Investigating congestion mitigation scenarios to reduce truck turn time at Port of Montreal using Discrete Event Simulation

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Abstract

Investigating congestion mitigation scenarios to reduce truck turn time at Port of Montreal using Discrete Event Simulation

Vignesh Alagesan

Container ports are facing the growing problem of congestion due to the high volume of container trucks entering the terminal. Globalization, growth of trade and increasing consumer demand have further added to this complexity which has resulted in increased greenhouse gas emissions at the ports. Several measures are being undertaken by the ports to reduce this problem and improve port sustainability. Examples of these measures are implementing advanced technology equipment, implementing extended gate hours, changing the arrival patterns of trucks, and implementing variable gate lane policies.

The objective of the thesis is to develop a discrete event simulation (DES) model to investigate the congestion mitigation scenarios to improve terminal productivity and reduce truck turn times at the Port of Montreal. A case study with the Montreal Port Authority is conducted. The results of our simulation study yield upgrade of technology at the terminals as the best solution followed by managing the arrival patterns, changing gate lanes and extended gating hours. The proposed work is novel and one of the very few to be conducted in the context of Port of Montreal. The generated results can be used by decision makers at Port of Montreal in developing strategies to mitigate congestion and reduce truck turn times at terminals.

Keywords: Discrete event simulation, Scenario analysis, Technology, Greenhouse gas emissions, Green harbor trucking, Congestion mitigation.

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List of acronyms

MPA	Montreal Port Authority
TEU	Twenty-foot equivalent unit
DES	Discrete event simulation
EG	Extended Gate hours
CT	Container Terminal
NE	No extended gating

Chapter 1

Introduction

Ports are important gateways for global trade and major accelerators of economic development. The increasing growth of the global trade has put high stress on the container terminals (CT) to manage their operations efficiently. A terminal's competitiveness is measured by the way it handles and solves the routing problems in the terminal. As the number of container trucks is increasing, the responsibility of CT operators to reduce congestion and manage operational efficiency of the ports has also gone up. This creates a greater demand in container logistics and management as well as on technology (Steenken et al. 2004). Therefore, the capacity of the terminals should be increased to manage the high inputs and sustain the productivity (Stahlbock and Voß 2008). Due to inadequate intermodal transportation infrastructure in the container port, the freight community has experienced significant delays (Rooney, 2006). The impact of increasing number of containers can be seen on congestion of trucks inside the terminal. The increase in congestion level reduces the travel time and increases the idle time of the trucks inside the port which results in increased level of unproductive greenhouse emissions, and increase in freight costs from trucking operations. This could also lead to increase in the price of the goods to the end customers (FHWA, 2004).

Figure 1 Port of Montreal Container terminal

1.1 Thesis Objective

The primary objective of the thesis is to investigate congestion mitigation scenarios to reduce the turn time of trucks at the Port of Montreal container terminals (figure 1) using discrete event simulation (DES). Several short-term measures have been proposed and tested using the simulation model developed in ARENA. The measures evaluated include implementing advanced technology equipment's, implementing extended gate hours, changing the arrival patterns and the flow of goods movements by changing different policies.

1.2 Thesis contribution

The proposed thesis contributes a discrete event simulation model that could help the Montreal Port authority to test various scenarios that could assist in reducing the turn time of the incoming container trucks. The simulation model is designed in such a way that critical inputs to the model can be controlled with excel data sheet. The staging lane logic and the inter-arrivals data can be changed directly from excel. This helps in avoiding the change directly in the simulation model. The simulation model presents the results of waiting time, queue length, the number of trucks according to the type, work in progress, utilization of resources at any time, the idle time of resources and entities, cycle time or turn time of each truck type. The model also helps in deciding the number of resources required in a particular scenario and avoids excess resources which assist in reducing the cost of operations. It contributes to study of how arrival patterns affect the system in terms of congestion and turn times. Hence, the proposed DES model can be used by Port Authorities as a decision tool to improve the turn time of trucks while at the same time minimizing the greenhouse gas emissions.

1.3 Organization of the thesis

Chapter 2 presents the literature review.

Chapter 3 states the problem definition.

