyses the data and generate some graph and table that may help to locate and quantify problems.

2.2.2 Analysis of Public Transport Performance developed by the software:

2.2.2.1 One day route analysis:

The program can generate a diagram for time/distance trajectories for any route. This graph is a very useful tool to analyze the headway and the on time performance of the system.

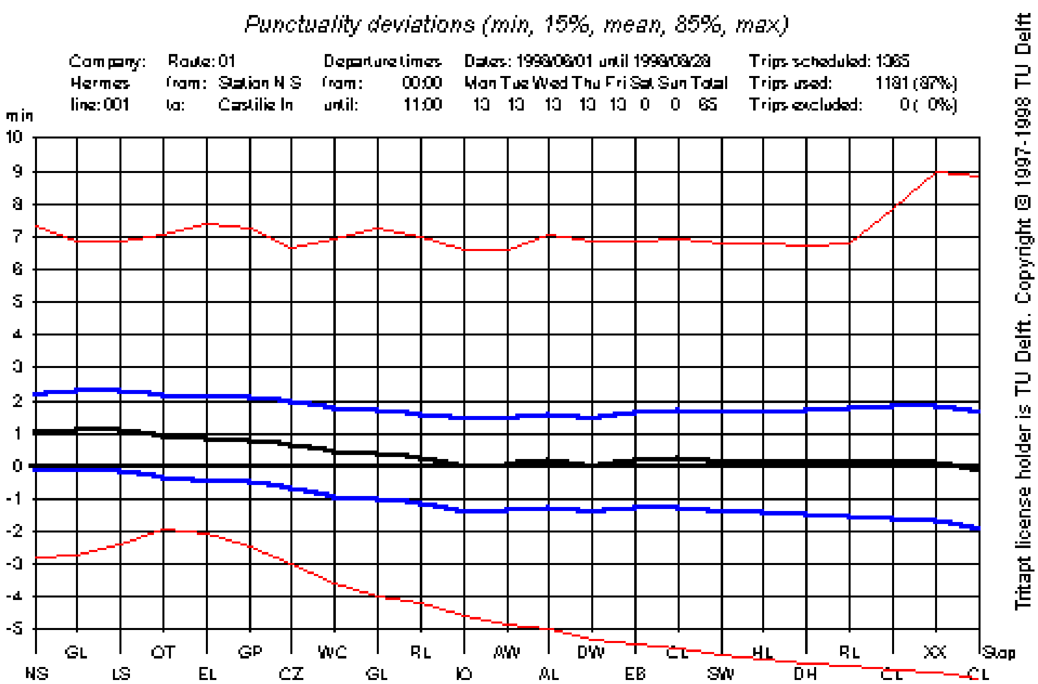
In addition the program provide the following types of graph an tables:

- Gross and net route section time.
- Feasibility of the time table
- Delay between stops
- Speed
- Regularity
- Punctuality Deviations

2.2.3 Punctuality Deviations:

The punctuality deviation is the difference between observed time and schedule time. This information are presented in a graph similar to the following figure:

Figure 2.1: TRITAP Punctuality Deviation Example



The horizontal axis in the graph is labeled with two-letter abbreviations of the station. The vertical axis shows punctuality deviation in minutes. A positive punctuality deviation means that a vehicle is late; a negative value indicates that a vehicle is early.

The red fine lines indicate the earliest and latest vehicle observed. The bold black line shows the mean punctuality deviation. The bold blue lines indicate the 15% and 85% values.

2.3 Performance measure in Rail system

To assure the rail system success it is important to offer a good quality of service. Transit agencies evaluate several parameters to measure the level of service for any transit system. This section present some important parameter used in mass transit system to measure the service reliability.

The most important parameter is the waiting time (WT). This is the time passengers spend for waiting for a train in the platform. This parameter is important because the passengers are very sensitive to waiting time. If the passengers spend too much time waiting for a train, projects an inefficient operation of the system that may cause a reduction in the ridership.

Transit agencies commonly use on-time performance to measure the reliability of the system. In various systems, the on-time performance is measured as percentage of late trips. In addition, several other measures are used to evaluate these parameters. For example, the software TRITAP measures the punctuality deviation. The punctuality deviation is the difference between schedule time and observed time. If the punctuality deviation is greater than cero means that a vehicle is late, rather a negative value indicates that a vehicle is early.

Other important parameter is the number of missed trip. This parameter is defines, as a schedule trip is not completed due to one of the following reason:

- Trip is removed for service
- Trip is not consistent with the schedule
- Any incident

Usually this parameter is measured as the number of missed trip or the percent of missed trip. This parameter represents service reductions and projects an inefficient operation and disorganization in the scheduling.

The average headway and its standard deviation is other representation of the service consistency. The average headway represents the mean of the train headway along the line in one period. The standard deviation is a measure of the headway variability. The headway affect directly the passenger waiting time at smaller variability minor is the passenger waiting time.

Starthman (1999) use the headway ratio as reliability measure for transit system. The headway ratio is defined as the ratio of observed headway to schedule headway. This reliability measure estimates the headway adherence, rather than schedule adherence.

3 The Simulation Process

3.1 What is simulation:

Simulation is the process of design a model of real system and conducting experiments whit that model [(4)]. A simulation model is used to describe the behavior of a process and predict the system performance. The simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance. Simulation is used in nearly every engineering, scientific, and technological discipline. Today, the techniques are used in the design of new systems, the analysis of existing systems, training for all types of activities, and as a form of interactive entertainment.

The Simulation help the engineers in several decision and analyze task and are effectively used in:

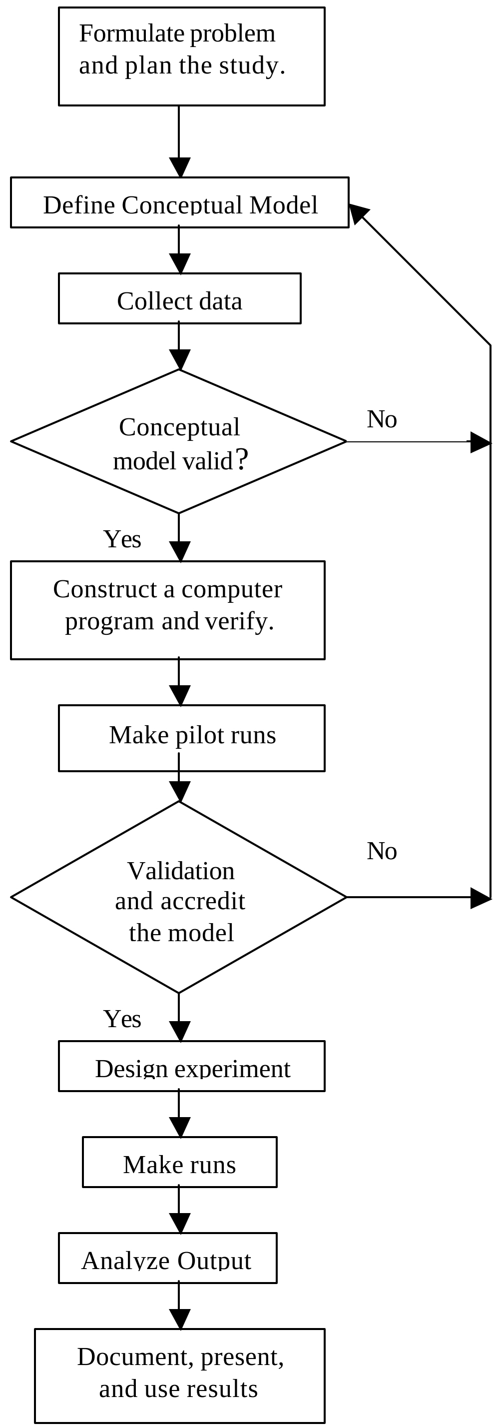
- Planning and analyzing several process
- Choosing a operating strategies
- Planning logistics system
- Evaluating capacity and performance of existing and planed systems.
- Predict the system performance in de future

Simulation usually is divided in two form discrete event and continuous, based on the manner in which the state variables change. Discrete event refers to the fact that state variables change instantaneously at distinct points in time. In a continuous simulation, variables change continuously, usually through a function in which time is a variable.

3.2 Step in a Simulation Study

The essence of simulation modeling is to help the ultimate decision maker solve a problem. The diagram in Figure 3.1 presents the different step to develop a simulation study.

Figure 3.1: The simulation process flowchart



3.2.1 Formulate the problem

The first step in developing a simulation model is to define the problem that must be addressed by the model. In this step, you define explicitly the objectives and the scope of the project. In addition, boundaries must be defined between the problem of interest and the surrounding environment. It is important in this step define clearly the expected results of the simulation.

3.2.2 Conceptual Model

Develop a preliminary model either graphically (e.g., block diagrams) to define the components, descriptive variables, and interactions (logic) that constitute the system.

This step includes the algorithms to be used to describe the system, impute required, and output generated. The assumptions made about the system are documented in this phase and evaluate how there assumptions affect the accuracy of the model.

The conceptual model includes a description of the amount of time, number of personnel and equipment assets that will require to produce the model.

3.2.3 Collect Data

During this phase the modeler, collect information on the system layout and operating procedures. This information serves as input parameters, aid in the development of the algorithm, and is used to evaluate the performance of the simulation replications.

It is important to specify model parameters and input probability distribution as is possible. In addition, collect data on the performance of the existing system for the validation purposes.

3.2.4 Conceptual Model is Valid?

During this step, the modeler performs a structured walk-through of the conceptual modeling using the assumptions documented. This step helps the modeler to ensure that the model's assumptions are correct. The model is compared with the real system until a single solution is defined that meet the objectives and requirements of the real problem.

3.2.5 Construct a computer program.

This step consists in formulating the conceptual model in an appropriate programming language (FORTRAN, C+++) or simulation language such as Arena, SLAMII and others. The simulation model is constructed based on the solution defined in the initials steps and collected data.

Before the model is created the modeler runs several pilot replication to validate the model.

3.2.6 Verify, Validate Accredit the Model

During this step confirming that the model operates the way analyst intended and that the output of the model is believable and representative of the real system. This is an essential step, because ensuring that the algorithm, input data, assumptions are correct to solve the problem defined in the first step.

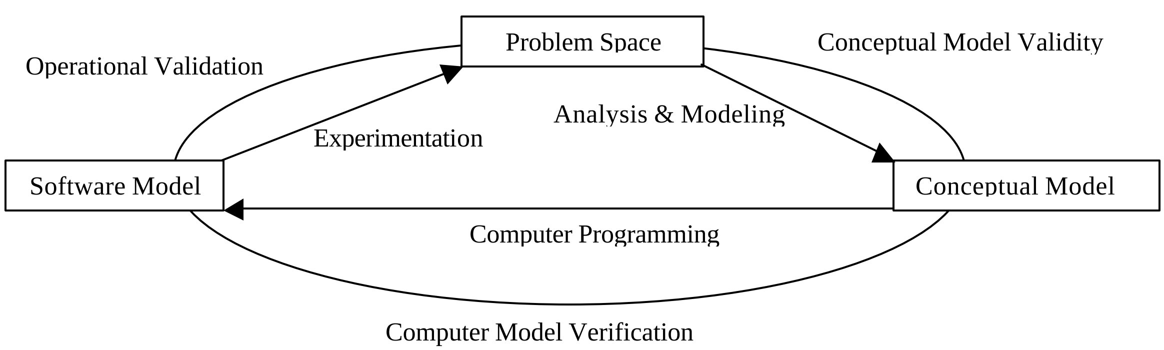


Figure 3.2 Verification, Validation and Accredit process (4)

Validation is the process of determining that the conceptual model and the final computer program reflect the real world situation.

By the verification step the modeler determines that the software accurately represent the conceptual model.

3.2.7 Design Experiment

Design an experiment that will yield the desired information and determine how each of the test runs specified in the experimental design is to be executed. Statistical techniques may be used to design the experiment that yields the most accurate and uncompromised data with the fewest number of simulation replicate.

3.2.8 Make runs and Collect Output Data

This is the execution of the designed and validated model according to the experimental requirements designed in the step above. The simulation run generates the output data required to answer the problem initially proposed.

3.2.9 Analyze Data

The major objective in analyzing data are determining the performance of the system configuration and comparing alternative system configuration. Detailed analyses must be performed to extract long term trend and to quantify the answers to the driving question that motivate the construction of the simulation. During this process, statistical technique must be used to analyze the result of the model. In Addition during this step the modeler generate some graphic, tabular information in form that can be easily understood by diverse audience.

3.2.10 Documents Result

The step are divided in the following three stages:

- Document the assumptions, the computer program and study result for use in the current and future projects.
- Present study results using animation technique that can be easily understood by diverse audience and visualize the system process.

- Results are used in the decision making process if they are both valid and credible.

3.3 Simulation Software

The simulation software can be divided in to bigger group Simulation Language and Simulators. The simulation language is programming based using simulation software. The simulator allows one to build a model of the desired system by using before-made modeling constructs.

In Simulation, language software the model is developed creating a program syntactically or graphically using language's modeling constructs. These types of simulation software are very flexible tools but the user needs to know programming concepts and longer modeling times.

While using simulator software in model building, little or no programming is required to build a model, compared to simulation languages. These kinds of tools reduce the modeling development time and are easy learning software. The disadvantage of this software is that they are limited to modeling only those system configurations allowed by their standard features. Flexibility in these simulators can be increased if use programming like constructs or call external routines in any part of the model.

Some example and description of simulation tool are presented in the following table.

Table 3.1: Simulations Languages and Software

SIMULATION LANGUAGE	DESCRIPTION
GPSS H	IBM developed the original version of this langue in 1969. This language provides iterating debugging environment and statistical function.
SIMSCRIPT II	This complete general programming language can be used to build discreet event simulation, continuous simulation and combined simulation.
SIMAN/ARENA	This is a combined simulation language and animation

	system. This software can be used to build discreet event simulation, continuous simulation and combined simulation.
SLAM II	This language is used for process-oriented simulation and event oriented simulation and the combine of the two. This language represent model in a network like structure that include node and branches.

3.4 What is SIMAN Arena?

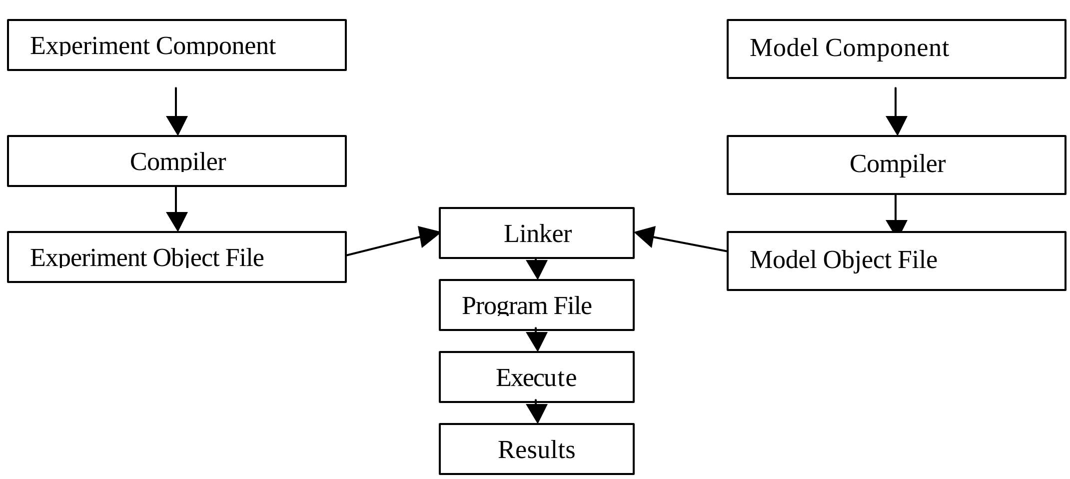
3.4.1 SIMAN/Arena

SIMAN is a powerful general propose simulation language for modeling discrete, continuous and combined systems. Arena is the animation component of the SIMAN simulation [(5)].

SIMAN is designed around a logical modeling framework in which the simulation problem is divided in to a “model” component and “experiment” component. This division is based on the theoretical concept about system developed by Zewigler (1976). The model describes the physical element and logical element of the systems. The experiment specifies the experimental condition under which will run including the initial condition, running time and replications.

3.4.2 SIMAN Process.

Figure 3.3 SIMAN Flowcharts



SIMAN modeling framework is divided in two components: the model frame, and the experimental frame, as shown in figure 3.3.

The model is a functional description of the system component and their interactions. This framework presents the logic of the model, the creation of an entity and the entity movement through the different queues and resources in the system. In the framework some blocks are presented that, assign values to an attribute or variable and other blocks, which can compute any system statistics.

The experimental framework defines the experimental condition of the model such as run lengths and initial conditions. In this framework the modeler defines all the resources, queues, attributes, variables, specific statistics that are used in the model. In addition, the modeler establishes the number of repetitions and the desired results in the report.

The system compiles the model framework and the experiment framework. When the model and the experiment are compiled, SIMAN sends an extended listing of the source file to the screen as each input statement is compiled. During this process, SIMAN presents the errors, if any, in the model and the experiment.

Once the model and the experiment source files have been compiled without error in to the object file, the next step is to link the tool resulting object in to the program file. The link file combines the experiment and the model object file in form that can be read and executed by the SIMAN simulation program.

When the files are successfully linked; the system is ready to execute the simulation. To accomplish this task, run the program named SIMAN, which is referred to ask the run processor. This program reads in the program file and executes the simulation. In this task, SIMAN creates and writes the data to any output files in the experiment and the result of the simulation.

4 Rail System Conceptual Frame Work and Modeling Variables.

The process of traveling by a rail system consists in fourth main processes, ticket vending and validation process, the platform waiting time process, the train process and leaves the station. Each process has many useful variable used to evaluate the efficiency of the service. These processes are based on the user perspective. The figure 4.1 presents the rail system conceptual framework.

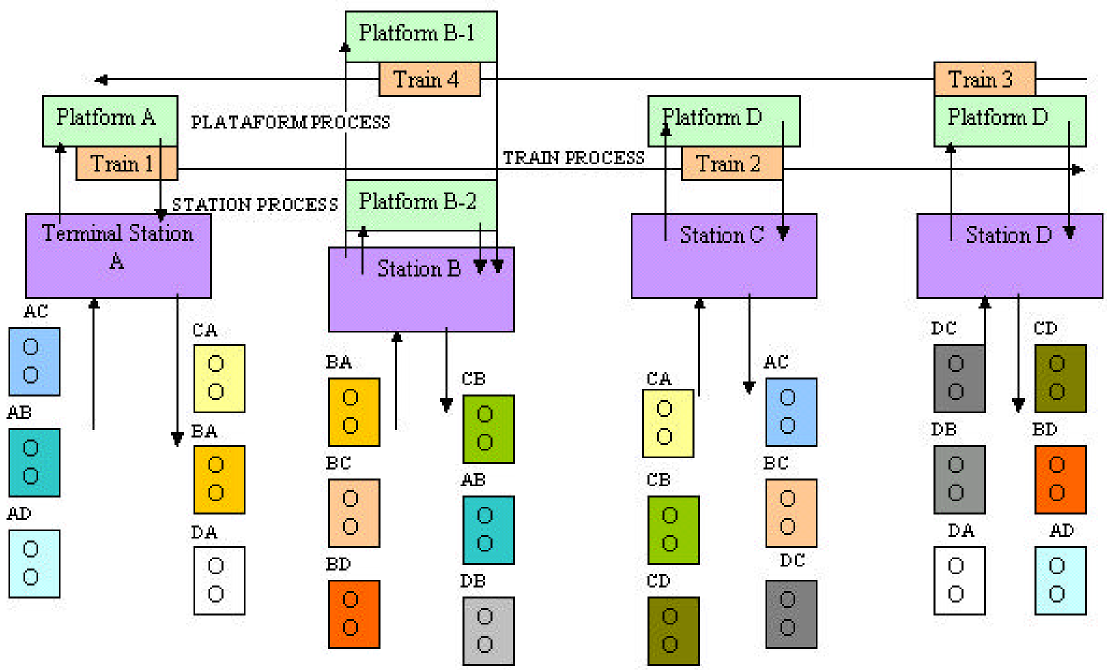


Figure 4.1: Rail System Conceptual Framework

4.1 Station Process

4.1.1 The Station Process

The station process in divided in two stages: to enter the station, and to exit the station.

4.1.1.1 Entering to the station

The users will arrive at the station by one of the following transportation modes: walking, taxi, car, bus transfer, and train transfer. The arrival of passengers is random and continuous. The exponential distribution is used to model the arrival process because exist much variability.

The passengers arriving at the station are divided in groups according to their destination. In addition, the passengers are divided in two groups according to the possession of their tickets: if the passenger has the ticket or if the passenger does not have a ticket. The user that has ticket goes directly to the entrance line, validate the ticket and enter the station. If the user does not have the ticket, he/she should go to a line and buy it in the ticket vending machine. Then he/she goes directly to the entrance line, validates the ticket and enters the station. Both groups pass to the corresponding platform.

4.1.1.2 Exit of the station

The other process that you can see in the station is the user departure of the arrivals from other stations. Some passengers stop and go to a line and buy it in the ticket vending machine for the next trip or use it to transfer to another system.

4.1.2 Important Variables

The important variables to model this process are:

- Inter-arrival means time and its distribution
- The modal distribution of the users
- The ticket or no-ticket distribution
- The destination distribution
- The number of entrance gates and ticket vending machine
- The ticket validation time and its distribution
- The tickets buying time and its distribution
- The arrival time of the user

4.2 Platform Process

4.2.1 Platform

The platform, equal to the station, has two stages: aboard the train, and the departure of the train. When the user goes aboard the train, he/she walks to the desired platform and waits for the arrival of the train. When a user leaves the train, he/she goes through the platform to the exit and passes to the station.

4.3.2 Important Variables

The important variables to model this process are:

- Arrival time of the user to the platform
- Arrival time of the train to the station
- The time when the user enter to the train
- Waiting time of the user
- Train headway

4.3 Train Process

4.3.1 The train process

The train process begins when the user aboard the train and finishes when the user leaves the train. When the user aboard the train goes to a seat if a seat is not available the user remain standing. Then he/she waits for the arrival of the train to the desired station and leaves the train.

4.3.2 Important Variable to model this process:

The important variables to model this process are:

- Train speed
- Dwell time
- Train acceleration rate
- Train deceleration rate
- Train capacity
- Train schedule
- Travel time

5 Rail system Operation

In the management of urban rail systems, Headway-based and Schedule-based are the control logic used to operate a rail system according to the operational goal. Headway-base is focuses in maintain constant headway between successive vehicles. Schedule-based is focused in controlling the vehicles to accomplish a desirable schedule.

In Headway-based and Schedule-based operation logic, various strategies are used to adhere to schedule or to maintain regular headway and consistent travel time. In practice, holding, short turning and stop-skipping control are applied to meet a desirable headway or schedule. Holding is used usually when there is a short preceding headway and long following headway to reduce headway variance. Stop-skipping control are used to speedup a late vehicle.

5.1 Schedule Based Operation:

Schedule-based strategies control trains so they keep the original schedule instead of maintaining a desired headway. Therefore, the location of the previous train is practically irrelevant in schedule-based control strategies. The direct objective of the Schedule-based control strategy is to increase on-time performance of train operation in order to prevent train bunching. The trains are controlled to adhere to their own schedule regardless of how much train bunching occurs. Nevertheless, when train movements are close to the schedule, train bunching will be reduced.

Exist two type of Schedule-based control, the binary schedule based control and proportional schedule based control. The Binary Schedule-Based Control (BSBC) implies two options: full control or no control. BSBC control can be implemented easily, because the vehicles are operated only according to the planned schedule and the given tolerable deviation values. For schedule-based operation the tolerable deviation parameters are composed of two bound, the early bound xH and the late bound yH, H is the normal operation time. Moreover, proportional Schedule-Based control holds all early train for a certain time according to the deviation from its schedule.

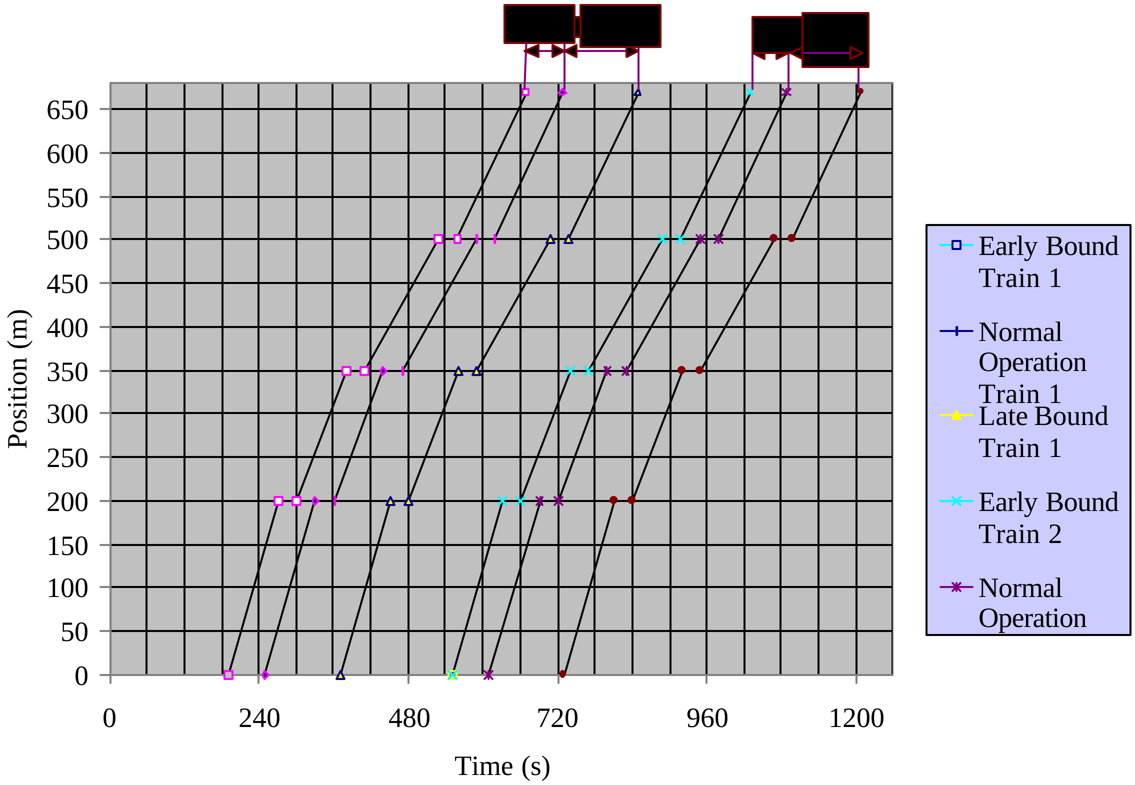
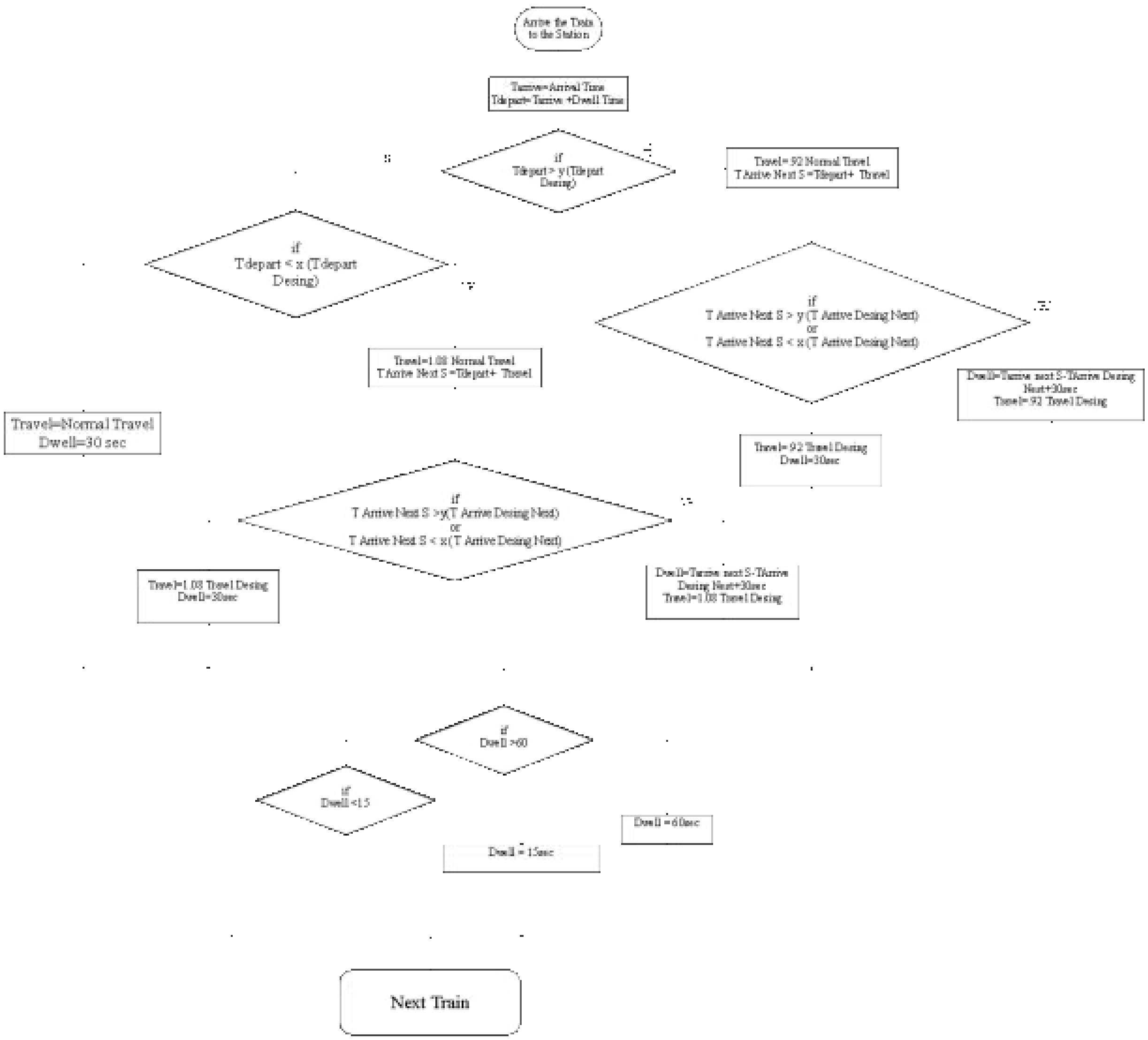


Figure 5.1 Schedule-Based Operation Space-Time Diagram

The figure 5.1 is an example of schedule-based operation Space-time Diagram. This graph present the schedule-based operation of a two train with the respective early bound and late bound. The factor x is the holding parameter and the factor y is the skipping control parameter. If a train is, arrive more early than the early bound (xH) is held to arrive inside the tolerable deviation values. If the train arrive later than the late bound schedule it may instructed to skip this station until return to the expected tolerance range.

Figure 5.2 Schedule-Based Adjustment Logic



When a system operates in "Schedule-Based Control," the system is set to the "Schedule Regulation Mode." In this mode the Automatic Train Operator adjust Dwell time and speed to correct any deviation from the planed schedule. This adjustment occurs immediately when a train arrives at a station. The Figure 5.2 presents a flow chart of the schedule based adjustment logic.

When a train arrives at the station, the prediction model estimates the departure time using the design dwell time. If the train is off-schedule, in other words the depart time is gather or less than the normal depart time range, the systems compute how much time the train can recover adjusting the travel speed. In the case that the train is late the system adjust the speed in the fast mode, in the opposite situation the system adjust the speed in the slow speed mode. For Tren Urbano specification the speed regimen is discrete whit three modes, normal speed mode, fast mode= 1.08 normal speed and slowest mode= 0.92 normal speed.

When the speed adjustment not completely corrects the deviation, the system corrects the dwell time. Although, if the speed adjustment result in a time adjustment grater than the necessary the system adjust only the dwell time. The dwell time is bounded by maximum and minimum default value. For Tren Urbano the planed maximum dwell time is 60 sec and minimum is 15 sec, for normal operation, the dwell time is 30 sec.

In addition to the previous mentioned adjustment, the system can also adjust the lead train in order to adjust the time between trains and preserve the schedule. The systems know the departure time for each station of the lead train. If the observed headway exceed the schedule headway plus a tolerance value (For Tren Urbano 8 minute) then the lead train will be delayed. The system adjusts the lead train because there is an increase in following headway; wish means that the trailing train is behind schedule. The adjustment depends in the location of each train if are entering, standing ore leaving the station. If a train is detected delayed entering to the station the system adjust the speed and the dwell time of the train at the station and adjust the lead train speed and dwell time at the next station. If the train is delayed at the station, the system adjusts the speed regimen and the dwell time at the next station. If the train is identified as delayed when leaving a station, the speed regimen and the dwell time of the lead train are adjusted. When the headway is minor than headway plus the tolerance value, the Automatic Train Regulator stop adjusting the speed and dwell for the lead train, but continue adjusting the delayed train.

5.2 Headway Based Operation

The major objective of the headway-based control strategies is to maintain proper train headways (that typically means equal headways) in order to reduce bunching and passenger wait time. Headway based control correct the train trajectory according to its location relative to the previous train. Hence, the departure time of the previous train at the station shall be collected in order to adjust the speed mode and the dwell time of the following train.

According to Ossuna (1972) and random incidence theory the expected value of the waiting time is given by the following expression:

$$E(W_t) = \frac{s_H^2 + E^2(H)}{2E(H)}$$ Equation 5.1

Where:

$E(W_t)$ = Expected Waiting Time for Random Arriving Passenger

E (H)= Average Headway Between Trains

s_H^2 = Headway Variance

The Headway-based operational logic is very helpful to reduce passengers waiting time. This control logic trying to reduce the variance of the headway will decrease the passengers waiting time.

The two subclasses of headway-based control are Binary Headway-Based Control (BIH) and Proportional Headway-Based Control (PRH). "Binary" implies two options: full control or no control. In a Proportional Headway-Based Control, headway is proportional to the deviation from a pre-planned headway H, and no rigid early bounds are applied.

A binary headway-based control strategy maintains the headway between tolerable bounds x H and y H with respect to a preceding vehicle. H is the normal headway respect to the preceding vehicle, x H is the minimum headway allowed and y H is the maximum headway accepted.

The main objective of proportional headway is to pull the early trains gradually to a desirable trajectory. When a train is more closer to a previous train than the preplanned headway, the train is hold proportional to the headway deviation and holding ratio x (0<x<1). At larger deviation from de expected trajectory, more is the holding time.

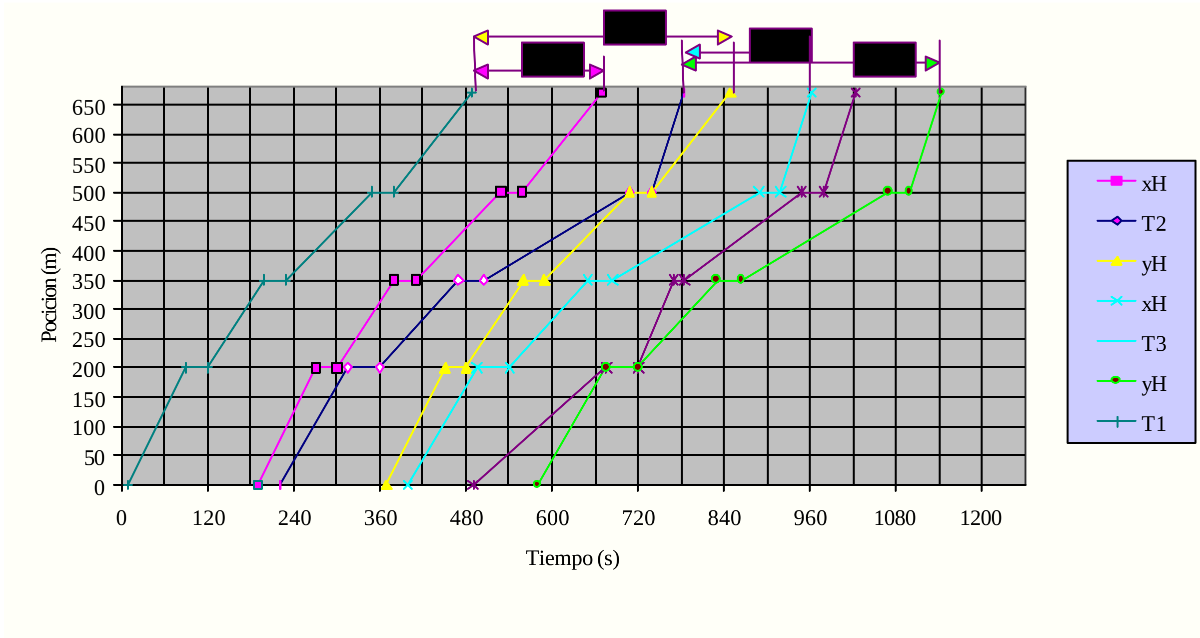
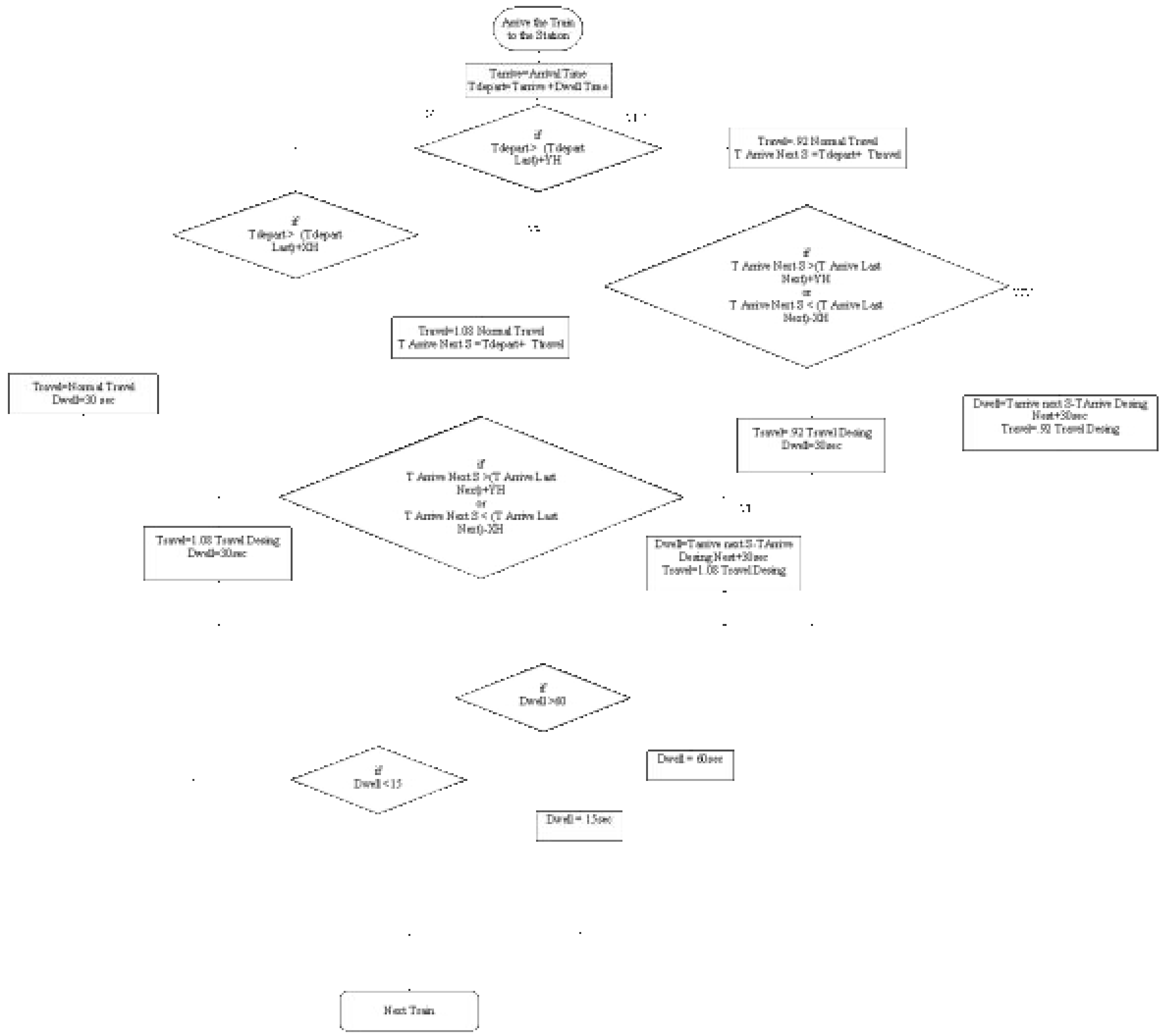


Figure 5.3 Headway-Based Operation Space-Time Diagram

The figure 5.3 presents an example of headway-based operation Space-time Diagram. This graph present the headway-based operation of a two train with the respective early bound and late bound. The factor x is the holding parameter and the factor y is the skipping control parameter. If the headway between the lead train and the preceding train is less than the early bond xH, the preceding train is held to arrive inside the tolerable deviation values. If the headway is gather than the late bond headway the dwell time is reduced and the speed is increased in order to adjust the delay. In some occasion, the preceding train is instructed to skip the station.

When a system operates under headway-based strategy, the system is set to the "Headway Regulation Mode." In this mode the Automatic Train Operator adjust dwell time and speed to correct any deviation from the planed headway. This adjustment are based according to he train location relative to the previous trains. The Figure 5.4 presents a flow chart of the headway based adjustment logic.

Figure 5.4 Headway-Based Adjustment Logic



When a train arrives at the station, the prediction model estimates the departure time using the design dwell time. If the depart time is gather or less than the normal depart time range relative to the previous train, the systems compute how much time the train can recover adjusting the travel speed. In the case that the train is late the system adjust the speed in the fast mode, in the opposite situation the system adjust the speed in the slow speed mode.

If the speed adjustment not completely corrects the headway deviation, the system corrects the dwell time. Although, if the speed adjustment result in a time adjustment grater than the necessary the system adjust only the dwell time. If the train is late the system reduce the dwell time moreover if the train is early the system increase the dwell time.

6 Tren Urbano Four Station Model

In order to study the operation of the Tren Urbano system from the user perspective, it is important to have a model that allows the examination of possible operational strategies that could be used by the operator. This research project describes the design process of a simulation model and the application SIMAN/Arena simulation tool to model the Tren Urbano system. This model includes an animation of the traffic processes that allow us to visualize the systems performance. The simulation model developed under this research project is expected to be used as a building block of the entire Tren Urbano network.

6.1. Stations to be modeled

The four Tren Urbano stations to be modeled are: Sagrado Corazon, Hato Rey, Roosevelt and Domenech.

The Sagrado Corazón Station will serve as turn back point for trains from a northerly direction of travel to a southerly direction of travel. A crossover will be located after the station in order to makes this change of direction. Under normal conditions it is projected that only one train will occupy the Sagrado Corazón station at a time, while the incoming trains will be arriving at Bayamón very close to the same time that the outgoing train is departing.

The table 6.1 presents the most important characteristic of the modeled station.

Table 6.1: Station Characteristics

Station	# gates	# tellers	Tvms	Platform	boardings (pasenger)
Domenech	3	1	3	Dual Side	2548
Roosevelt	8	2	6	Dual side	6,788
Nuevo Centro	13	3	8	Center	11,711
Sagrado Corazón	6	2	5	Center	13,855
Total	27	7	16		32354

6.2. Conceptual Model

This section describes the preliminary model either graphically (e.g., block diagrams) and defines the components, descriptive variables, and interactions (logic) that constitute the system. In addition this section includes the algorithms to be used to describe the system, impute required, and output generated. The assumptions made about the system are presented in this section.

6.2.1 System Diagram and variables

The analyzed system consists of fourth consecutive station whit 4-minute headway during the morning peck hours. The model diagram is presented in the figure 6.2. Each station has similar layout and are modeled according to the most important passengers processes in a heavy rail system. The four main processes are vending and validation process, the platform waiting time process, the train process and leave the station. The figure 6.2 presents the typical station layout.