Chapter 4 explains the DES-based solution approach.

Chapter 5 presents a case study on Montreal Port authority for the proposed model.

Chapter 6 presents the simulation model development in Arena.

Chapter 7 provides the conclusions and future works.

Chapter 2

Literature Review

In this chapter, we present the literature review on measures to reduce congestion inside port terminal which leads to the reduction of greenhouse emissions. The most common techniques used to reduce the congestion inside the terminal includes implementation of appointment systems, implementation of advanced technology, changing arrival patterns, DES simulation for ports.

2.1 Causes of congestion in ports

There are several reasons for congestion at the ports, some of the main causes for congestion at the terminals are due to breaks in work at the terminal gates, trouble in the system or due to weather condition. Sometimes there are trucks with confusing documents which increases the service time to a considerable extent. It can be observed from certain port studies that trouble in the transaction in the port is an important reason for the congestion inside the terminal. Implementation of appointment system along with the latest gate technology could reduce the service time at the gates and reduce the delay in the service (Huynh et al. 2011).

2.2 Managing congestion in ports

2.2.1 Appointment Systems

Several ports around the world are testing appointment systems for the incoming trucks by creating a web portal where the truckers can book their time of arrival as preferred. There are different types of appointment systems such as appointment windows, reservation system etc. several ports in China have tested appointment systems which have proven to have an efficient truck turn times. There are also scenarios where having appointments have made the situation worse. Several studies have been conducted on the appointment systems. (Huynh and Hutson, 2005) and (Huynh and Walton, 2008) discussed truck appointment systems. If an efficient truck appointment system is implemented in a container terminal, the result would be reduced queue lengths, shorter turn times, and certain entry times of truck. A multi-server queueing model was developed to analyze gate congestion at the terminal and evaluated terminal appointment system. Sample data for the truck arrivals and processing time at gates are collected at the container terminal in New York. They concluded that the appointment systems are an effective tool for controlling the idle time inside the terminal (Guan and Liu (2009)). A better distribution of trucks would reduce congestion inside the terminals. Appointment systems can be defined as the maximum number of trucks that can approach a terminal in a given time window. Port of Vancouver, Port of Los Angeles/Long beach introduced the truck appointment systems (Morais and Lord 2006). Several authors proposed different strategies for controlling trucks to reduce the congestion inside the terminal. Huynh and Walton (2011) developed a DES model to simulate various appointment rules. The benefits of truck appointment systems were written by Zehendner and Feillet (2013). Chen et al. (2013) introduced a non-stationary queueing model and proposed two types of appointment systems namely static and dynamic. The appointment systems are one kind of managerial solution for handling the increased truck turn times and congestion inside the terminal. DES models were used for evaluating truck appointment systems for finding the effect of congestion and improving the flow of trucks Kiani et al., 2010; Sharif et al., 2011; and Karafa, 2012. A traffic DES model was developed to estimate the emission levels at the terminal Karafa (2012). A mathematical model was developed to determine arrival time window of trucks at a terminal. They used a simulation model to test the performance parameters (Do et al., 2014). The vessel dependent time window system was introduced to control the arrival of trucks by Chen et al. (2013).

2.2.2 Extended Gate hours

Extended gate hours are one of the best solutions for reducing congestion. Extending the regular gate hours can help in managing the arrival patterns of trucks and reduce the peak hour congestion. Both the appointment systems and extended gate hours could be implemented together for an efficient system. There are several ports which have implemented this system and benefitted. Many studies focus on the implementation of extended gate hours. In this thesis, we will be discussing extending the gate hours for Cast and Racine in the early hours of the day and also extend the hours for all the terminals at the end of the day. The issues for implementing the strategy was studied by (Giuliano and O'Brien 2007) which includes providing incentives for the drayage operators, pay rise to the workers to the workers at the port. They showed an improvement of 20% shift of drayage from the peak to off-peak hours. Spasovic, Dimitrijevic, & Rowinski, (2009) experimented with the extended gate hours at the port of Newark/Elizabeth which resulted in no peak hour shifts and had still the same level of congestion. A majority of the studies proved extended gate hours to be effective to a considerable extent.