Figure 6.1: System Diagram

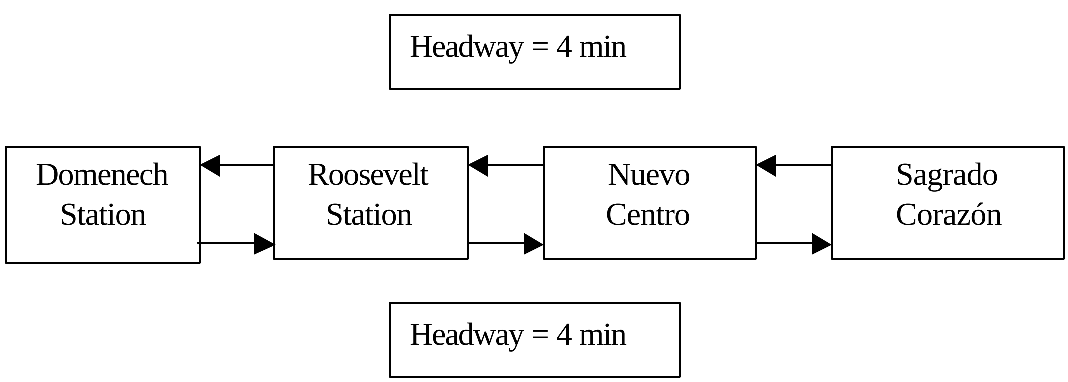
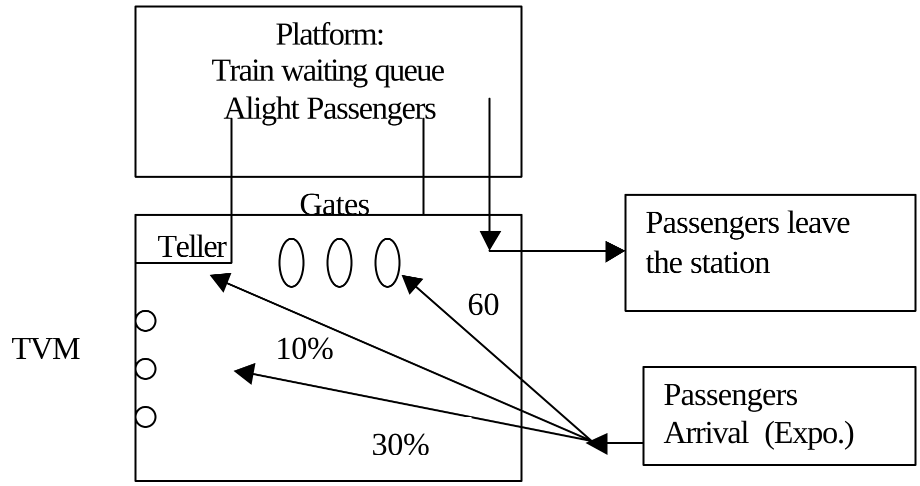


Figure 6.2: Typical Station Diagram



System Variable

A. Entities

1. Dynamic Entities – users
2. Static Entities – TVM, Gates, Train and Tellers

B. Variables of state

1. TVM station # 1 (0,1,2,3,4, N y 0,1,2,3,4 S) busy or idle
2. TVM station # 2 (0-8)S and (0-4)N busy or idle
3. TVM station # 3 (0-4)N and (0-4)S busy or idle
4. Gates station #1 (0-4) N and (0-4) S busy or idle
5. Gates station #2 (0-3) N, (0-5) SA and (0-5) SB busy or idle
6. Gates station #3 (0-4) N and (0-4) S busy or idle
7. Number of people in line in station (integer variable)
8. Number of people on the platform (integer variable)
9. Teller 1,2 or 3 busy or idle

C. Events

1. Arrival of a passenger to a station
2. Transfer of a passenger to another station
3. Transfer of a passenger from a Tvm to gate.
4. Departure of a passenger

5. Transfer of passenger from teller to platform
6. Transfer of passenger from gates to platform

D. Attributes

1. Destine
2. Have ticket? 1= have 2 = buy at TVM, buy at Teller
3. Arrival time to platform

6.3. Model Assumption:

Several assumptions are made to simplify the model because we do not have known of several details of the system. The most important are listed below:

- The system operates in the morning peak hour.
- Assume people arrive randomly with an exponential distribution
- The Queuing discipline is FIFO.
- The service rates are adapted from similar system.
- No Train Control Strategies Restriction
- The distribution of passenger payment method is 60% have ticket, 20% buy at TVM and 10% buy at Teller.
- The walking time between the gates and the platform discard elevator time an mechanic escalators time.

6.4. Data Collection

Data collected for this model was provided by the Tren Urbano Office, and was used to evaluate the overall performance of the system under specified conditions and chosen environment. The service rates are adapted from systems similar to the Tren Urbano.

The passenger inter-arrival time assumed to be exponential and is based on the Tren Urbano ridership projections. The Table 6.2 presents the inter-arrival time for each station in the morning peak period. The passenger distributions are presented in the Origin-Destine Matrix in Table 6.3 this matrix is based on the Cambridge Systematic studies for Tren Urbano Project. Each value in the table represents the percent of the arrived passenger go to the respective station.

Table 6.2: Station Passenger Inter-arrival time

STATION	INTER-ARRIVAL TIME TO SC (MIN/PSG)	INTER-ARRIVAL TIME TO BAY (MIN/PSG)
Domenech	.8571	.3821
Roosevelt	1.7143	.2222
Nuevo Centro	2.1429	.2359
Sagrado Corazon	0	.0554

Table 6.3: Tren Urbano Origin-Destine Distribution Matrix

	BAY	DEP	RBA	TOR	MRN	SAL	SFR	CME	CUP	RPI	UPR	CJU	DOM	HAR	NCE	SCO
BAY	0.0	0.1	1.8	1.1	3.3	2.3	1.7	5.8	11.3	18.1	20.5	4.3	3.4	9.3	7.9	9.0
DEP	1.0	0.0	2.0	1.0	3.4	2.4	1.8	5.7	12.6	18.0	20.3	4.1	3.2	9.4	7.6	8.6
RBA	55.7	44.3	0.0	5.8	5.3	4.1	2.1	4.8	10.0	16.5	16.1	3.3	2.5	8.2	6.3	14.9
TOR	51.4	26.1	22.5	0.0	2.8	3.2	1.9	5.1	15.7	21.4	19.4	3.5	2.7	6.3	6.0	12.0
MRN	53.0	34.5	8.7	3.8	0.0	0.1	0.9	4.9	14.9	17.4	22.8	3.4	2.9	6.7	6.7	19.5
SAL	53.0	32.6	9.3	5.0	0.2	0.0	0.8	4.8	11.8	16.4	23.6	3.4	2.8	7.4	6.9	22.0
SFR	51.6	34.0	6.4	4.6	0.8	2.6	0.0	2.0	13.6	4.9	30.4	4.3	3.4	8.5	7.2	25.8
CME	51.1	30.8	4.8	4.8	2.4	5.9	0.3	0.0	8.7	5.0	30.3	4.1	3.6	9.2	7.4	31.7
CUP	41.3	26.0	3.5	7.5	2.9	5.4	8.0	5.3	0.0	0.6	20.0	4.9	4.9	16.4	11.7	41.5
RPI	43.5	28.3	3.7	6.2	2.3	5.4	9.4	1.2	0.0	0.0	0.4	0.7	3.6	17.6	24.3	53.4
UPR	35.8	21.1	2.7	3.8	1.8	5.4	8.6	6.7	13.9	0.1	0.0	0.0	5.0	21.1	16.7	57.3
CJU	42.0	25.6	3.4	3.6	1.3	4.2	6.4	4.0	7.0	1.6	0.9	0.0	0.7	19.9	25.7	53.7
DOM	27.4	16.9	2.2	2.2	1.2	2.9	4.5	3.1	12.8	13.6	13.3	0.0	0.0	7.6	11.2	81.2
HAR	24.3	14.8	1.9	1.6	1.0	2.6	3.8	2.4	13.2	18.4	14.4	1.0	0.5	0.0	0.0	100.0
NCE	23.0	14.0	1.8	1.7	1.1	2.5	3.4	1.9	13.4	20.3	14.2	1.6	1.1	0.0	0.0	100.0
SCO	12.6	6.2	1.4	1.4	1.5	3.9	6.1	5.1	19.7	20.6	16.6	3.3	1.5	0.2	0.0	0.0

The service rate is adapted of system similar to the Tren Urbano. The table 6.4 presents the service rates and its statistical distribution.

Table 6.4: Resources Service Rate and its Distribution

RESOURCE	MEAN SERVICE TIME (MIN)	DISTRIBUTION (MIN)
Teller	.75	Triangular (.6,.75,1.1)
TVM	.75	Triangular (.5,.75,1)
Gates	.075	Triangular (.05,.075,.1)

6.5. Model development

In this section is formulated the conceptual model in an appropriate simulation language such as Arena. The simulation model is constructed based on the solution defined in the initials steps and collected data.

The station Model:

This model represents the arrival process of people to the station, Payment method and gates. The passenger is created and then is transported to the Station. Then According if have ticket or no are distributed in the different station. If the passenger has ticket go directly to the entrance gates, moreover, if the passengers do not has ticket go to the TVM or teller and then go to the entrance gates. Then the passengers go to the desired platform according to the travel direction.

The figure 6.3 show the Arena Interface related to passenger creation and attribute designation. The arrival of passengers is random and continuous. The exponential distribution is used to model the arrival process because exist much variability. The typical station logic is presented figure 6.4. , The passengers are divided in two groups according to the possession of their tickets: if the passenger has the ticket or if the passenger does not have a ticket. The user that has ticket goes directly to the entrance line, validate the ticket and enter the station. If the user does not have the ticket he/she should go to a line and buy it in the ticket vending machine. Then he/she goes directly to the entrance line, validates the ticket and enters the station. Finally the passenger pass to the corresponding platform according to the destination. The Appendix 1 has an SIMAN model example.

Figure 6.3: Arena Model Passenger Creation

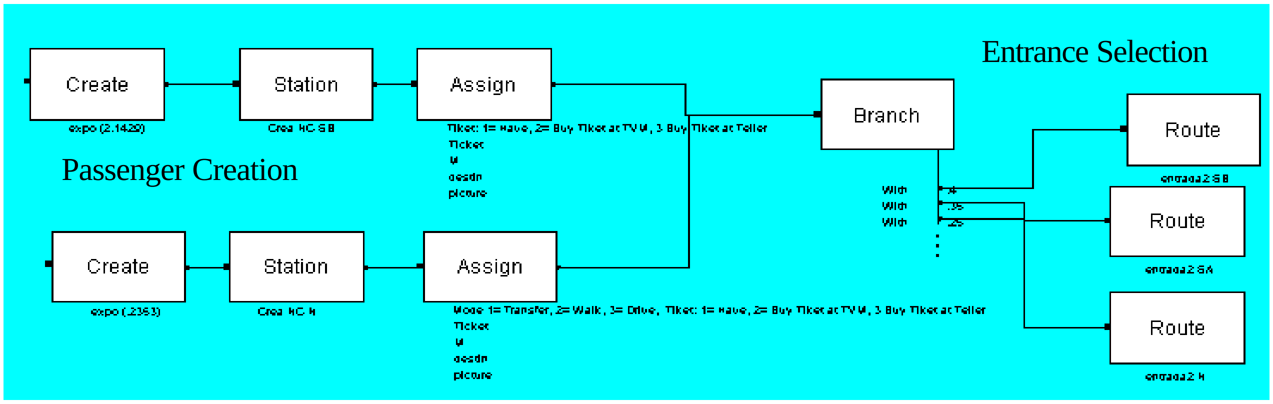


Figure 6.3: Arena Model Station Process

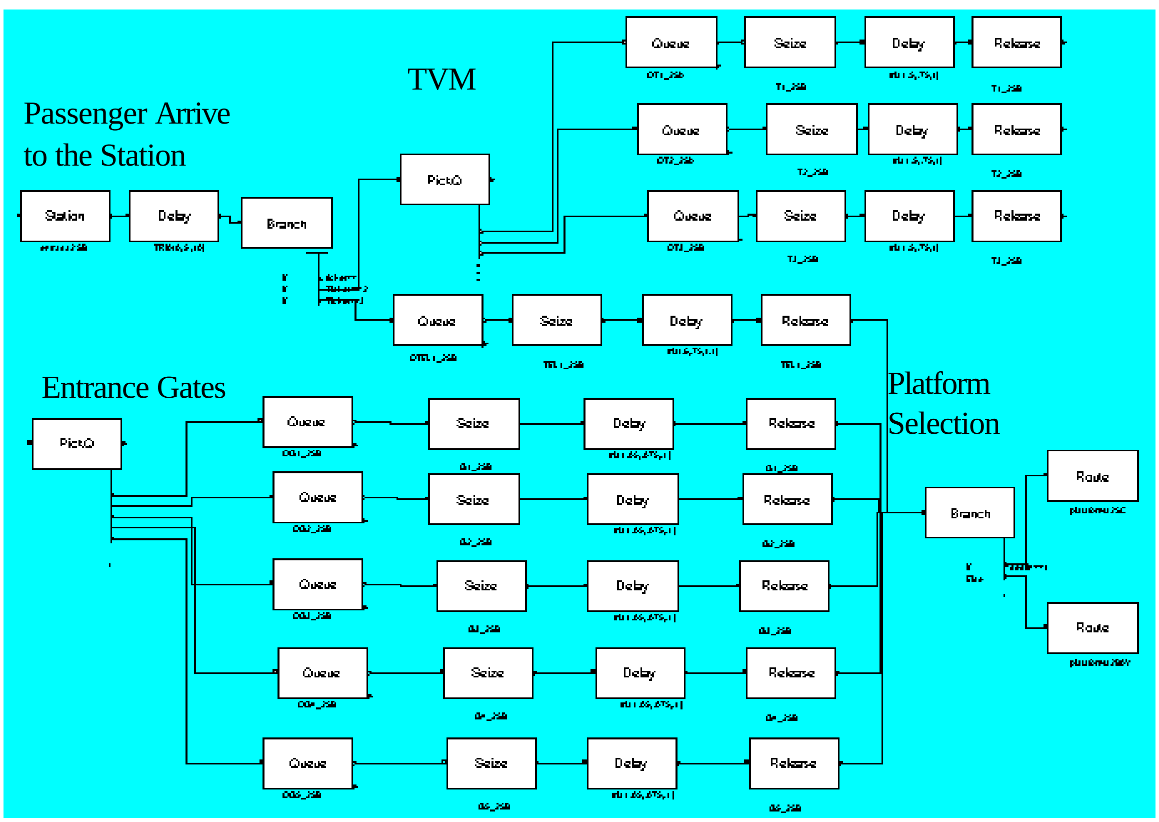


Figure 6.5: Terminal Stations platform process

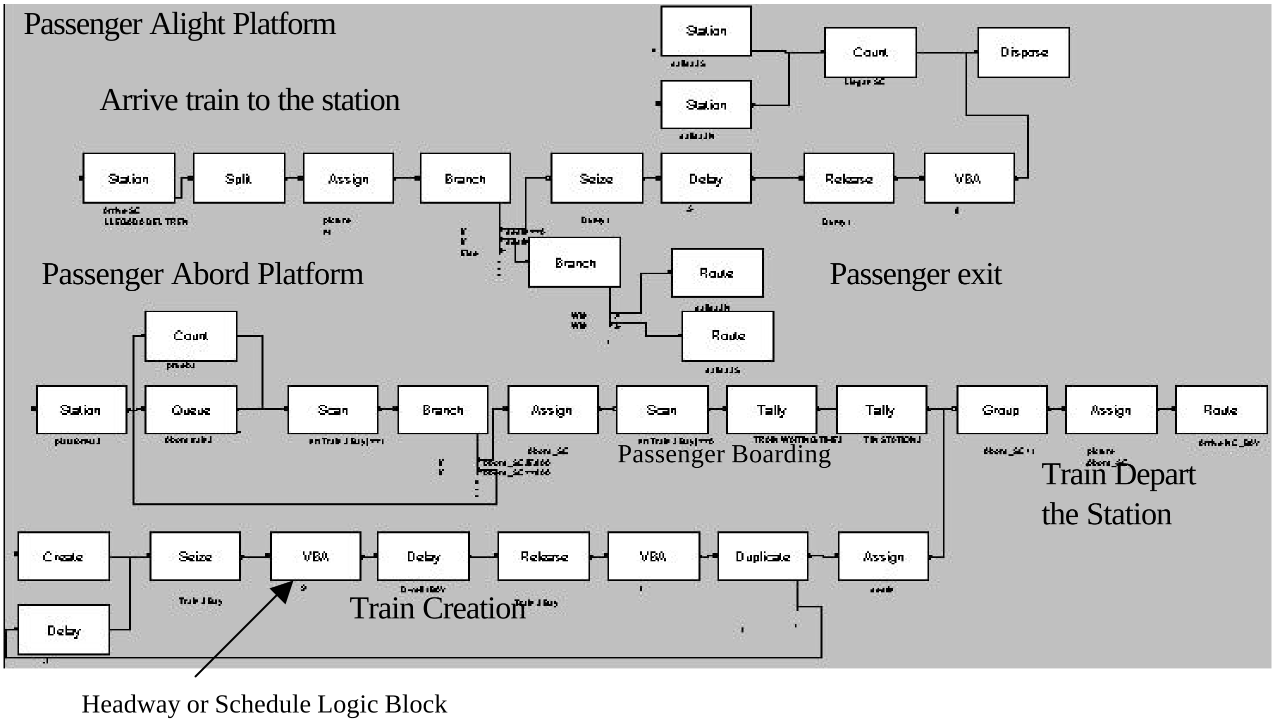
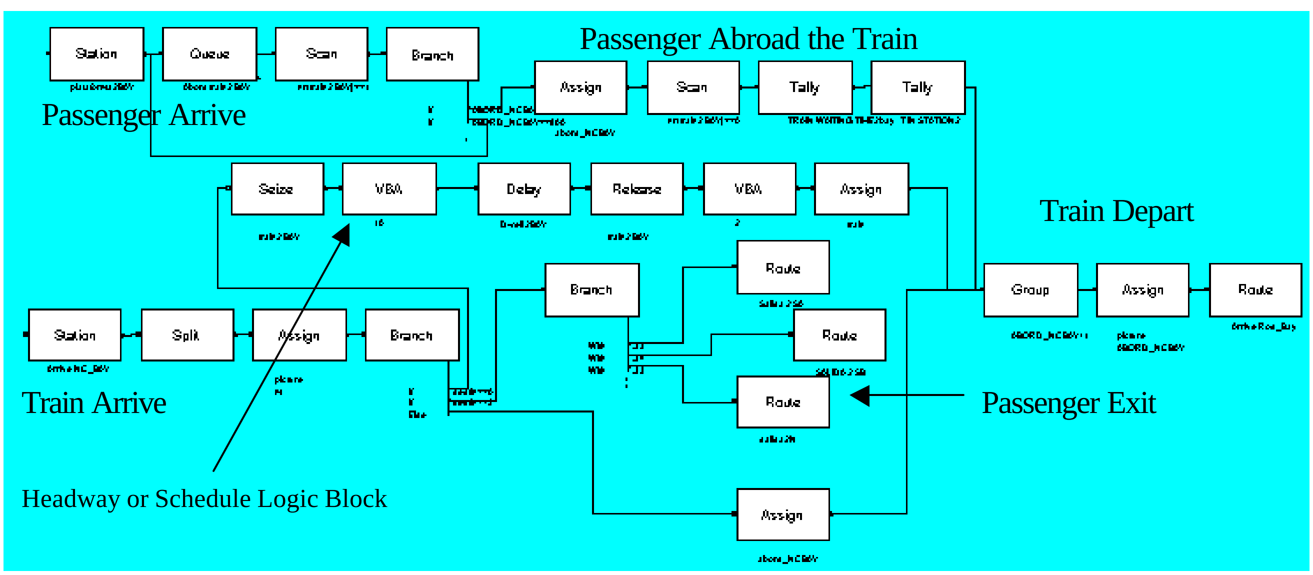


Figure 6.6: Intermediate Stations platform process



The platform and train processes are presented together and vary if the station is a terminal station or the platform is an intermediate station. Both cases are presented in the Figure 6.5 and Figure 6.6 respectively In this process the passenger arrive to the platform and white for a train. When the train arrives the system check if the passenger can hold the train. When a train arrives at the stations the passenger have 30 second to leave or pick-up passengers. If a passengers no leave the train at this station and is added to the train group.

The headway based or Schedule based logic is implemented using Visual Basic Application VBA in the respective VBA block. The schedule based and headway-based logic used in the VBA is previously discussed in the Rail system operation section. Both codes are presented in the Appendix 2 and 3 respectiveley.

7 Model Validation

We use Queuing Theory and Random incidence theory to validate the system queuing process and train waiting time. Before validate the model is necessary to run a pilot run in order to analyze the model performance. Ten replications are conducted in order to perform the system validation.

7.1 The Random Incidence Theory

The Random incidence theory is based on a random time assumption. A potential train passenger, start observing the process at random time, and he or she wishes to obtain the mean time she or he must wait until the next arrival occur. This expected waiting time depend on the history of actual arrival time process. If the system has no incident situation, the expected waiting time is nearest to a half of the headway. For headway of 4 minutes, the expected waiting time is 2 minutes. For the system, the average waiting time is 1.985 minute whereby the model waiting time validates.

The Table 7.1 and 7.2 presents the random incidence verification for both travel directions.

Table 7.1 Train Waiting Time Validations in Direction to Bayamón

STATION	AVERAGE WAITING TIME	UPPER BOND	LOWER BOND	EXPECTED VALUE	VALIDATE?
Domenech	1.9947	2.0212	1.9947	2	YES
Nuevo Centro	1.988	2.024	1.952	2	YES
Roosevelt	1.986	2.022	1.901	2	YES
Domenech	2.0125	2.0485	1.9465	2	YES

Table 7.2 Train Waiting Time Validations in Direction to Sagrado Corazon

STATION	AVERAGE WAITING TIME	UPPER BOND	LOWER BOND	EXPECTED VALUE	VALIDATE?
Domenech	NA	NA	NA	NA	NA
Nuevo Centro	1.9675	1.7775	1.9675	2	YES
Roosevelt	1.963	2.009	1.917	2	YES
Domenech	1.9854	2.0414	1.9294	2	YES

7.2 Open Jackson Network Queuing Process Validation

The second part of the validation is made using Queuing Theory with a M/M/1/inf system whit parallel channels. To validate the model using queuing theory is necessary to considerate the following:

- Its important that the parameter arrival rate divided by the service rate(r) <1
- The probability that a server its Busy= ρ .