2.2.3 Gate Technology

Several technologies are in use in port terminals around the world to improve the overall efficiency. The key performance indicator that is concentrated by several ports is the turn time. Port of Montreal is one of the most technologically advanced ports in the world. It uses technologies such as License plate readers, Barcode scanners, Biometrics etc. Recently Port of Montreal developed a web portal to update the live congestion inside the terminal and the estimated waiting time in each terminal. The portal has an updated image of each terminal which refreshes every five minutes. Use of advanced automation technologies helps in increasing the port efficiency and improve the average truck turn times inside the terminal.

Several technologies are available which include optical character recognition (OCR), global positioning systems (GPS), License plate readers (LPR), real-time location systems (RTLS) and radio frequency identification device (RFID). There are also many other technologies apart from this. The proper use of technology is critical which was revealed by several studies. (Hu et al. 2011) studied the use of RFID technology in which the vehicle and the driver information can be collected from the RFID tag. To automate the identification of the trucks and containers, trucking companies are using intelligent technologies to locate and identify freight (Wolfe and Troup; 2005; Morais and Lord; 2006; Tsilingris et al.; 2007). Currently, Montreal port authority uses RFID, License plate readers and some gate processing technologies. There are several problems faced in collecting data where only 70% of the data could be recorded without any error. Port of Vancouver employs the global positioning system (GPS) to track the drayage trucks at any point in time. They also employ advanced gate technologies for efficient terminal operations.

2.2.4 Arrival Patterns

Arrival patterns differ from time to time and it is challenging to control the arrival patterns. Several ports around the world are trying to understand the arrival patterns. There are very few studies in this field that are published. It is very important to note that Port of Montreal deals with thousands of container trucks and is one of the busiest ports in the North American continent. The Port of Montreal is trying to control the congestion to reduce the greenhouse gas emissions. The arrival pattern of trucks plays an important role in the congestion of trucks inside the terminal. Several truck arrival patterns and their effects on turn time and congestion were studied by Azab and Eltawil (2016). A discrete event simulation model was developed to examine the effects of different arrival patterns on turn time of trucks. Five different scenarios were tested which includes different patterns such as default, increasing trend, decreasing trend, uniform and distributed peak arrival. The results showed that arrival patterns have a great impact on the truck turn time. Without reducing the throughput, by only changing the pattern of arrivals, the turn time efficiency can be significantly improved. There are several ports which are trying to cap the number of trucks entering every hour and distribute them in different patterns to reduce the truck numbers within the maximum capacity. Capping is one of the best practices followed by several ports as it involves lower risk compared to other strategies in a terminal.

2.3 Modeling congestion in ports

2.3.1 DES for ports

Simulation models help to understand the system better and test different scenarios before actual implementation and avoid risks. A simulation model mimics the real system which means it will behave identically to the existing port operations with the truck as entities and all the gates as resources. DES helps in testing the system without any interference with the real system. It is recommended to design a customizable model which could be customized anytime if there are any future improvements in the actual system. The model can be used to test any scenario without even thinking about the consequence. This flexibility is not possible in the real system which involves high-risk such as loss of revenue, increased congestion, loss of customer satisfaction, worker satisfaction, increased greenhouse gas emission etc. Discrete event simulation has the ability to study complex systems and their dynamics more effectively, model stochastic systems. Shabayek and Yeung (2002) developed a DES model for the port of Kwai Chung container terminals in Hong Kong. The model focused on the efficient operations of the terminal. There are several other studies on the use of discrete event simulation to model the port operations. Congestion inside ports may lead to several problems such as delays in the cargo delivery delay, loss of product value, and so on. There is a broad range of solutions to this problem which varies from port to port (Chen, Zhou, et al., 2011; Van Asperen, Borgman, et al., 2011). Most of these issues are evaluated via queueing theory (Van Woensel and Vandaele, 2007). To define the truck traffic flows, a microscopic model based on the queueing theory is proposed. Queueing theory is the mathematical study of waiting queues developed by Agner Kraup Erlang for analyzing telephone networks (Erlang, 1909). Subsequently, queueing theory has been applied for many other applications such as telecommunications, business, medicine, transportation, and industries (Denning and Buzen, 1978; Edmond and Maggs, 1978; Floyd and Jacobson, 1993; Daganzo, 1994).