Domenech station is selected to analyze the validation of the model because all station has similar characteristic.

Open Jackson Network Software is used to analyze the passenger arrival rate and node performance for Domenech station. The diagram presented in Figure 7.1 present the passenger arrival step to each stage.

Figure 7.1 System Arrival Rate Distribution Diagram

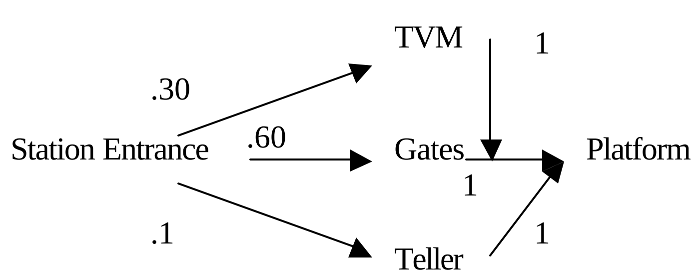


Table 7.3: Model Validation for Domenech Station

Domenech AVERAGE						
Node Performance Measures						
Node		LLEG	TVM	GATE	TELLER	PLAT
g		2.617116	0	0	0	0
m		0.000001	1.333333	13.33333	1.333333	0.00001
Servers		10	3	3	1	1
l		2.617116	0.785135	2.355404	0.261712	2.617116
r			19.63%	5.89%	19.63%	
L			0.594581	0.176707	0.24422	
Lq			0.00573	5.12E-05	0.047936	
W			0.757298	0.075022	0.933165	
Wq			0.007298	2.17E-05	0.183165	
Domenech MAX						
Node Performance Measures						
Node		LLEG	TVM	GATE	TELLER	PLAT
g		2.617116	0	0	0	0
m		0.000001	1	10	0.909091	0.00001
Servers		10	3	3	1	1
l		2.617116	0.785135	2.355404	0.261712	2.617116
r			26.17%	7.85%	28.79%	
L			0.802719	0.2357	0.404263	
Lq			0.017584	0.000159	0.11638	
W			1.022396	0.100068	1.544689	
Wq			0.022396	6.76E-05	0.444689	
Domenech MIN						
Node Performance Measures						
Node		LLEG	TVM	GATE	TELLER	PLAT
g		2.617116	0	0	0	0
m		0.000001	1.666667	20	2	0.00001
Servers		10	3	3	1	1
l		2.617116	0.785135	2.355404	0.261712	2.617116
r			15.70%	3.93%	13.09%	
L			0.473483	0.117781	0.150557	
Lq			0.002402	1.03E-05	0.019701	
W			0.60306	0.050004	0.575279	
Wq			0.00306	4.37E-06	0.075279	

	Domenech Station Validation						
TVM							
PARAMETER	MODEL AVERAGE	MAX	AVERAGE	MIN			
r	21%	26.17%	19.63%	15.70%	TRUE	TRUE	Validate
Lq	0.010137	0.017584	0.00573	0.002402	TRUE	TRUE	Validate
Wq	0.01	0.022396	0.007298	0.00306	TRUE	TRUE	Validate
GATES							
PARAMETER	MODEL AVERAGE	MAX	AVERAGE	MIN			
r	7.83%	7.85%	5.89%	3.93%	TRUE	TRUE	Validate
Lq	4.01E-05	0.000159	5.12E-05	1.03E-05	TRUE	TRUE	Validate
Wq	5.30E-06	6.76E-05	2.17E-05	4.37E-06	TRUE	TRUE	Validate
TELLER							
PARAMETER	MODEL AVERAGE	MAX	AVERAGE	MIN			
r	28.76%	28.79%	19.63%	13.09%	TRUE	TRUE	Validate
Lq	0.04	0.11638	0.047936	0.019701	TRUE	TRUE	Validate
Wq	0.2	0.444689	0.183165	0.075279	TRUE	TRUE	Validate

As presented in the table 7.3 the system validates for Domenech station so the model logic validate.

8 Result and Incident Scenarios Analysis:

This section present the most relevant result related to the simulation model.

The firs result presented are related to an ideal operation of the system. These results are used as base case scenario to compeer the system normal operation and system incident scenarios.

The minors incident scenarios analyzed in this research project are presented in the table 8.1. The Scenario is divided in two case by the delay time and is solved using headway based operation and Schedule based operation.

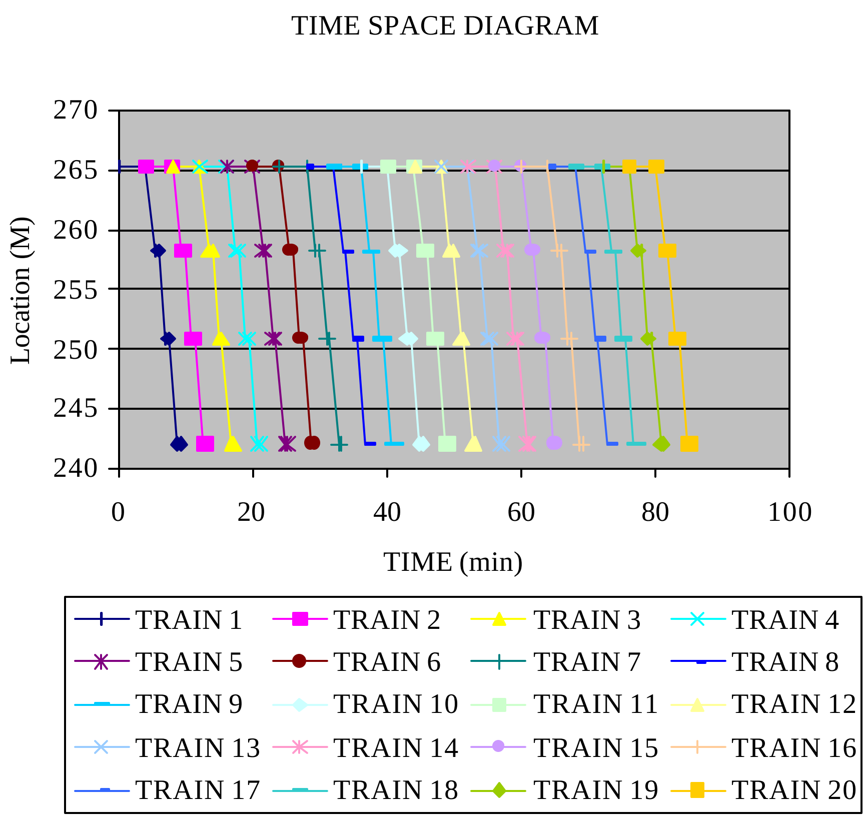
Table 8.1 Studied Scenarios Description

SCENARIO	DELAY RANGE	DESCRIPTION
1	Less than one headway	3 minute NC direction to Bay
2	Greater than one headway but less than two headways	7 minutes delay at Roosevelt station direction to Bay.

8.1 Ideal Operation

The normal operation analyzed in this section represents the morning peak hour. The headway is 4 minutes and no incident situation occurs during the two our modeled. The Figure 8.1 presents the normal operation Time Space Diagram in Direction to Bayamón. Appendix 4 presents a result summary.

Figure 8.1 Ideal Operation Time Space Diagram in Direction to Bayamón



The number of passenger waiting depends in the passenger arrival process to the station and the resources performance. The table 8.2 presents the Average passenger waiting for an Ideal operation and average waiting time. In addition the figure 8.2 and 8.3 present the ideal operation passenger waiting time and passenger waiting respectively for station Roosevelt.

Table 8.2 Average Passenger Waiting and Waiting Time Ideal Operation

STATION	LOCATION	AVERAGE WAITING	WAITING TIME
SC	265.33	53.130	2.14
NC	258.21	17.73	2.05
ROS	250.85	39.32	2.02

Figure 8.2 Ideal Operation Passenger Waiting Time

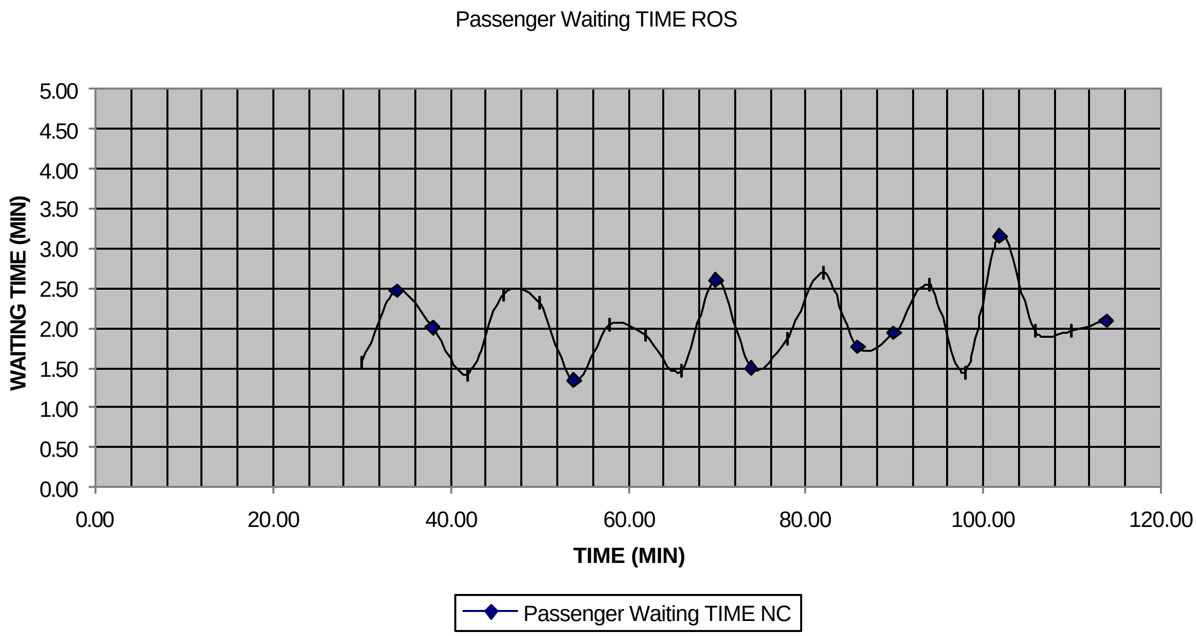
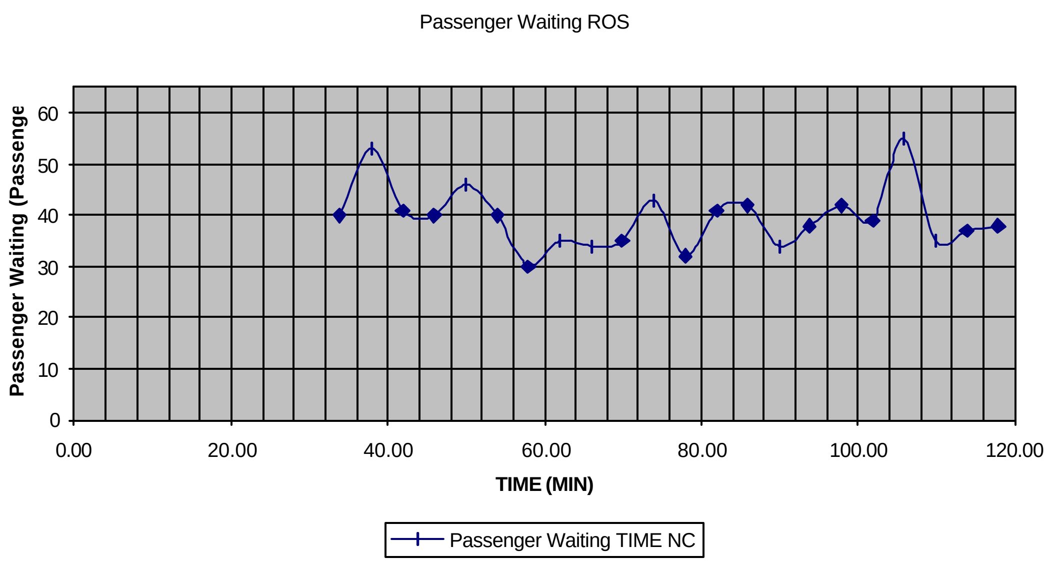


Figure 8.3 Ideal Operation Passenger Waiting



8.2 Less than one headway Disruption

The incident scenario 1 represents a minor disruption that is less than one headway. This scenario is a failure in the system at station Nuevo Centro at 7:27 AM. The disruption caused by this scenario is 3 minute.

8.2.1 Schedule Base Approach

The results presented in this section are based on a schedule-based approach to recuperate to the delay. Figure 8.4 p resent the time space diagram for the established scenario. The train 14 is affected by the failure in the station NC. The train 15 is to close to the train 14 this cause bunching in the system. The waiting time increase at the incidents time but then return to the normal value. Similar occurs with the passenger waiting in the platform. The figure 8.5 and 8.6 present how vary the passenger Waiting Time at NC and ROS respectively. In addition the Figure 8.7 and 8.8 present how vary the passenger Waiting at NC and ROS respectively.

Figure 8.4 Three Minutes Delay Time Space Diagram in Direction to Bayamón:

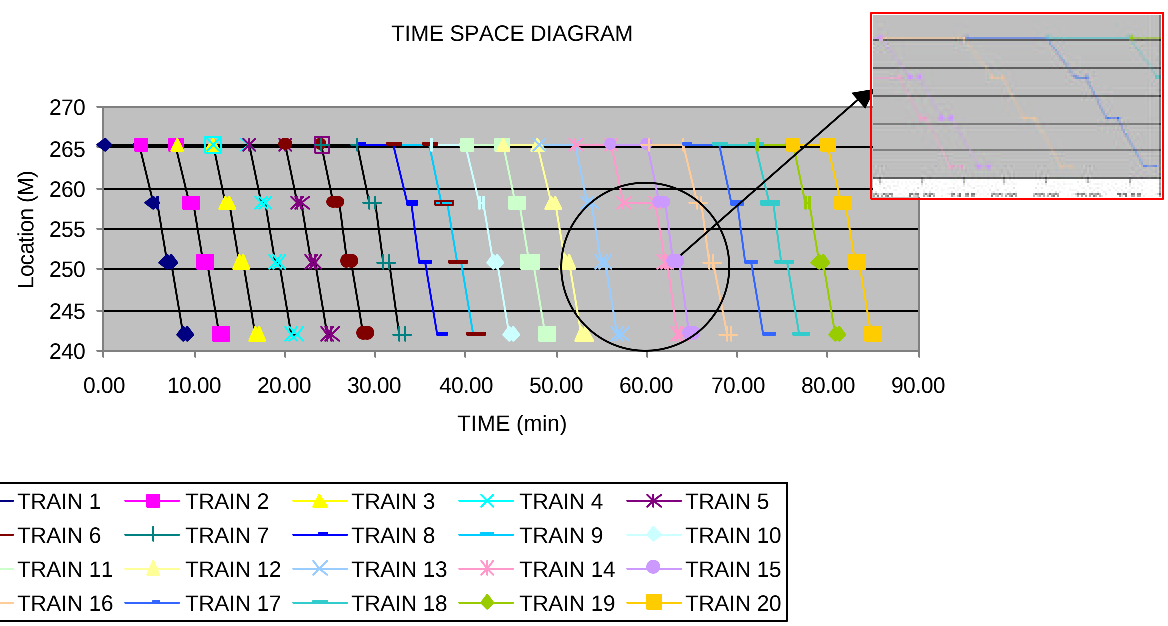


Figure 8.5 Three-Minute Delay Passenger Waiting Time Nuevo Centro:

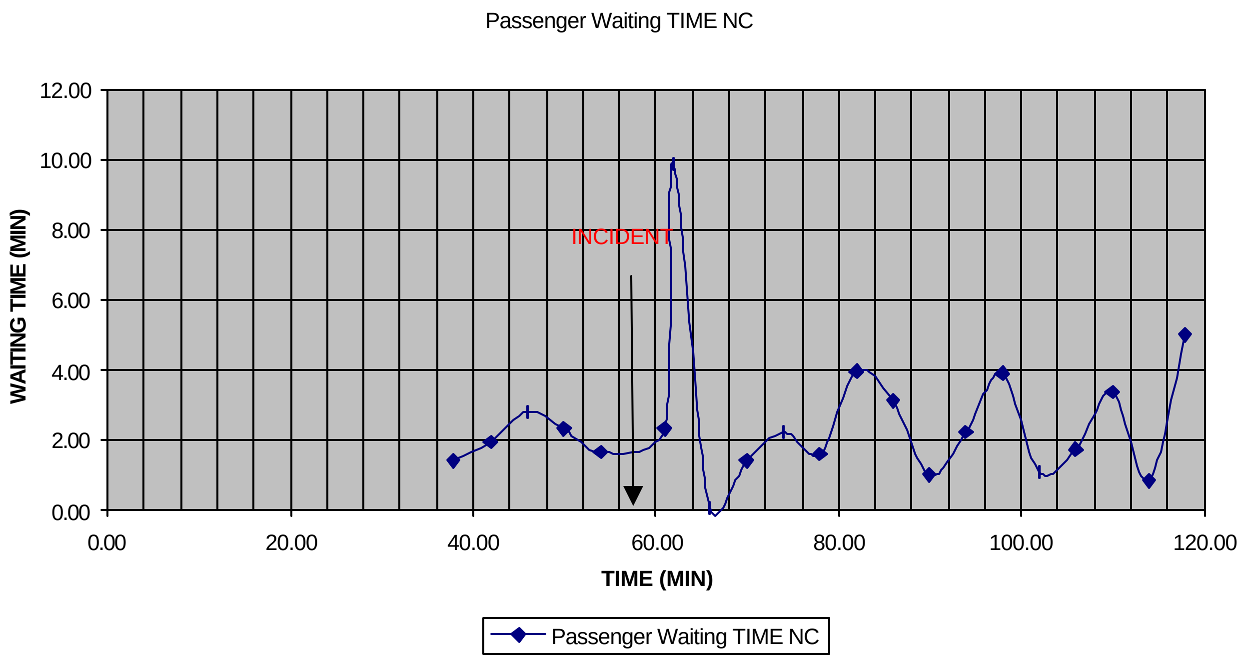


Figure 8.6 Three-Minute Delay Passenger Waiting Time Roosevelt:

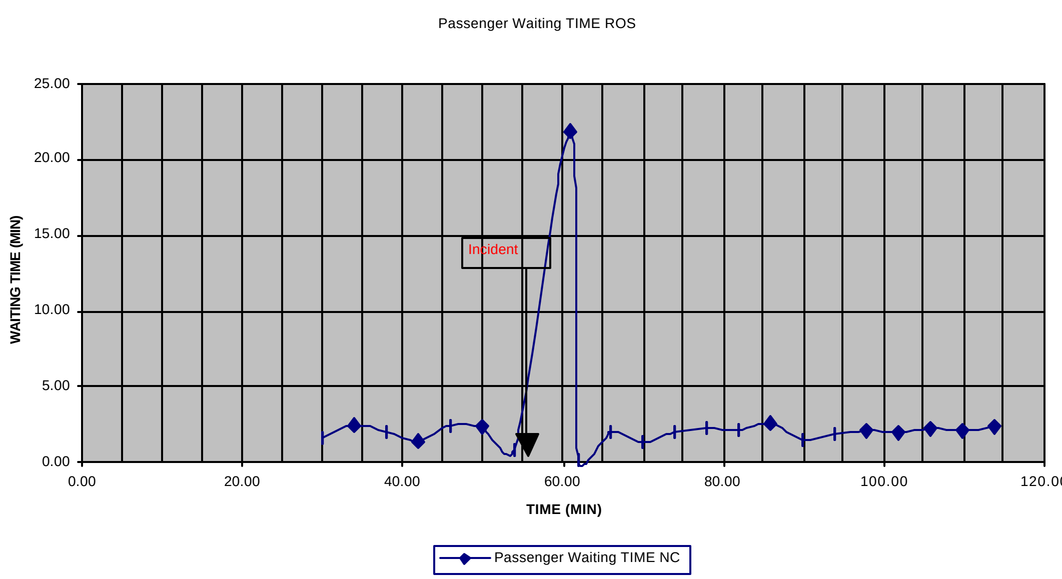


Figure 8.7Three-Minute Delay Passenger Waiting Nuevo Centro:

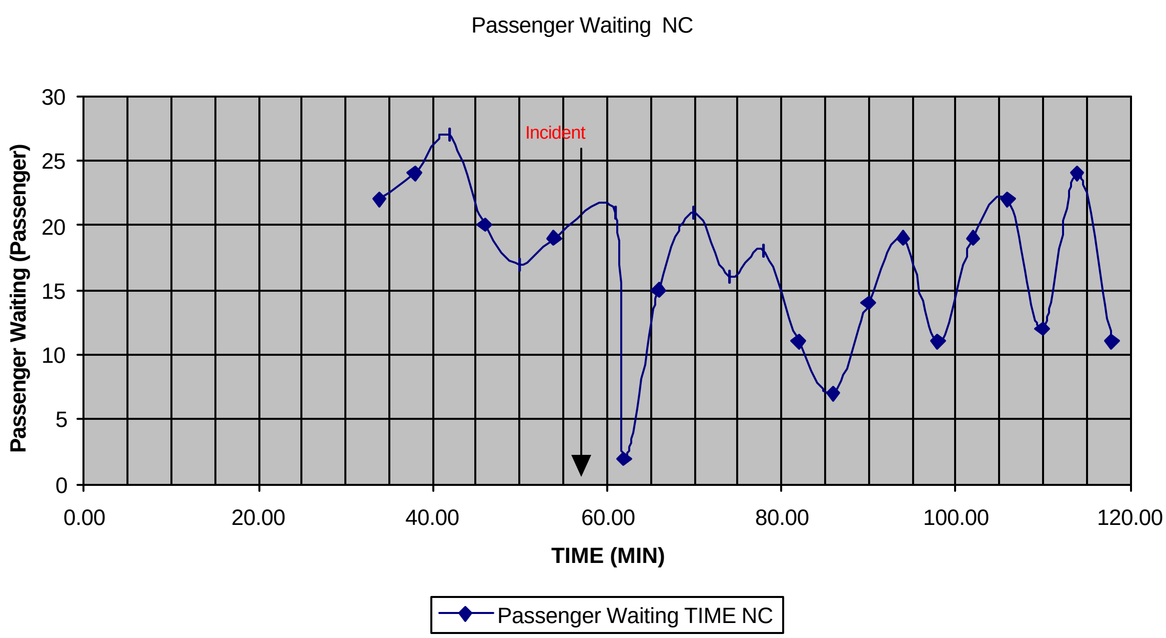
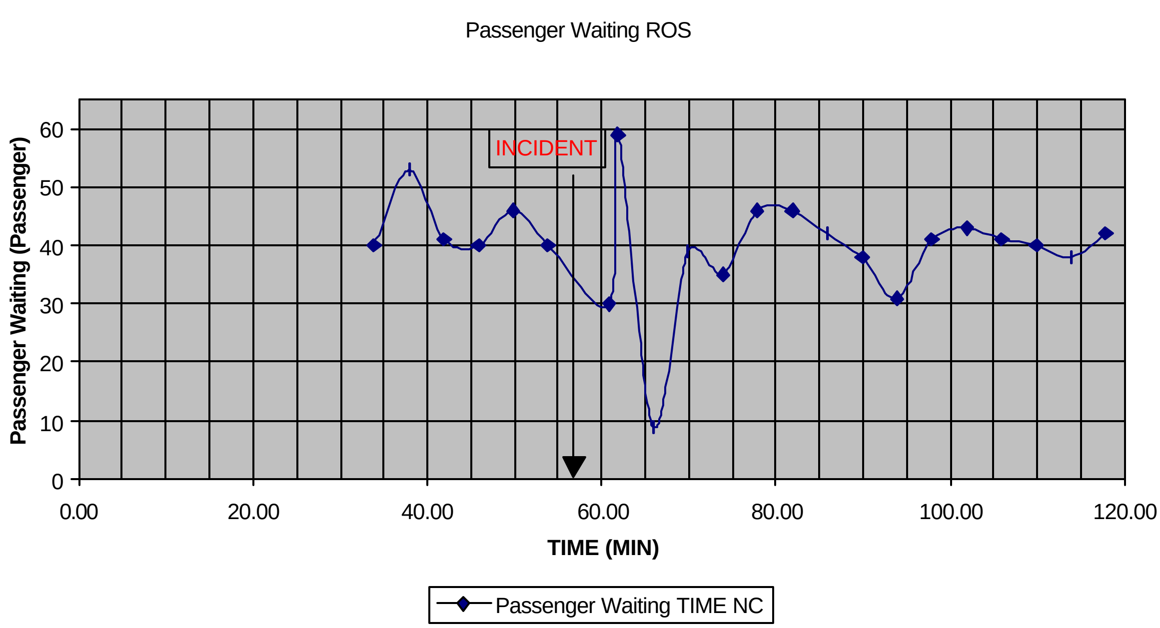


Figure 8.8 Three-Minute Delay Passenger Waiting Roosevelt:



8.2.2 Headway Based Solution Approach

The results presented in this section are based on a headway-based approach to recuperate to the delay. Figure 8.8 present the time space diagram for the established scenario. The train 14 is affected by the failure in the station NC. The train 15 is to close to the train 14 this cause bunching in the system. The waiting time increase at the incidents time but then return to the normal value. Similar occurs with the passenger waiting in the platform. The figure 8.9 and 8.10 present how vary the passenger Waiting Time at NC and ROS respectively. In addition the Figure 8.11 and 8.12 present how vary the passenger Waiting at NC and ROS respectively.

Figure 8.9 Three Minutes Delay Time Space Diagram in Direction to Bayamón:

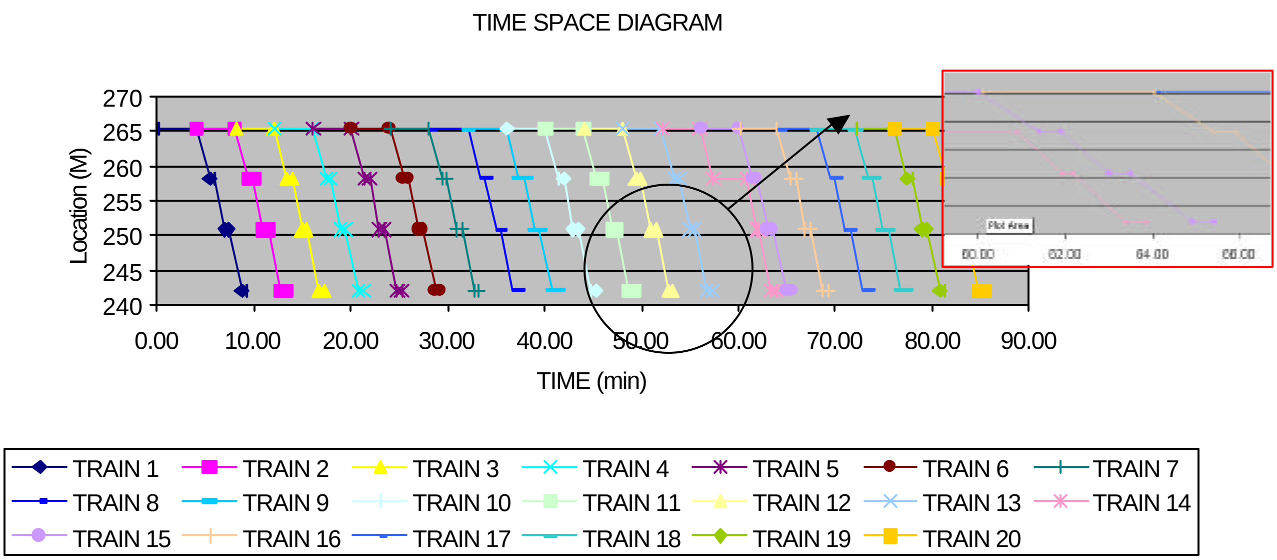


Figure 8.10 Three-Minute Delay Passenger Waiting Time Nuevo Centro:

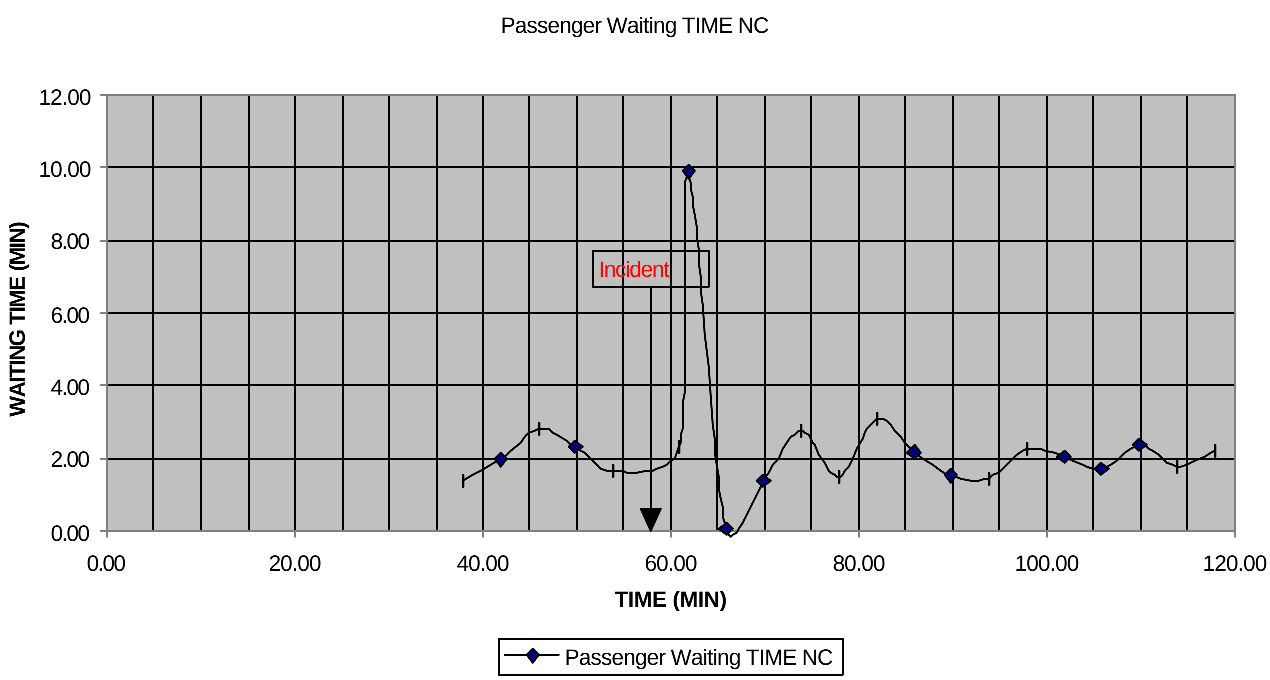


Figure 8.11 Three-Minute Delay Passenger Waiting Time Roosevelt:

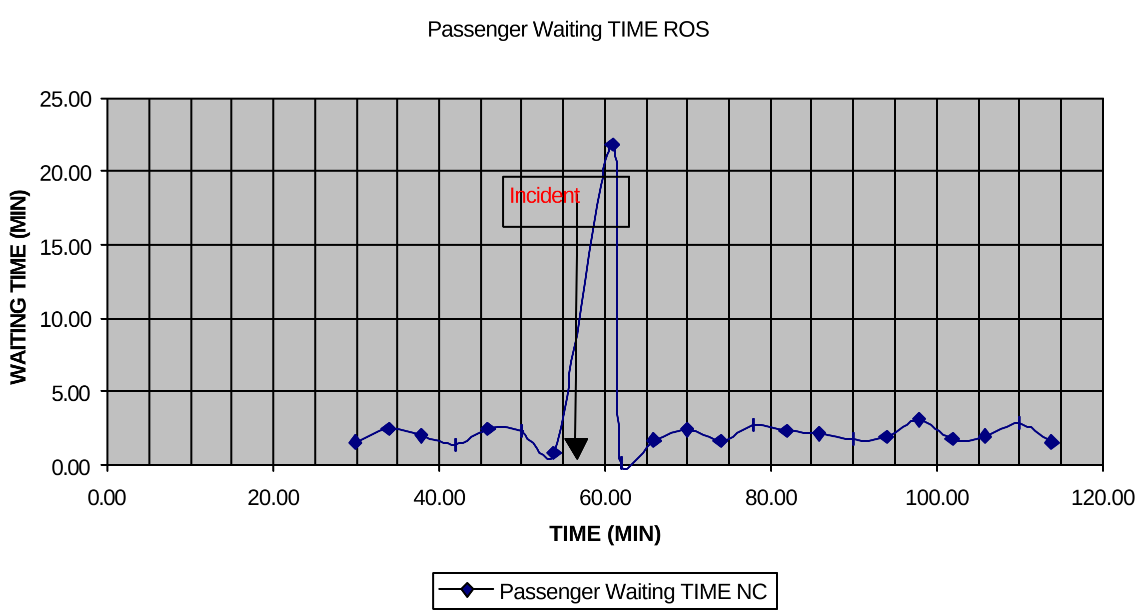


Figure 8.12 Three-Minute Delay Passenger Waiting Nuevo Centro:

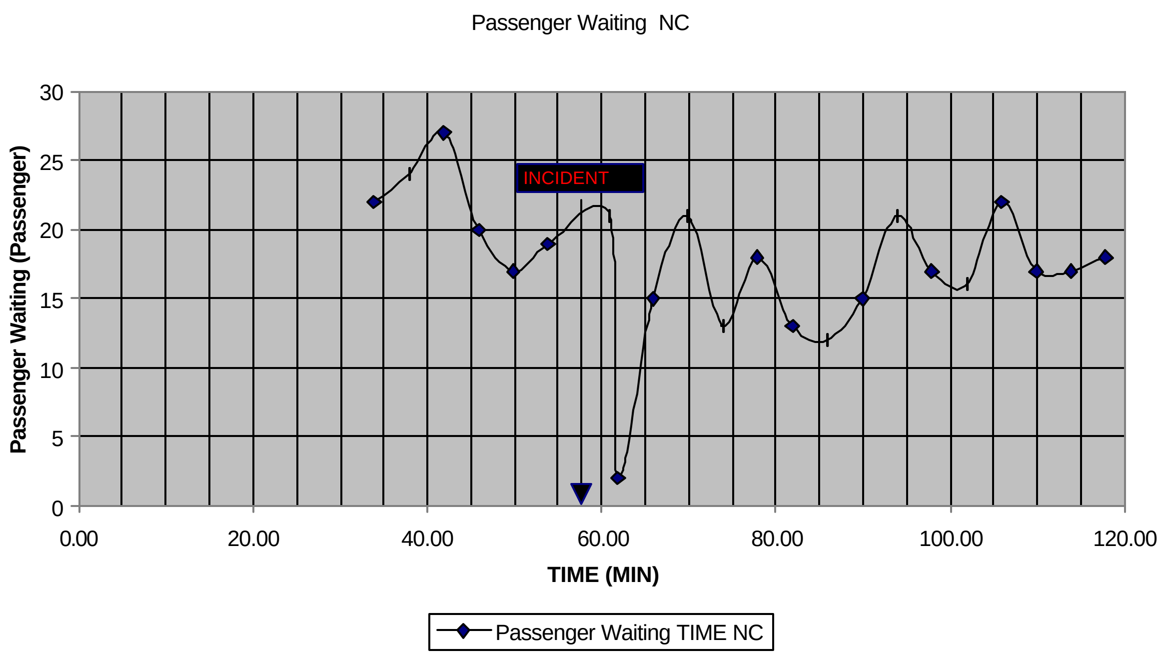
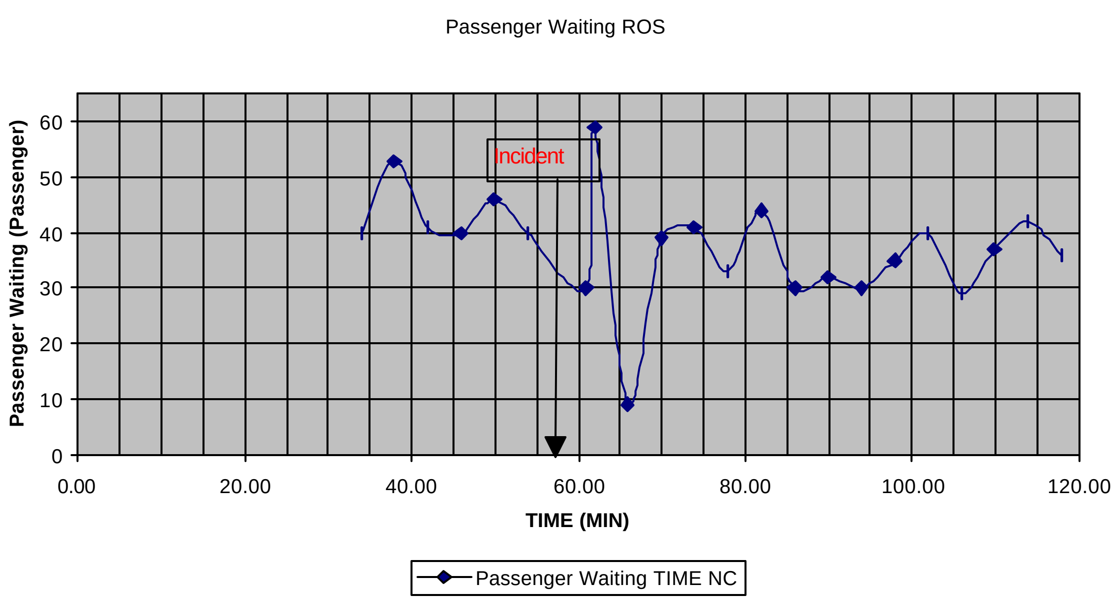


Figure 8.13 Three-Minute Delay Passenger Waiting Roosevelt:



8.2.3 Result Comparison

To determine where approach is better is necessary to compeer the performance of both system. The table 8.3 compares the Passenger Waiting time. The table 8.4 compares the Passengers Waiting in Each Station. Then present some important service reliability parameter to compeers both operations.

Table 8.3 Average Train Waiting Time (min)

STATION	IDEAL OPERATION	SCHEDULE OPERATION	HEADWAY OPERATION
Sagrado Corazon	2.14	2.07	2.05
Nuevo Centro	2.05	2.57	2.31
Hato Rey	2.02	2.78	2.75

According to the presented in Table 8.3, the headway base operation results in minor train waiting times in each station. Moreover, the passenger waiting time is greatly affected by the operation mode and the disruption time.

Table 8.4 Average Passengers Waiting in Each Station

STATION	IDEAL OPERATION	SCHEDULE OPERATION	HEADWAY OPERATION
Sagrado Corazon	53.13	53.65	54.7
Nuevo Centro	17.73	16.91	17.59
Hato Rey	39.32	39.95	37.68

According to the presented in Table 8.4 the schedule base operation reduce the number of passengers waiting. Nevertheless, the headway based operation work better after the affected station. Furthermore, the numbers of passengers that are waiting in any station is not sever affected by any less than one headway incident or operational strategies.

Table 8.5 Headway Indicators

STATION	IDEAL OPERATION	SCHEDULE OPERATION	HEADWAY OPERATION
Sagrado Corazon	1	1	1
Nuevo Centro	1	1	1
Roosevelt	1	1.4	1.4
Domenech	1	1.4	1

The headway indicator is a measure of headway adherence defined as the running headway and design headway ratio. If the headway indicator is grater than one, mean that the train is late in some station rather if the headway indicator is less than one mean that the train is early in some station. As presented in the table 8.5 the headway base operation work more effectively with incident in order to maintain service regularity.

Table 8.6 Schedule Adherence

STATION	IDEAL OPERATION	SCHEDULE OPERATION	HEADWAY OPERATION
Sagrado Corazon	0	0	0
Nuevo Centro	0	-.11	-.11
Roosevelt	0	-.1	-.1
Domenech	0	0	-.1

The schedule adherence measure is defines as the different between the design arrival time and the arrival time. If the schedule adherence is negative means that the train arrives late to some station, rather mean that the train arrives early to the station. As shown in the table 8.6 the schedule based operation adjusts the system better to the schedule time. Furthermore, the headway base operation also adjusts easily to the headway.

8.3 Greater than one headway but less than one headway Disruption analysis:

The incident scenario 1 represents a minor disruption that is greater than one headway but less than two headway. This scenario is a failure in the system at station Roosevelt Centro at 7:33 AM. The disruption caused by this scenario is 7 minute.

8.3.1 Schedule Base Approach

The results presented in this section are based on a schedule-based approach to recuperate to the delay. Figure 8.14 presents the time space diagram for the established scenario. The train 15 is affected by the failure in the station NC. The trains 16,17 are affected by the delay and wait in a queue until the station is free. Then the train runs to close to the train causing bunching in the system and service irregularity. The waiting time increase at the incidents time but then return to the normal value. Similar occurs with the passenger waiting in the platform. The figure 8.15 and 8.16 present how vary the passenger waiting time at NC and ROS respectively. In addition the Figure 8.17 and 8.18 present how vary the passenger waiting at NC and ROS respectively.