Discrete event systems (DES) have been recognized as an efficient tool for the study of complex systems. Decision support systems can be developed with DES models (Thiers and Janssens, 1998; Mastrolilli, Fornara, et al., 1998; Gambardella and Rizzoli, 2000; Saanen, 2000 and 2002; Murty, Liu, et al., 2005). It has many applications in the field of terminal containerization. It mainly helps in making strategic decisions such as allocating the resources and terminal planning (Gambardella, Rizzoli, et al., 1998). The design process of the entire port operations is difficult, most of the studies were simplified from stochastic to deterministic for the sake of simplicity (Steenken, Voß et al., 2004 and 2008). Most of the authors focused on the essential activities of the port terminal, such as terminal yard management (Hayuth, Pollatschek et al., 1994; Kim, Wang et al., 2002; Koh, Goh, et al., 1994; Mosca, Giribone et al., 1994), transportation within terminal (Duinkerken, Ottjes et al., 1996) and on the berth, crane operations inside terminal, shipyards and their layouts (Bruzzone and Signorile, 1998; Moon, 2000; Soriguera, Robusté et al. 2006).

Various authors have demonstrated discrete event simulation as an effective tool for developing operations of a port. For the port system in Italy, a simulation model was designed by Parola and Sciomachen (2005). Likewise, a DES model for military operations was developed by Leathrum et al. (2004). Port simulation models were also proposed by several other authors such as Bruzzone et al. (2000), Koh et al. (1994) and Legato and Mazza (2001). A DES model was developed in ARENA to analyze the issues in a raw material inland terminal. With the help of the DES model, they could improve the terminal operations by testing their optimization measures (Yuan, Zhang and Yang (2010)). Jie et al (2010) developed an ARENA model of a container terminal to find the optimal allocation of terminal resources, reduce operation time and improve the utilization of the resources. Arango et al. (2011) solved allocation of berth issues by developing a simulation model in ARENA. The results improved the efficiency of the port of Seville.

2.3.2 Other modeling approaches

There are several other software's used to model and simulate ports. Some of the complete models include the port of LA/Long Beach modeled with the Quick trip. This was a high-level model which did not include entrance gates, terminal yard, exit gates, and road network. It included very little detail (Fischer et al. (2006)). Lee et al (2011) modeled the port of Singapore with terminal yard and road network. There were no entrance gates and exit gates modeled. Dougherty (2010) modeled the port of Newark/Elizabeth using VISSIM but the model only included road network inside the port. This model was simulated to study the traffic inside the port territory. Karafa and Golias (2012) modeled the Port of Newark/ Elizabeth in detail and included the entrance gates, terminal yard, exit gates and the road networks. Port simulations can be built in C and C++, Fortran, Java, Matlab, Awesim, Portsim, Modsim, Slam, Gpss/H, Viscot, Monte Carlo, Visual Basic, Em-Plant, Pascal, Siman, Portmodel, Ithink and Micro World (Mw), Simport, Anylogic and NetLogo respectively.

2.4 Research Gaps

Based on the review of literature, following research gaps were identified,

- Most of the research papers study the congestion mitigation approaches individually such as implementing gate technology, logistics, overall operations, operational policies, and storage to improve the efficiency and reduce congestion inside the terminal. But, none of them have tested two or more strategies together.

- Majority of the papers concentrate mainly on the modeling of yard process, berthing area rather than the movement of trucks in DES.
- Highly customizable and upgradeable simulation models are not developed. Simulations were built with minimum capabilities.

In this thesis, we will be discussing discrete event simulation of truck movements in detail in the context of Port of Montreal. We will be testing few such as implementing advanced technology equipment's, implementing extended gate hours, changing the arrival patterns and changing the logic of goods movements by changing different policies using data from the Port of Montreal. The proposed model is highly customizable and upgradable. We recommend policies based on testing of various operation scenarios to the Port of Montreal.