Figure 8.14 Seven Minutes Delay Time Space Diagram in Direction to Bayamón:

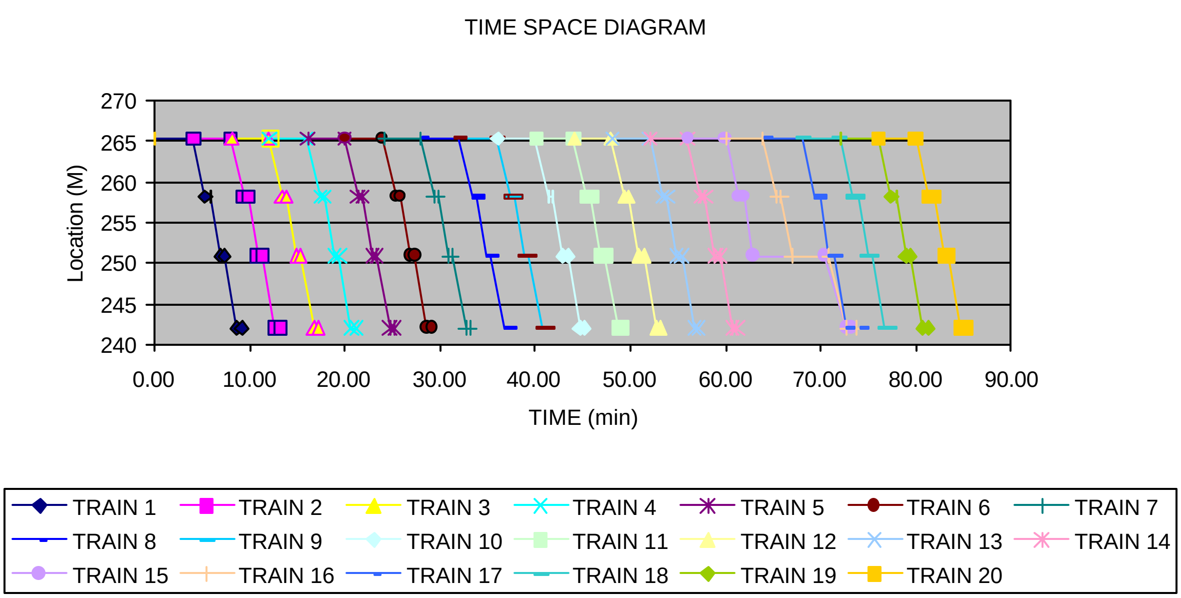


Figure 8.15 Seven-Minute Delay Passenger Waiting Time Nuevo Centro:

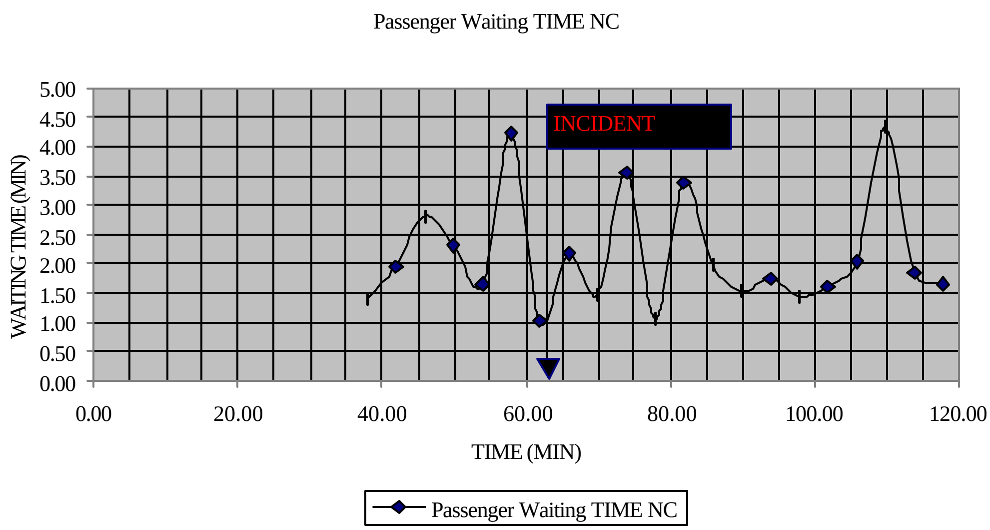


Figure 8.16 Seven-Minute Delay Passenger Waiting Time Roosevelt:

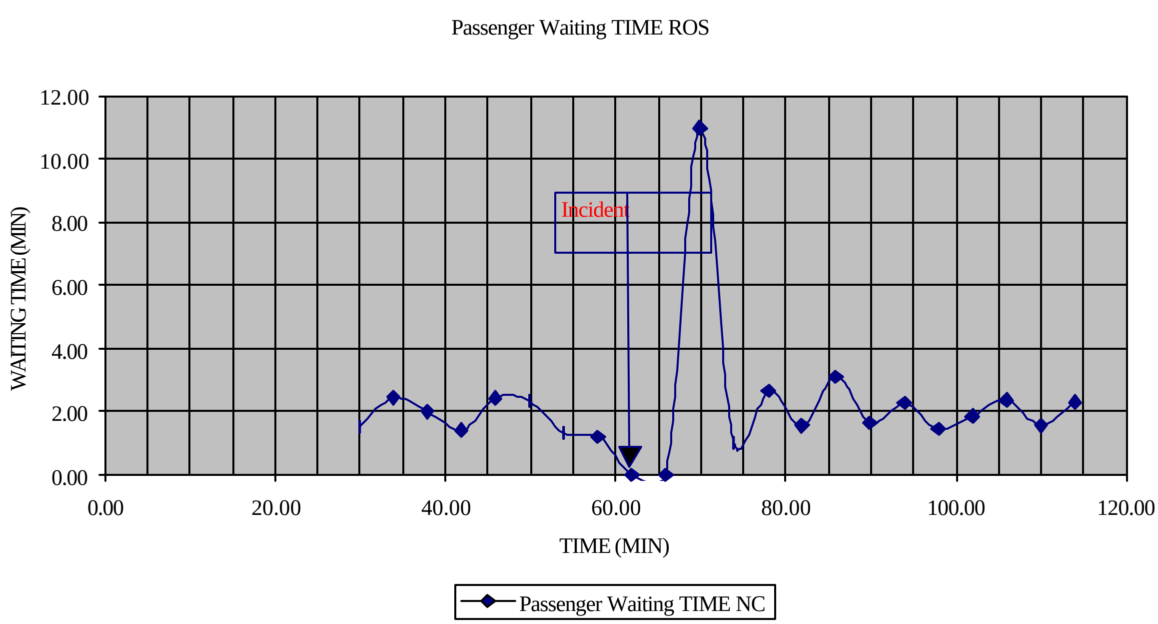


Figure 8.17 Seven-Minute Delay Passenger Waiting Nuevo Centro:

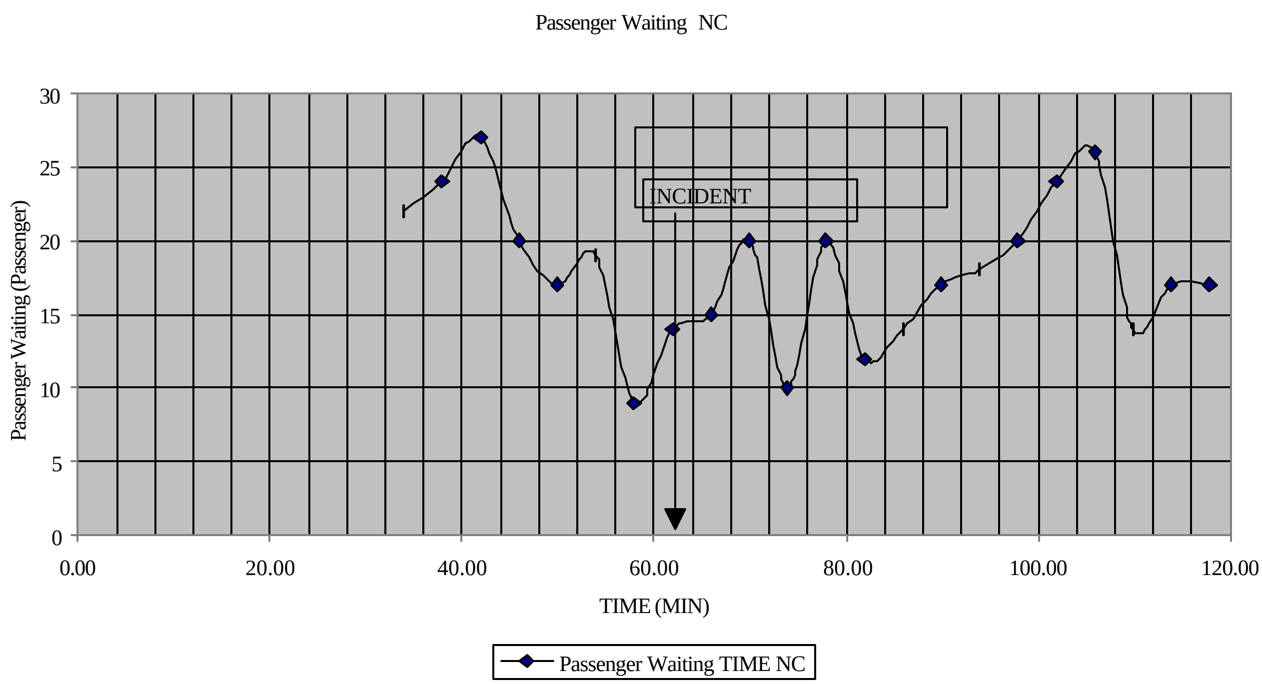
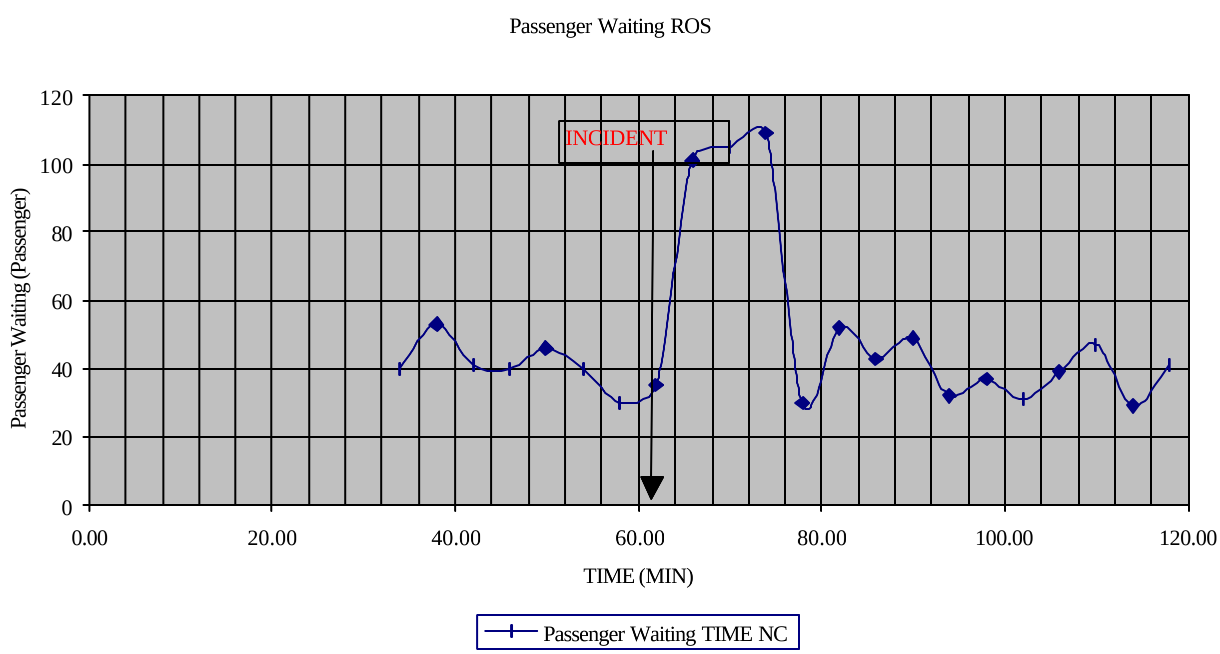


Figure 8.18 Seven -Minute Delay Passenger Waiting Roosevelt:



8.3.2 Headway Based Solution Approach

The results presented in this section are based on a headway-based approach to recuperate to the delay. Figure 8.19 present the time space diagram for the established scenario The train 15 is affected by the failure in the station NC. The trains 16,17 are affected by the delay and wait in a queue until the station is free. Similar to the schedule base approach the train runs to close to the train causing bunching in the system and service irregularity and instability. The waiting time increase at the incidents time but then return to the normal value. Similar occurs with the passenger waiting in the platform. The figure 8.20 and 8.21 present how vary the passenger waiting time at NC and ROS respectively. In addition, the Figure 8.22 and 8.23 present how vary the passenger waiting at NC and ROS respectively.

Figure 8.19 Seven Minutes Delay Time Space Diagram in Direction to Bayamón:

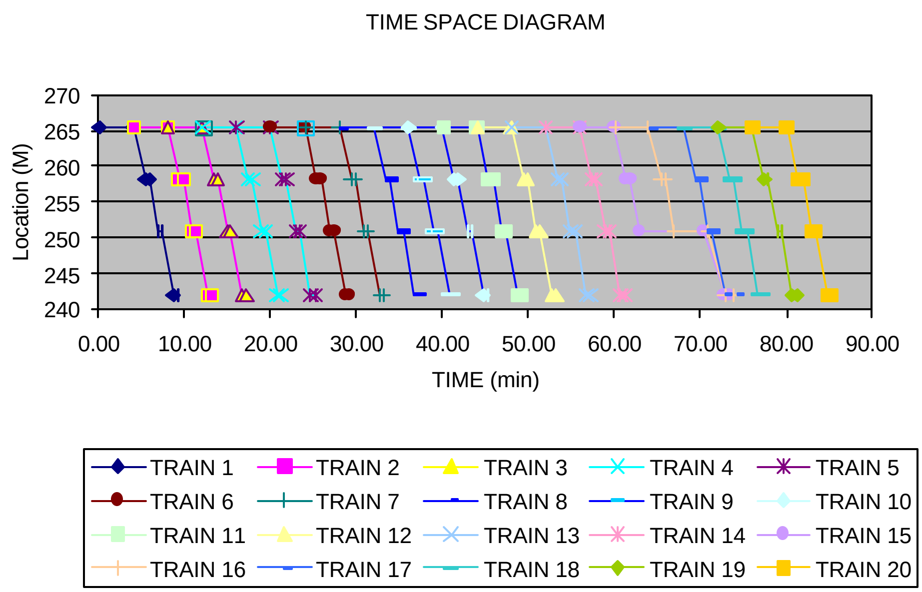


Figure 8.20 Seven-Minute Delay Passenger Waiting Time Nuevo Centro:

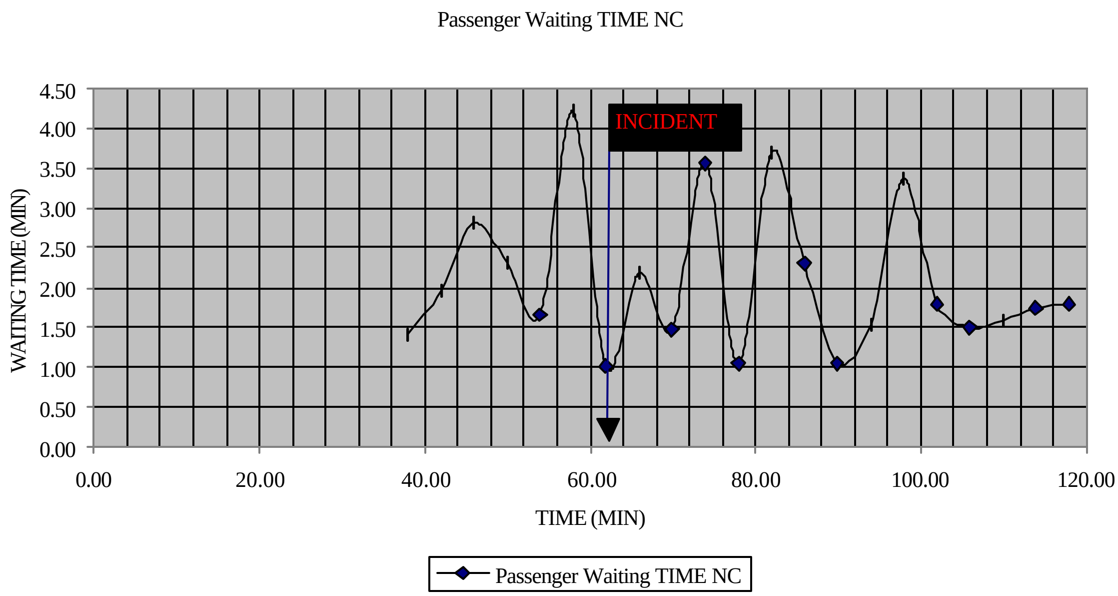


Figure 8.21 Seven-Minute Delay Passenger Waiting Time Roosevelt:

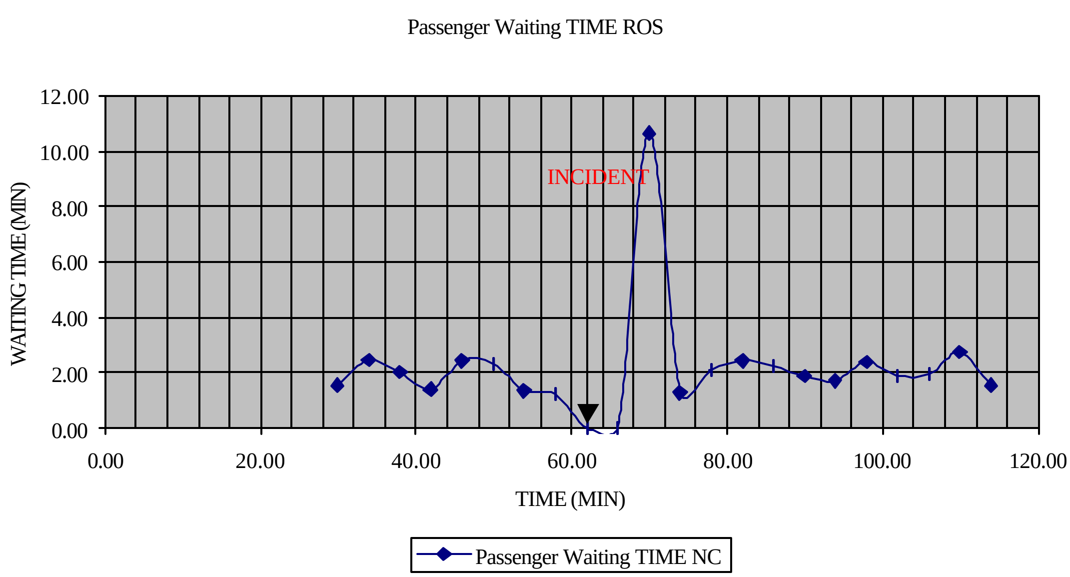


Figure 8.22 Seven-Minute Delay Passenger Waiting Nuevo Centro:

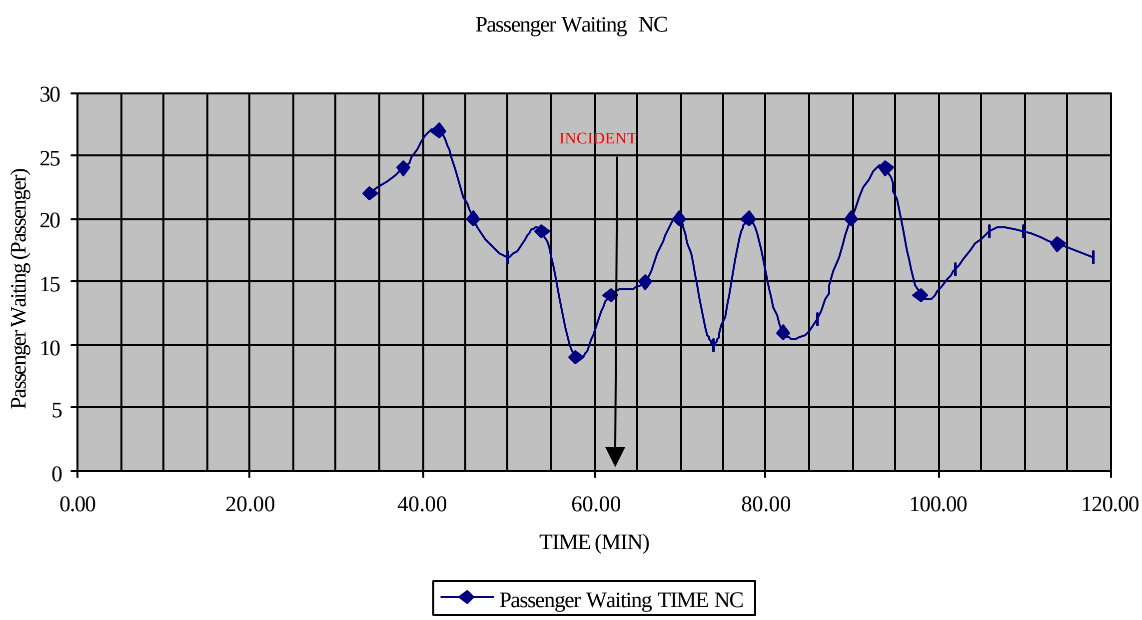
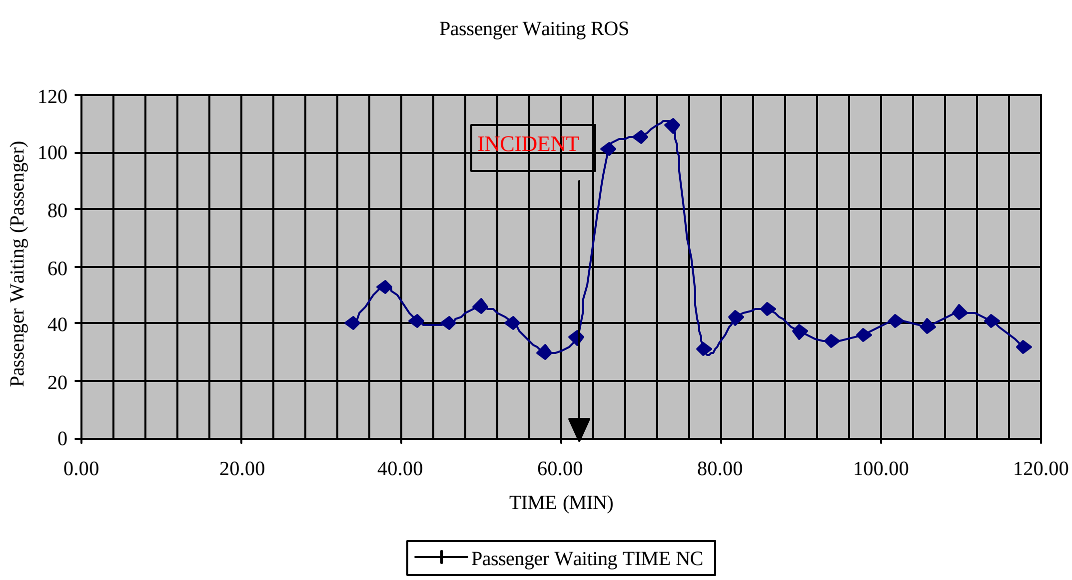


Figure 8.23 Seven-Minute Delay Passenger Waiting Roosevelt:



8.3.3 Result Comparison

This section compeer the performance of both system under incidents greater than one headway but less than two headway. The table 8.3 compares the Passenger Waiting time. The table 8.4 compares the Passengers Waiting in Each Station. Then present some important service reliability parameter to compeers both operations.

Table 8.7 Average Train Waiting Time (min)

STATION	IDEAL OPERATION	SCHEDULE OPERATION	HEADWAY OPERATION
Sagrado Corazon	2.14	2.07	2.04
Nuevo Centro	2.05	2.15	2.09
Hato Rey	2.02	2.16	2.16

According to the presented in Table 8.7, the headway base operation results in minor train waiting times in each station. However, in the last station both system are similar.

Table 8.8 Average Passengers Waiting in Each Station

STATION	IDEAL OPERATION	SCHEDULE OPERATION	HEADWAY OPERATION
Sagrado Corazon	53.13	55	54.16
Nuevo Centro	17.73	18	17.59
Hato Rey	39.32	48.59	48.41

According to the presented in Table 8.8 the headway base operation reduce the number of passengers waiting. Furthermore, the numbers of passengers that are waiting in any station are strongly affected by any grater than one headway incident or operational strategies.

Table 8.9 Headway Indicators

STATION	IDEAL OPERATION	SCHEDULE OPERATION	HEADWAY OPERATION
Sagrado Corazon	1	1	1
Nuevo Centro	1	1	1
Roosevelt	1	1.04	1.04
Domenech	1	1.04	1

As presented in the table 8.9 the headway base operation work more effectively with incident in order to maintain service regularity.

Table 8.10 Schedule Adherences

STATION	IDEAL OPERATION	SCHEDULE OPERATION	HEADWAY OPERATION
Sagrado Corazon	0	0	0
Nuevo Centro	0	0	0
Roosevelt	0	-.39	-.39
Domenech	0	-.44	-.46

As shown in the table 8.10 the schedule based operation and headway-based operation tend to be similar and has similar adherence the schedule time. The system adjust better to the schedule when using schedule-based operation, but the headway base operation also adjusts easily to the schedule.

9 Conclusions

9.1 The importance of the simulation in the transportation and engineering

Simulation will certainly play a greater role in the future development of railways and public transportation systems. This process is very important to key stakeholders to visualize how the system will respond in order to support the project.

This simulation model provides a tool to demonstrate the systems capacities as well as describing how the system will react when certain parameters are changed. This is very useful, especially when great quantities of money are involved. It is also important to obtain high executive support in order for a project of this magnitude to succeed

The Simulation help us the engineers in several decision and analyze task for transportation issues for example:

- Planning and analyzing several process
- Choosing a operating strategies
- Planning logistics system
- Evaluating capacity and performance of existing and planed systems.
- Predict the system performance in de future

Simulation usually is divided in two form discrete event and continuous, based on the manner in which the state variables change. Discrete event refers to the fact that state variables change instantaneously at distinct points in time. In a continuous simulation, variables change continuously, usually through a function in which time is a variable.

9.2 SIMAN Arena simulation tool Benefit:

The all around Arena program is a powerful tool in analyzing any real system on a smaller scale and for a fraction of the cost. The combination of the model with the animation process helps make critical decisions in evaluating and making recommendations on the system under study.

9.3 The Tren Urbano Simulation Mode

Not only has the Tren Urbano project provided a injection to the economy, but also has provided a basis for several investigations and projects. In our case through the modeling of this project, learn the importance and ease Siman/Arena provides to reduce the complexity of analyzing a real world system.

The model presented in this research describes the full process of creating a way to reflect the real world conditions but on a smaller scale. Through experimentation and evaluation, we have studied the way the system reacts and have evaluated various strategies in how it should be operated.

In this model, we have taken under consideration four stations with great economical and social impact in Puerto Rico. This stations as mentioned before are Domenech Roosevelt, Nuevo Centro and Sagrado Corazón. This model also can be used to predict how the system in the future could change due to changes in demand, resources and other parameters.

9.4 Headway-Based and Schedule Based Comparison:

The analyze made in this research allows us to understand how the system react to a incidents situation using only travel time and dwell time adjustment based in a schedule or a headway. In general, Comparing schedule-based operation and headway based operation; headway results in minors waiting time and more uniform service.

In the case of incidents that cause disruption minor than one headway, the system can easily recuperate the headway or schedule simply adjusting the travel time and dwell time. For the analyzed study in this research, the headway based operation results in minor passenger waiting time and better service regularity. Moreover, the schedule based operation result better to adjust the system to recuperate its planed schedule.

In the case of incidents that cause disruption grater than one headway, the system can not easily recuperate the headway or schedule simply adjusting the travel time and dwell time. In this situation the system may need to use more strongly control strategies to recuperate to the delay, for example the system can skip station, make short-turning or deadheading depending of the situation severity. For the analyzed study in this research, the headway based operation results in minor passenger waiting time and better service regularity. Finally, the system adjust better to the schedule when using schedule-based operation, but the headway base operation also adjusts easily to the schedule.

10 Reference

1. Puerto Rico Highway Authority, *Tren Urbano Final Environmental Impact Statement, 1995*
2. Siemens Transit Team, *Tren Urbano Project Operation and Maintenance Plan*, 4th edition, October 2000.
3. Theo H.J. Miller and Peter Knoppers, *TRITAPT-TRIp Time Analysis in Public Transport*, http://www. TRITAPT-TRIp Time Analysis in Public Transport.com
4. Roger D. Smith, *Simulation Article*, Encyclopedia of Computer Science, 4th edition, July 2000, New York.
5. Pegden, Dennis C., *Introduction to Simulation Using SIMAN*, Mc. Graw Gill, 1990 page 3-26
6. Janice P. Li, *Train Station Passenger Flow Study*, Proceeding of the 2000 Winter Simulation Conference, Pages1173-1176.
7. Thomas Schulze, *Simulation of Streetcar and Bus Traffic*, Proceeding of the 1993 Winter Simulation Conference, Pages1239-1243.

8. Puerto Rico Highway Authority, *Tren Urbano Final Environmental Impact Statement, 1995*
9. Siemens Transit Team, *Tren Urbano Project Operation and Maintenance Plan*, 4th edition, October 2000.
10. Theo H.J. Miller and Peter Knoppers, *TRITAPT-TRIp Time Analysis in Public Transport*, http://www. TRITAPT-TRIp Time Analysis in Public Transport.com
11. Roger D. Smith, *Simulation Article*, Encyclopedia of Computer Science, 4th edition, July 2000, New York.
12. Pegden, Dennis C., *Introduction to Simulation Using SIMAN*, Mc. Graw Gill, 1990 page 3-26
13. Janice P. Li, *Train Station Passenger Flow Study*, Proceeding of the 2000 Winter Simulation Conference, Pages1173-1176.
14. Thomas Schulze, *Simulation of Streetcar and Bus Traffic*, Proceeding of the 1993 Winter Simulation Conference, Pages1239-1243.

11 Appendix

Appendix 1: SIMAN Language Example

```
    Experiment:
PROJECT,    "NODELO ESTACION","Francisco
Martine",,Yes,No,No,No,No,No,No,No;

ATTRIBUTES:  2,T ARRIVE:
        3,Ticket:
        4,plaTIME:
        5,Destin:
        6,traveltime:
        7,ENTER:
        TrainDepTime:
        tipo:
        train:
        TrainArTime:
        llegada:
        dwellt;

VARIABLES:   travel 1,CLEAR(System),CATEGORY("None-None"):
        Travel 2,CLEAR(System),CATEGORY("None-None"):
        Travel 3,CLEAR(System),CATEGORY("None-None"):
        travel 4,CLEAR(System),CATEGORY("None-None"):
        Waiting ROS SC,CLEAR(System),CATEGORY("None-None"),0:
        Dwell 4sc,CLEAR(System),CATEGORY("None-None"):
        travel 28,CLEAR(System),CATEGORY("None-None"):
        Travel 29,CLEAR(System),CATEGORY("None-None"):
        Time SC BAY,CLEAR(System),CATEGORY("None-None"),0:
        Time ROS BAY,CLEAR(System),CATEGORY("None-None"),0:
        Travel 30,CLEAR(System),CATEGORY("None-None"):
        Time NC SC,CLEAR(System),CATEGORY("None-None"),0:
        ABORD_DomBAY,CLEAR(System),CATEGORY("None-None"),0:
        Waiting ROS BAY,CLEAR(System),CATEGORY("None-None"),0:
        Abord_ROS SC,CLEAR(System),CATEGORY("None-None"),0:
        Time DOM SC,CLEAR(System),CATEGORY("None-None"),0:
        Waiting NC SC,CLEAR(System),CATEGORY("None-None"),0:
        Waiting NC BAY,CLEAR(System),CATEGORY("None-None"),0:
        TIME ROS SC,CLEAR(System),CATEGORY("None-None"),0:
        ABORD_NCBAY,CLEAR(System),CATEGORY("None-None"),0:
        Dwell 1BAY,CLEAR(System),CATEGORY("None-None"):
        Dwell 2BAY,CLEAR(System),CATEGORY("None-None"):
        Dwell 3BAY,CLEAR(System),CATEGORY("None-None"):
        Dwell 4BAY,CLEAR(System),CATEGORY("None-None"):
        Waiting SC BAY,CLEAR(System),CATEGORY("None-None"),0:
        Dwell 2SC,CLEAR(System),CATEGORY("None-None"):
```

Abord_Dom. SC,CLEAR(System),CATEGORY("None-None"),0:
Abord_Ros BAY,CLEAR(System),CATEGORY("None-None"),0:
Time NC BAY,CLEAR(System),CATEGORY("None-None"),0:
Abord_SC,CLEAR(System),CATEGORY("None-None"),0:
Abord_NCSC,CLEAR(System),CATEGORY("None-None"),0:
Dwell 3SC,CLEAR(System),CATEGORY("None-None"):
Waiting DOM SC,CLEAR(System),CATEGORY("None-None"),0;

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3,QG3_1N,FirstInFirstOut,,AUTOSTATS(Yes,,):
4,QG4_1N,FirstInFirstOut,,AUTOSTATS(Yes,,):
5,QG1_1S,FirstInFirstOut,,AUTOSTATS(Yes,,):
6,QG2_1S,FirstInFirstOut,,AUTOSTATS(Yes,,):
7,QG3_1S,FirstInFirstOut,,AUTOSTATS(Yes,,):
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29,QG2_2N,FirstInFirstOut,,AUTOSTATS(Yes,,):
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36,QT3_2SB,FirstInFirstOut,,AUTOSTATS(Yes,,):
37,QT1_2N,FirstInFirstOut,,AUTOSTATS(Yes,,):
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41,QTEL1_2N,FirstInFirstOut,,AUTOSTATS(Yes,,):
42,Abord train2 SC,FirstInFirstOut,,AUTOSTATS(Yes,,):
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45,QG2_3N,FirstInFirstOut,,AUTOSTATS(Yes,,):
46,QG3_3N,FirstInFirstOut,,AUTOSTATS(Yes,,):
47,QG1_3S,FirstInFirstOut,,AUTOSTATS(Yes,,):
48,QG2_3S,FirstInFirstOut,,AUTOSTATS(Yes,,):
49,QG3_3S,FirstInFirstOut,,AUTOSTATS(Yes,,):
50,QT1_3N,FirstInFirstOut,,AUTOSTATS(Yes,,):
51,QT2_3N,FirstInFirstOut,,AUTOSTATS(No,,):
52,QT3_3N,FirstInFirstOut,,AUTOSTATS(Yes,,):
53,QT1_3S,FirstInFirstOut,,AUTOSTATS(Yes,,):
54,QT2_3S,FirstInFirstOut,,AUTOSTATS(Yes,,):
55,QT3_3S,FirstInFirstOut,,AUTOSTATS(Yes,,):
56,QTEL1_3N,FirstInFirstOut,,AUTOSTATS(Yes,,):
57,QTEL1_3S,FirstInFirstOut,,AUTOSTATS(Yes,,):
58,Abord train3,FirstInFirstOut,,AUTOSTATS(Yes,,):
59,QG1_4N,FirstInFirstOut,,AUTOSTATS(Yes,,):
60,QG2_4N,FirstInFirstOut,,AUTOSTATS(Yes,,):
61,QG3_4N,FirstInFirstOut,,AUTOSTATS(Yes,,):
62,QT1_4N,FirstInFirstOut,,AUTOSTATS(Yes,,):
63,QT2_4N,FirstInFirstOut,,AUTOSTATS(Yes,,):
64,QT3_4N,FirstInFirstOut,,AUTOSTATS(Yes,,):
65,QTEL1_4N,FirstInFirstOut,,AUTOSTATS(Yes,,):
66,Abord Train 4 SC,FirstInFirstOut,,AUTOSTATS(Yes,,):
67,Abord Train 4 BAY,FirstInFirstOut,,AUTOSTATS(Yes,,):
68,Abord Train 1 BAY,FirstInFirstOut,,AUTOSTATS(Yes,,);

PICTURES: 1,des1:
2,des2:
3,des3:
4,des4:
5,des5:
6,des6:
7,tren;

FAILURES: Falla3,Time(5,0,):
Falla4,Time(63,7,):
Falla8,Time(6,0,):
FALLA TREN5,Time(expo(700),0,):
FALLA TREN6,Time(expo(700),0,):
FALLA TREN 7,Time(5,0,):
FALLA TREN,Time(expo(700),0,):
FALLATREN2,Time(57.5,3,);

```
RESOURCES:
1,G1_1N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	2,G2_1N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	3,G3_1N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	4,G4_1N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	5,G1_1S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	6,G2_1S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	7,G3_1S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	8,G4_1S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	9,T1_1N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	10,T2_1N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	11,T3_1N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	12,T1_1S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	13,T2_1S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	14,T3_1S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	15,TEL1_1N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	16,TEL1_1S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	17,train1SC,Capacity(1),,Stationary,COST(0.0,0.0,0.0),FAILURE(FALLA
TREN,Preempt),AUTOSTATS(Yes,,):
	18,G1_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	19,G2_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	20,G3_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	21,G4_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	22,G5_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	23,G1_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	24,G2_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	25,G3_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	26,G4_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	27,G5_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	28,G1_2N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	29,G2_2N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	30,G3_2N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	31,T1_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	32,T2_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	33,T3_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	34,T1_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	35,T2_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	36,T3_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	37,T1_2N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	38,T2_2N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	39,TEL1_2SA,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	40,TEL1_2SB,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	41,TEL1_2N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
	42,train2 SC,Capacity(1),,Stationary,COST(0.0,0.0,0.0),FAILURE(FALLA
TREN5,Ignore),AUTOSTATS(Yes,,):
```

43,train2
BAY,Capacity(1),,Stationary,COST(0.0,0.0,0.0),FAILURE(FALLATREN2,Ignore),AUTOSTATS(Yes,,):
44,G1_3N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
45,G2_3N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
46,G3_3N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
47,G1_3S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
48,G2_3S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
49,G3_3S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
50,T1_3N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
51,T2_3N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
52,T3_3N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
53,T1_3S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
54,T2_3S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
55,T3_3S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
56,TEL1_3N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
57,TEL1_3S,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
58,Train 3 BAY,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):

59,train1BAY,Capacity(1),,Stationary,COST(0.0,0.0,0.0),FAILURE(Falla4,Preempt),AUTOSTATS(Yes,,):
60,G1_4N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
61,G2_4N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
62,G3_4N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
63,T1_4N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
64,T2_4N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
65,T3_4N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
66,TEL1_4N,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):

67,train4BAY,Capacity(1),,Stationary,COST(0.0,0.0,0.0),FAILURE(Falla3,Ignore),AUTOSTATS(Yes,,):
68,train4 SC,Capacity(1),,Stationary,COST(0.0,0.0,0.0),FAILURE(FALLATREN6,Ignore),AUTOSTATS(Yes,,):
Dumy1,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
Dumy2,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
Dumy4,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,);

STATIONS: 1,Crea Ros N:
2,Crea Ros S:
3,Crea NC N:
4,Crea NC S:
5,CREA SC N:
6,CREA SC S:
7,Arrive ROS_ SC:
8,Arrive NC_BAY:
9,Arrive NC_SC:
10,Arrive SC:

```
          11,entrada1 North:
          12,entrada2 N:
          13,Salida 2 SA:
          14,SALIDA 2 SB:
          15,entrada3 N:
          17,salida1N:
          18,salida 1S:
          20,salida3N:
          21,entrada3 S:
          22,entrada2 SA:
          23,entrada2 SB:
          24,plataforma2SC:
        Model:
0$        CREATE,      1:expo (1.7143):NEXT(1$);                    Creacion Pasageros
Direccion SC

1$        ASSIGN:      llegada=tnow:
                  destin=discrete(.001,2,1,1):
                  Ticket=discrete(.6,1,.9,2,1.0,3):
                  M=1:
                  picture=destin;                     Tiket: 1= Have, 2= Buy Tiket at
TVM, 3 Buy Tiket at Teller
372$      BRANCH:      With,.5,271$,Yes:
                  With,.5,371$,Yes;
271$      ROUTE:       tria(1,2,3),entrada1 North;

371$      ROUTE:       tria(3,4,5),entrada1 Sur;


36$       STATION,     entrada1 North;
19$       DELAY:       TRIA(0, 5 ,10),,Other:NEXT(2$);

2$        BRANCH,      1:
                  If,ticket==1,Gates1N,Yes:
                  If,Ticket == 2,205$,Yes:
                  If,Ticket==3,20$,Yes;
Gates1N   PICKQ,       CYC:
                  3$:
                  4$:
                  5$:
                  6$;
3$        QUEUE,       QG4_1N;
16$       SEIZE,       1,Other:
                  G4_1N,1:NEXT(17$);

17$       DELAY:       tria ( .05, .075,.1 ),,Other:NEXT(18$);
```

```
18$        RELEASE:      G4_1N,1;
478$       BRANCH,       1:
                If,destin>3,479$,Yes:
                If,destin<3,480$,Yes;
479$       ROUTE:        0.0,Plataform1 BAY;

480$       ROUTE:        0.0,plataform 1SC;

4$         QUEUE,        QG3_1N;
13$        SEIZE,        1,Other:
                G3_1N,1:NEXT(14$);

14$        DELAY:        tria ( .05, .075,.1 ),,Other:NEXT(15$);

15$        RELEASE:      G3_1N,1:NEXT(478$);

5$         QUEUE,        QG2_1N;
10$        SEIZE,        1,Other:
                G2_1N,1:NEXT(11$);

11$        DELAY:        tria ( .05, .075,.1 ),,Other:NEXT(12$);

12$        RELEASE:      G2_1N,1:NEXT(478$);

6$         QUEUE,        QG1_1N;
7$         SEIZE,        1,Other:
                G1_1N,1:NEXT(8$);

8$         DELAY:        tria ( .05, .075,.1 ),,Other:NEXT(9$);

9$         RELEASE:      G1_1N,1:NEXT(478$);

205$       PICKQ,        ran:
                24$:
                25$:
                26$;
24$        QUEUE,        QT1_1N;
33$        SEIZE,        1,Other:
                T1_1N,1:NEXT(34$);

34$        DELAY:        tria ( .5, .75,1),,Other:NEXT(35$);

35$        RELEASE:      T1_1N,1:NEXT(Gates1N);

25$        QUEUE,        QT2_1N;
30$        SEIZE,        1,Other:
                T2_1N,1:NEXT(31$);
```

```
31$       DELAY:      tria ( .5, .75,1),,Other:NEXT(32$);

32$       RELEASE:     T2_1N,1:NEXT(Gates1N);

26$       QUEUE,      QT3_1N;
27$       SEIZE,      1,Other:
                T3_1N,1:NEXT(28$);

28$       DELAY:      tria ( .5, .75,1),,Other:NEXT(29$);

29$       RELEASE:     T3_1N,1:NEXT(Gates);

Gates     PICKQ,      cyc:
                170$:
                171$:
                172$:
                173$;
170$      QUEUE,      QG1_1S;
183$      SEIZE,      1,Other:
                G1_1S,1:NEXT(184$);

184$      DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(185$);

185$      RELEASE:     G1_1S,1;
475$      BRANCH,      1:
                If,destin>3,476$,Yes:
                If,destin<3,477$,Yes;
476$      ROUTE:      0.0,Plataform1 BAY;

477$      ROUTE:      0.0,plataform 1SC;

171$      QUEUE,      QG2_1S;
180$      SEIZE,      1,Other:
                G2_1S,1:NEXT(181$);

181$      DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(182$);

182$      RELEASE:     G2_1S,1:NEXT(475$);

172$      QUEUE,      QG3_1S;
177$      SEIZE,      1,Other:
                G3_1S,1:NEXT(178$);

178$      DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(179$);

179$      RELEASE:     G3_1S,1:NEXT(475$);
```

```
173$         QUEUE,         QG4_1S;
174$         SEIZE,         1,Other:
                      G4_1S,1:NEXT(175$);

175$         DELAY:         tria ( .05, .075,.1 ),,Other:NEXT(176$);

176$         RELEASE:       G4_1S,1:NEXT(475$);

20$          QUEUE,         QTEL1_1N;
21$          SEIZE,         1,Other:
                      TEL1_1N,1:NEXT(22$);

22$          DELAY:         tria(.6,.75,1.1),,Other:NEXT(23$);

23$          RELEASE:       TEL1_1N,1:NEXT(478$);


72$          STATION,       entrada2 SA;
54$          DELAY:         TRIA(0, 5 ,10),,Other:NEXT(37$);

37$          BRANCH,        1:
                      If,ticket==1,Gates2SA,Yes:
                      If,Ticket == 2,59$,Yes:
                      If,Ticket==3,55$,Yes;
Gates2SA     PICKQ,         CYC:
                      38$:
                      39$:
                      40$:
                      41$:
                      273$;
38$          QUEUE,         QG1_2SA;
51$          SEIZE,         1,Other:
                      G1_2SA,1:NEXT(52$);

52$          DELAY:         tria ( .05, .075,.1 ),,Other:NEXT(53$);

53$          RELEASE:       G1_2SA,1;
160$         BRANCH,        1:
                      If,destin==1,161$,Yes:
                      Else,162$,Yes;
161$         ROUTE:         tria(5,10,15),plataforma2SC;

162$         ROUTE:         tria(5,10,15),plataforma2BAY;

39$          QUEUE,         QG2_2SA;
48$          SEIZE,         1,Other:
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```
                G2_2SA,1:NEXT(49$);

49$       DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(50$);

50$       RELEASE:      G2_2SA,1:NEXT(160$);

40$       QUEUE,       QG3_2SA;
45$       SEIZE,       1,Other:
                G3_2SA,1:NEXT(46$);

46$       DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(47$);

47$       RELEASE:      G3_2SA,1:NEXT(160$);

41$       QUEUE,       QG4_2SA;
42$       SEIZE,       1,Other:
                G4_2SA,1:NEXT(43$);

43$       DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(44$);

44$       RELEASE:      G4_2SA,1:NEXT(160$);

273$      QUEUE,       QG5_2SA;
274$      SEIZE,       1,Other:
                G5_2SA,1:NEXT(275$);

275$      DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(276$);

276$      RELEASE:      G5_2SA,1:NEXT(160$);

59$       PICKQ,      SNQ:
                60$:
                61$:
                62$;
60$       QUEUE,       QT1_2SA;
69$       SEIZE,       1,Other:
                T1_2SA,1:NEXT(70$);

70$       DELAY:      tria ( .5, .75,1),,Other:NEXT(71$);

71$       RELEASE:      T1_2SA,1:NEXT(Gates2);

Gates2    PICKQ,      cyc:
                207$:
                208$:
                209$:
                210$:
```

```
                  277$;
207$       QUEUE,      QG1_2SB;
220$       SEIZE,      1,Other:
                  G1_2SB,1:NEXT(221$);

221$       DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(222$);

222$       RELEASE:    G1_2SB,1;
242$       BRANCH,     1:
                  If,destin==1,243$,Yes:
                  Else,244$,Yes;
243$       ROUTE:      tria(5,10,15),plataforma2SC;

244$       ROUTE:      tria(5,10,15),plataforma2BAY;

208$       QUEUE,      QG2_2SB;
217$       SEIZE,      1,Other:
                  G2_2SB,1:NEXT(218$);

218$       DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(219$);

219$       RELEASE:    G2_2SB,1:NEXT(242$);

209$       QUEUE,      QG3_2SB;
214$       SEIZE,      1,Other:
                  G3_2SB,1:NEXT(215$);

215$       DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(216$);

216$       RELEASE:    G3_2SB,1:NEXT(242$);

210$       QUEUE,      QG4_2SB;
211$       SEIZE,      1,Other:
                  G4_2SB,1:NEXT(212$);

212$       DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(213$);

213$       RELEASE:    G4_2SB,1:NEXT(242$);

277$       QUEUE,      QG5_2SB;
278$       SEIZE,      1,Other:
                  G5_2SB,1:NEXT(279$);

279$       DELAY:      tria ( .05, .075,.1 ),,Other:NEXT(280$);

280$       RELEASE:    G5_2SB,1:NEXT(242$);
```

```
61$         QUEUE,        QT2_2SA;
66$         SEIZE,        1,Other:
                    T2_2SA,1:NEXT(67$);

67$         DELAY:        tria ( .5, .75,1),,Other:NEXT(68$);

68$         RELEASE:      T2_2SA,1:NEXT(Gates2);

62$         QUEUE,        QT3_2SA;
63$         SEIZE,        1,Other:
                    T3_2SA,1:NEXT(64$);

64$         DELAY:        tria ( .5, .75,1 ),,Other:NEXT(65$);

65$         RELEASE:      T3_2SA,1:NEXT(Gates2);

55$         QUEUE,        QTEL1_2SA;
56$         SEIZE,        1,Other:
                    TEL1_2SA,1:NEXT(57$);

57$         DELAY:        tria(.6,.75,1.1),,Other:NEXT(58$);

58$         RELEASE:      TEL1_2SA,1:NEXT(160$);


103$        STATION,      entrada3 N;
73$         BRANCH,       1:
                    If,ticket==1,Gates1N,Yes:
                    If,Ticket == 2,90$,Yes:
                    If,Ticket==3,86$,Yes;
90$         PICKQ,        SNQ:
                    91$:
                    92$:
                    93$;
91$         QUEUE,        QT1_3N;
100$        SEIZE,        1,Other:
                    T1_3N,1:NEXT(101$);

101$        DELAY:        tria ( .5, .75,1),,Other:NEXT(102$);

102$        RELEASE:      T1_3N,1:NEXT(Gates3N);

Gates3N     PICKQ,        cyc:
                    74$:
                    75$:
                    76$;
74$         QUEUE,        QG1_3N;
```

```
83$      SEIZE,     1,Other:
                 G1_3N,1:NEXT(84$);

84$      DELAY:     tria ( .05, .075,.1 ),,Other:NEXT(85$);

85$      RELEASE:    G1_3N,1;
104$      ROUTE:     tria(5,10,15),plataforma3;

75$      QUEUE,     QG2_3N;
80$      SEIZE,     1,Other:
                 G2_3N,1:NEXT(81$);

81$      DELAY:     tria ( .05, .075,.1 ),,Other:NEXT(82$);

82$      RELEASE:    G2_3N,1:NEXT(104$);

76$      QUEUE,     QG3_3N;
77$      SEIZE,     1,Other:
                 G3_3N,1:NEXT(78$);

78$      DELAY:     tria ( .05, .075,.1 ),,Other:NEXT(79$);

79$      RELEASE:    G3_3N,1:NEXT(104$);

92$      QUEUE,     QT2_3N;
97$      SEIZE,     1,Other:
                 T2_3N,1:NEXT(98$);

98$      DELAY:     tria ( .5, .75,1),,Other:NEXT(99$);

99$      RELEASE:    T2_3N,1:NEXT(Gates3N);

93$      QUEUE,     QT3_3N;
94$      SEIZE,     1,Other:
                 T3_3N,1:NEXT(95$);

95$      DELAY:     tria ( .5, .75,1),,Other:NEXT(96$);

96$      RELEASE:    T3_3N,1:NEXT(Gates3N);

86$      QUEUE,     QTEL1_3N;
87$      SEIZE,     1,Other:
                 TEL1_3N,1:NEXT(88$);

88$      DELAY:     tria(.6,.75,1.1),,Other:NEXT(89$);

89$      RELEASE:    TEL1_3N,1:NEXT(104$);
```

```
109$        STATION,      plataform 1SC:MARK(plaTIME);
108$        QUEUE,        Abord Train 1 SC;
110$        SCAN:         nr(train1SC)==1;
```