Chapter 3

Problem Statement

The objective of the thesis is to develop a DES model to investigate the following four scenarios to reduce truck turn time in the Port of Montreal.

1. **Extension of gate hours**: Implementing extended gate hours reduces the peak truck arrival numbers and spreads them across the day. This helps in reducing the congestion inside the terminal. Hence idling can be avoided which generates unproductive greenhouse gases.
2. **Modeling the truck arrival patterns:** Changing the arrival patterns and capping the number of incoming trucks to a specific level helps to increase the smoothness of the truck flow in the terminal.
3. **Dedicated gate lanes:** The second stage gating at the port entry has 26 lanes in which Maisonneuve trucks and the Viau trucks have dedicated lanes, but the Cast and the Racine trucks have shared lanes. Hence different gate policies are tested for Cast and Racine to find the best policy which reduces the turn time.
4. **Use of advanced technology**: Implementing advanced technology can rapidly reduce the turn time. Turn time here refers to the time a drayage truck spends at the marine terminal. The time a truck spends in the terminal is known as the terminal time and the time a truck spends at the staging area is referred as the staging time. Both the time together represents the turn time.

A case study with the Montreal Port Authority is conducted.

Chapter 4

Solution Approach

In this chapter, we firstly provide a brief introduction to DES and describe the various steps involved. Then, we present their application to our specific problem context.

1. **Problem formulation**: The first step in any simulation study is the problem formulation. The problem formulation has five critical phases. These are defining the problem, defining the system, establishing performance metrics, developing the conceptual model, and documenting the assumptions. The problem should be precisely defined so that the analysts can have a clear understanding. Once the problem definition phase is completed, the system should be defined with all the boundaries.
2. **Objectives and Introduction**: The primary objective of our simulation model is to evaluate the impact of various scenarios that affect the turn time of incoming container trucks. Then the overall project plan was developed based on the simulation results.
3. **Model Conceptualization**: The conceptual model is the actual representation of a system or a simulation model which helps understand the operations and the workflow in the form of process chart, flowchart or activity diagram. In this phase, we define the process flow which helps in building the discrete event simulation model.
4. **Data collection**: All the input data for a simulation model are collected in this phase. Historical data related to turn times, terminal and gate information, arrival times are collected from the Montreal port authority for our simulation model, and the data are analyzed using input analyzer.

5. **Model translation**: The conceptual model is converted into a complex discrete event simulation model with the help of high-level flowchart and algorithm using M-VISIO software. It is then converted into actual simulation model using ARENA software.
6. **Verification**: This step makes sure that the conceptual model is translated into computerized model properly and truthfully. Few ways to do verification include carefully examining the output, the Interactive run controller (IRC) or use of debugger, an essential component of successful simulation model building to check if the behavior is at least reasonable.
7. **Validation**: Validation involves a comparison process to test the results of the DES model outputs with the real system outputs. Different input data sets are created to test the model output changes. This is the most important step to decide if the simulation model works appropriately. There are various types of validation techniques such as event validity, face validity, internal validity, Parameter- variability sensitivity analysis, and so on (Sargent,2007). In our case, we make use of face validity where expert opinion is sought for the judging the results, and sensitivity analysis where modeling parameters are changed, and the changes are observed in the output.

The flow chart below represents the various steps used in a simulation study. Figure 2 depicts the flowchart.