Appendix 2: VBA Headway Based Code

```
Private Sub VBA_Block_1_Fire()
'Retrive SC train Arrival and Depart time from siman object data direction to BAY
Dim arrivet As Double, depart, WAITINGTIME, PERSON, T, TAC, TLAST As Double
arrivet = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity, g_TrainArrive)
depart = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity, g_TrainDepart)
'Write the Values to the spreadsheet

If g_SIMAN.RunCurrentTime > 30 Then
TAC = SMVAR.VariableArrayValue(SMVAR.SymbolNumber("Time SC BAY"))
T = TAC - T1
T1 = TAC
PERSON = SMVAR.VariableArrayValue(SMVAR.SymbolNumber("Waiting SC BAY"))
WAITINGTIME = T / PERSON

End If
With g_XLDataSheetBAY
   .Cells(g_nextrow1BA, g_LL1) = arrivet
   .Cells(g_nextrow1BA, g_S1) = depart
   .Cells(g_nextrow1BA + 35, g_LL1) = WAITINGTIME
   .Cells(g_nextrow1BA + 70, g_LL1) = PERSON
End With
'Increment the row variable
g_nextrow1BA = g_nextrow1BA + 1
SBDEPART1BAY = depart
End Sub

Private Sub VBA_Block_10_Fire()
'Schedule Based logic NC station  to Bayamon
Dim Tarrive, Tdepart, TarriveNext, Travel, Dwell As Double
Tarrive = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity, g_TrainArrive)
Tdepart = Tarrive + 0.5
'The train is more than 2 minutes late
If Tdepart > 2 + SBDEPART2BAY + 4 Then
   Travel = 0.92 * 61 / 60
   TarriveNext = Tdepart + Travel
   If TarriveNext > SBDEPART2BAY + 61 / 60 + 2 + 4 Or TarriveNext >
SBDEPART2BAY + 61 / 60 - 1 + 4 Then
      Dwell = (SBDEPART2BAY + (4 + 61 / 60)) - TarriveNext + 0.5
      Travel = 0.92 * 61 / 60
    Else
```

```
        Dwell = 0.5
        Travel = 0.92 * 61 / 60
    End If
End If
'The train is more than 1 minutes early
If Tdepart < SBDEPART2BAY + 4 - 1 Then
        Travel = 1.08 * 61 / 60
        TarriveNext = Tdepart + Travel
         '4 es de headway,2y -1 son margenes permitido
         If TarriveNext > SBDEPART2BAY + 61 / 60 + 2 + 4 Or TarriveNext >
SBDEPART2BAY + 61 / 60 - 1 + 4 Then
            Dwell = (SBDEPART2BAY + (4 + 61 / 60)) - TarriveNext + 0.5
            Travel = 1.08 * 61 / 60
        Else
            Dwell = 0.5
            Travel = 1.08 * 61 / 60
        End If
End If
'The arrival train is in the aceptable range
If Tdepart < 2 + SBDEPART2BAY + 4 And Tdepart > SBDEPART2BAY + 4 - 1 Then
    Travel = 61 / 60
    Dwell = 0.5
End If
If Dwell > 1 Then
        Dwell = 1
Else
    If Dwell < 0.25 Then
    Dwell = 0.25
    End If
End If
SMVAR.VariableArrayValue(SMVAR.SymbolNumber("travel 2")) = Travel
SMVAR.VariableArrayValue(SMVAR.SymbolNumber("dwell 2bay")) = Dwell

End Sub
```

Appendix 3: VBA Schedule Based Code

```
Private Sub VBA_Block_1_Fire()
'Retrive SC train Arrival and Depart time from siman object data direction to BAY
Dim arrivet As Double, depart, WAITINGTIME, PERSON, T, TAC, TLAST As Double
arrivet = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity, g_TrainArrive)
depart = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity, g_TrainDepart)
'Write the Values to the spreadsheet

If g_SIMAN.RunCurrentTime > 30 Then
TAC = SMVAR.VariableArrayValue(SMVAR.SymbolNumber("Time SC BAY"))
T = TAC - T1
T1 = TAC
PERSON = SMVAR.VariableArrayValue(SMVAR.SymbolNumber("Waiting SC BAY"))
WAITINGTIME = T / PERSON

End If
With g_XLDataSheetBAY
   .Cells(g_nextrow1BA, g_LL1) = arrivet
   .Cells(g_nextrow1BA, g_S1) = depart
   .Cells(g_nextrow1BA + 35, g_LL1) = WAITINGTIME
   .Cells(g_nextrow1BA + 70, g_LL1) = PERSON
End With
'Increment the row variable
g_nextrow1BA = g_nextrow1BA + 1
SBDEPART1BAY = SBDEPART1BAY + 4
End Sub

Private Sub VBA_Block_10_Fire()
'Schedule Based logic NC station  to Bayamon
Dim Tarrive, Tdepart, TarriveNext, Travel, Dwell As Double
Tarrive = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity, g_TrainArrive)
Tdepart = Tarrive + 0.5
'The train is more than 2 minutes late
If Tdepart > 2 + SBDEPART2BAY + 4 Then
   Travel = 0.92 * 61 / 60
   TarriveNext = Tdepart + Travel
   If TarriveNext > SBDEPART2BAY + 61 / 60 + 2 + 4 Or TarriveNext >
SBDEPART2BAY + 61 / 60 - 1 + 4 Then
      Dwell = (SBDEPART2BAY + (4 + 61 / 60)) - TarriveNext + 0.5
      Travel = 0.92 * 61 / 60
    Else
      Dwell = 0.5
      Travel = 0.92 * 61 / 60
   End If
```

```
End If
'The train is more than 1 minutes early
If Tdepart < SBDEPART2BAY + 4 - 1 Then
        Travel = 1.08 * 61 / 60
        TarriveNext = Tdepart + Travel
         '4 es de headway,2y -1 son margenes permitido
         If TarriveNext > SBDEPART2BAY + 61 / 60 + 2 + 4 Or TarriveNext >
SBDEPART2BAY + 61 / 60 - 1 + 4 Then
            Dwell = (SBDEPART2BAY + (4 + 61 / 60)) - TarriveNext + 0.5
            Travel = 1.08 * 61 / 60
        Else
            Dwell = 0.5
            Travel = 1.08 * 61 / 60
        End If
End If
'The arrival train is in the aceptable range
If Tdepart < 2 + SBDEPART2BAY + 4 And Tdepart > SBDEPART2BAY + 4 - 1 Then
    Travel = 61 / 60
    Dwell = 0.5
End If
If Dwell > 1 Then
        Dwell = 1
Else
    If Dwell < 0.25 Then
    Dwell = 0.25
    End If
End If
SMVAR.VariableArrayValue(SMVAR.SymbolNumber("travel 2")) = Travel
SMVAR.VariableArrayValue(SMVAR.SymbolNumber("dwell 2bay")) = Dwell

End Sub
```

Appendix 4: SIMAN Summary Result Sheet:

```
Beginning replication 2 of 5
Beginning replication 3 of 5
Beginning replication 4 of 5
Beginning replication 5 of 5

                        ARENA Simulation Results
                           Francisco Martinez

                    Output Summary for 5 Replications

Project:NODELO ESTACION                          Run execution date :
5/30/2002
Analyst:Francisco Martine                        Model revision date:
5/30/2002


                                OUTPUTS
```

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Dom.Gate 1N Util	.12476	.00270	.12254	.12711	5
Dom.Gate 2N Util	.12550	.00274	.12325	.12888	5
Dom.Gate 3N Util	.12580	.00260	.12424	.12943	5
Dom.Gate 4N Util	.12620	.00481	.12296	.13290	5
Dom.Gate 1SUtil	.04588	.00230	.04335	.04748	5
Dom.Gate 2SUtil	.04555	8.1526E-04	.04484	.04629	5
Dom.Gate 3SUtil	.04543	.00222	.04264	.04705	5
Dom.Gate 4 SUtil	.04513	.00166	.04345	.04686	5
Dom.Q Gate 1N Util	6.0340E-05	1.2122E-04	.00000	2.2443E-04	5
Dom.Q Gate 2 N Util	.00000	.00000	.00000	.00000	5
Dom.Q Gate 3N Util	1.1748E-04	1.3693E-04	.00000	2.2804E-04	5
Dom.Q Gate 4N Util	1.1476E-04	1.8260E-04	.00000	3.5040E-04	5
Dom.Q Gate 1S Util	.00000	.00000	.00000	.00000	5
Dom.Q Gate 2S Util	.00000	.00000	.00000	.00000	5
Dom.Q Gate 3S Util	.00000	.00000	.00000	.00000	5
Dom.Q Gate 3S Util	.00000	.00000	.00000	.00000	5
Dom.TVM1N Ut	.18108	.02563	.15706	.20462	5
Dom.TVM2N Ut	.16818	.02704	.13881	.19216	5
Dom.TVM3N Ut	.21454	.04584	.16659	.27020	5
Dom.TVM1S Ut	.44739	.03774	.39639	.47605	5
Dom.TVM 2S Ut	.05508	.02288	.02711	.06893	5
Dom.TVM 3S Ut	.00257	.00451	.00000	.00769	5
Q Dom.TVM1N Ut	.02224	.01435	.01212	.04043	5
Dom.Q TVM3N	.04838	.04847	.00121	.09312	5
Dom.Q TVM1S Ut	.09923	.02347	.07282	.12230	5
Dom.Q TVM3S	.00000	.00000	.00000	.00000	5
Dom.Teller 1N Ut	.17444	.02645	.14751	.19974	5
Dom.Teller 2S Ut	.18547	.03576	.15199	.21633	5
Dom.Q Teller 1N	.02143	.01613	.00138	.03467	5
Dom.Q Teller 1S	.02184	.02525	.00204	.05408	5

NC GATE 1 SA	.01513	.00201	.01327	.01752	5
NC GATE 2 SA	.01532	.00236	.01294	.01819	5
NC GATE 1 SA	.01488	.00196	.01338	.01728	5
NC GATE 4 SA	.01503	.00209	.01292	.01750	5
NC GATE 5 SA	.01465	.00229	.01289	.01773	5
NC GATE 1 SB	.02873	.00339	.02550	.03184	5
NC GATE 2 SB	.02852	.00320	.02566	.03160	5
NC GATE 3 SB	.02863	.00362	.02487	.03244	5
NC GATE 4 SB	.02837	.00317	.02481	.03196	5
NC GATE 5 SB	.02804	.00364	.02492	.03179	5
NC GATE 1 N	.02626	.00268	.02297	.02813	5
NC GATE 2 N	.02589	.00231	.02328	.02806	5
NC GATE 3 N	.02574	.00202	.02342	.02773	5
NC GATE 1 SA Q	.00000	.00000	.00000	.00000	5
NC GATE 2 SA Q	.00000	.00000	.00000	.00000	5
NC GATE 3 SA Q	.00000	.00000	.00000	.00000	5
NC GATE 4 SA Q	.00000	.00000	.00000	.00000	5
NC GATE 50 SA Q	.00000	.00000	.00000	.00000	5
NC GATE 1 SB Q	.00000	.00000	.00000	.00000	5
NC GATE 2 SB Q	.00000	.00000	.00000	.00000	5
NC GATE 3 SB Q	.00000	.00000	.00000	.00000	5
NC GATE 4 SB Q	.00000	.00000	.00000	.00000	5
NC GATE 5 SB Q	.00000	.00000	.00000	.00000	5
NC GATE 1 N Q	.00000	.00000	.00000	.00000	5
NC GATE 2 N Q	.00000	.00000	.00000	.00000	5
NC GATE3 N Q	.00000	.00000	.00000	.00000	5
NC TVM 1SA U	.29491	.08009	.20638	.36414	5
NC TVM 2 SA U	.01352	.01452	.00000	.03061	5
NC TVM 3 SA U	.00000	.00000	.00000	.00000	5
NC TVM 1SB U	.34757	.07900	.25385	.43083	5
NC TVM 2SB U	.02184	.01450	.01036	.03979	5
NC TVM 3 SB U	.00000	.00000	.00000	.00000	5
NC TVM 1 N	.23854	.03388	.20632	.26767	5
NC TVM 2 N	.00912	.00795	.00000	.01767	5
NC TVM 1 SA Q	.03174	.02626	.00794	.06055	5
NC TVM 2 SA Q	.00118	.00327	.00000	.00590	5
NC TVM 3 SA Q	.00000	.00000	.00000	.00000	5
NC TVM 1 SB Q	.06496	.02250	.04168	.09029	5
NC TVM 2 SB Q	.00000	.00000	.00000	.00000	5
NC TVM 3 SB Q	.00000	.00000	.00000	.00000	5
NC TVM 1 N Q	.03074	.01174	.02070	.04216	5
NC TVM 2 N Q	.00000	.00000	.00000	.00000	5
NC TEL1 SA U	.12932	.02791	.10947	.16725	5
NC TEL1 SB U	.14619	.01109	.13300	.15768	5
NC TEL1 N U	.08782	.02931	.05470	.12040	5
NC TEL1 SB Q	.01042	.00929	.00000	.01836	5
NC TEL1 N Q	.00358	.00730	.00000	.01354	5
SC Gate 1N Util	.06084	.00180	.05911	.06293	5
SC Gate 2N Util	.06136	.00155	.06040	.06324	5
SC Gate 3N Util	.06166	.00149	.06037	.06355	5
SC Gate 1SUtil	.20686	.00845	.19894	.21582	5
SC Gate 2SUtil	.20459	.01013	.19303	.21449	5
SC Gate 3SUtil	.20385	.00953	.19154	.21193	5
SC Q Gate 1N Util	.00000	.00000	.00000	.00000	5
SC Q Gate 2 N Util	.00000	.00000	.00000	.00000	5
SC Q Gate 3N Util	.00000	.00000	.00000	.00000	5
SC Q Gate 1S Util	.00176	7.6810E-04	.00105	.00235	5

SCQ Gate 2S Util	.00190	5.5455E-04	.00136	.00258	5
SC Q Gate 3S Util	.00187	9.1322E-04	.00102	.00287	5
SC TVM1N Ut	.90084	.00879	.89006	.90866	5
SC TVM2N Ut	.65975	.01621	.64244	.67521	5
SC TVM3N Ut	.28715	.04809	.25394	.35358	5
SC TVM1S Ut	.67212	.05623	.61116	.71786	5
SC TVM 2S Ut	.66017	.04789	.60293	.69900	5
SC TVM 3S Ut	.66495	.06295	.58665	.71444	5
SC R TVM1N Ut	.58537	.03540	.54570	.61785	5
Dom.Q TVM2N	.01982	.01984	.00000	.03956	5
Q SC TVM3N	.09598	.01882	.07813	.11829	5
Q SC TVM1S Ut	.15037	.08395	.05904	.24460	5
Dom.Q TVM 2S	.00691	.00498	.00000	.01024	5
Q 106 TVM3S	.16364	.09605	.06722	.24784	5
SC Teller 1N Ut	.64826	.11565	.49425	.74573	5
SC Teller 1S Ut	.72486	.10045	.63177	.84379	5
Q SC Teller 1N	.81183	.60202	.20547	1.5573	5
Q R Teller 1S	1.7514	2.1287	.42184	4.6775	5
Dom Gate 1 Util.	.08117	.00480	.07669	.08621	5
Dom Gate 2 Utili.	.08275	.00432	.07857	.08704	5
Dom Gate 3 Utili.	.08156	.00416	.07797	.08597	5
Dom No in Gate Q.1N	1.8689E-04	3.5071E-04	.00000	6.3643E-04	5
Dom No in Q.Gate 2 N	6.3715E-05	1.7687E-04	.00000	3.1858E-04	5
Dom.No in Q.Gate 3N	5.2178E-05	1.0918E-04	.00000	2.0297E-04	5
Dom.TVM 1 Utilization	.62451	.05359	.55380	.66673	5
Dom.TVM 2 Utilization	.15974	.03440	.11936	.19617	5
Dom.TVM 3 Utilization	.00704	.00950	.00000	.01751	5
Dom.No.in Q.TVM 1	.00000	.00000	.00000	.00000	5
Dom.No.in Q.TVM 2	.20163	.03972	.16502	.23637	5
Dom.No.in Q.TVM 2	.02736	.01088	.01218	.03324	5
Dom.No.in Q.TVM 3	.00186	.00334	.00000	.00589	5
Dom.Teller 1 Utili.	.26077	.04548	.20163	.29182	5
Dom.No.in Q.Teller 1	.06045	.02744	.04006	.09169	5
Train W.Time SC	1.9817	.02857	1.9569	2.0166	5
Train Waiting Time 4 Ba	2.4990	.06953	2.4348	2.5841	5
Train Waiting Time 4 SC	1.9801	.19099	1.7769	2.2025	5
Number Abord Train 4 Ba	.11667	.00000	.11667	.11667	5
SC ABORD TRAIN	.01360	.00415	.00978	.01763	5
Abording Train Ros.	.80450	.08985	.72842	.88256	5
NC ABORDING TRAIN SC	.52663	.15052	.35997	.68592	5
Train W.Time Ros	1.9466	.14127	1.7965	2.1149	5
NC ABORDING BAY	5.2795	.36636	4.9343	5.6574	5
davg(Dom.Abord Train SC	1.6270	.21756	1.5149	1.9374	5
Train W.Time 2 Bay	1.9408	.04285	1.9086	1.9954	5
Train W.Time 2 SC	1.8590	.22103	1.5672	2.0062	5

Simulation run time: 2.80 minutes.
Simulation run complete.