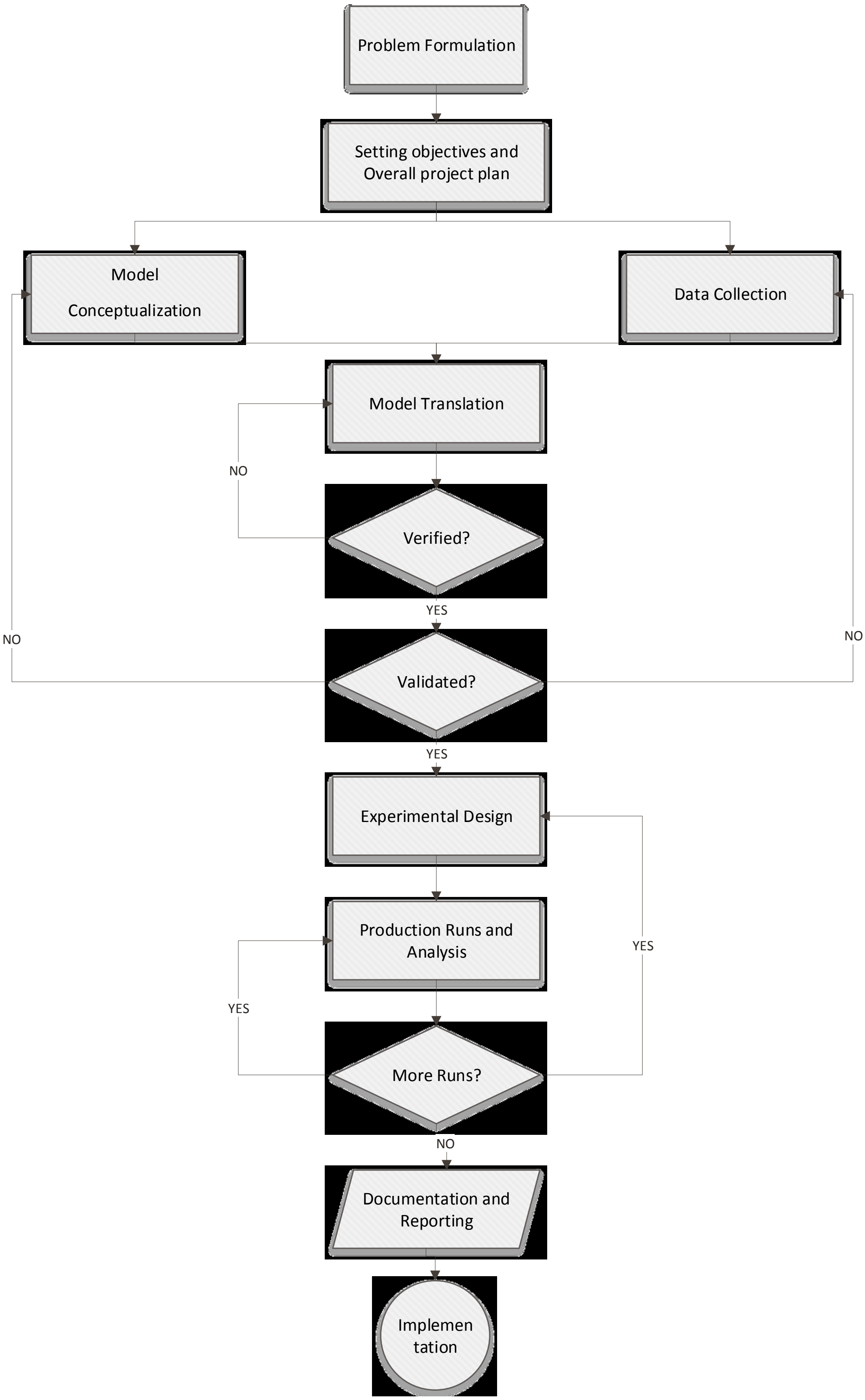


Figure 2 Steps in simulation study (Banks et al 2010)

4.1 Introduction

The primary objective of our simulation model is to evaluate the impact of various scenarios that affect the turn time of incoming container trucks. Reducing the truck turn times has a direct impact on the reduction in greenhouse gas emissions. To analyze the congestion issues, a simulation model was developed to represent the existing situation of truck movement at Port of Montreal container terminals. Arena simulation software was selected to design the simulation due to its ability to do detailed modeling and flexibility. The modules used in the software to build the model have specific actions that relate to the flow, and the timing, the precise representation of the real system is subject to the modeler. Complex programming can also be done. External Software such as Microsoft Excel, Access etc. can be linked for building more complex models. All of this can be done on one platform which is ARENA.

4.2 Input modeling

Input modeling is an important part of any simulation because the result of the entire simulation model depends on the input. This is referred to as "garbage in garbage out". There are three steps involved in this stage:

1. **Collection of data from the real system**: This phase is a challenging step which involves a lot of work, sometimes expensive and always error-prone. In some cases, the data is not easily available. Hence, a perfect knowledge of the process is necessary to make an educated guess.
2. **Identifying the probability distribution**: Approximating the given data by a distribution function is very important. All the data are not approximated. Few data's are deterministic and few are probabilistic. Once the distribution is found for a given set of data it can be given as an input to the model.

3. **Goodness of fit**: The goodness of fit test is done to find the best fit for the data. This is done with the arena input analyzer which provides the results based on the Chi-square test and Kolmogorov-Smirnov test.

4.2.1 Data collection

In this section, we will discuss the data obtained from the Montreal Port Authority and on-site analysis which includes the following:

1. The arrival time of trucks.
2. Type of trucks.
3. T0, T1, T2, T3 Gate service delay.
4. T2 gate paperwork service delay.
5. Yard service time.
6. Average truck speed.

All the data was collected for April 3rd and April 4^{th,} 2017. The reason for selecting this date was because April 3rd represented the average daily trucks pattern and April 4th had the maximum number of trucks of the month. This is explained in detail in the case study. Most of the data used in the model are deterministic, and the port authorities helped with the data. There are very few stochastic data used mainly for the yard delay, gate service times, and paper work delay. The gate time delays were provided with maximum, minimum and mean values. Hence a triangular distribution was selected which best represents the given data. Only few yard service times were recorded. Most of the time only 20 to 30 percent of the service time data are recorded due to some issues with the system recording it. As the data were limited when compared to the total number of trucks, the best distribution of the available limited data was found using input analyzer in Arena. This provides the result for best fit based on the Chi-square test and K-S test results.

4.2.2 Identifying the probability distribution

The probability distribution was found using the Arena input analyzer software. The inter-arrival time of the entities used in the model is taken from the real scenario. Hence, an excel sheet is used as input for the inter-arrival times. For the yard process, a set of data for a few trucks were given, and the probability distribution was found using the software. A different set of data was given for April 3rd, and April 4th different yard delay distributions were found.

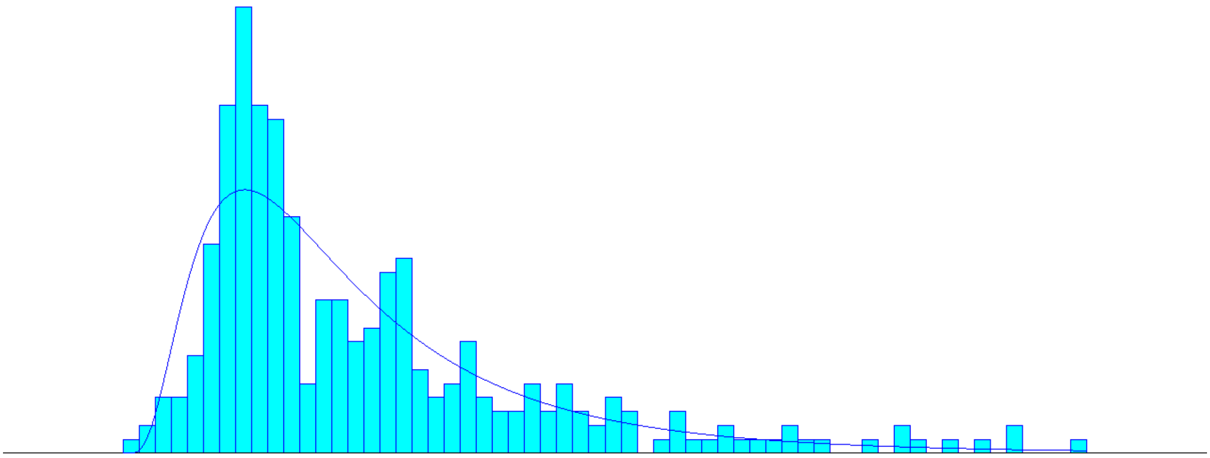


Figure 3 Input analyzer graph

The above histogram shows the best fit for the Maisonneuve yard process data on April 4th. The distribution was found to be 5.5 + LOGN (15.2, 11.7). The distribution was selected based on the two tests as mentioned before by the input analyzer.

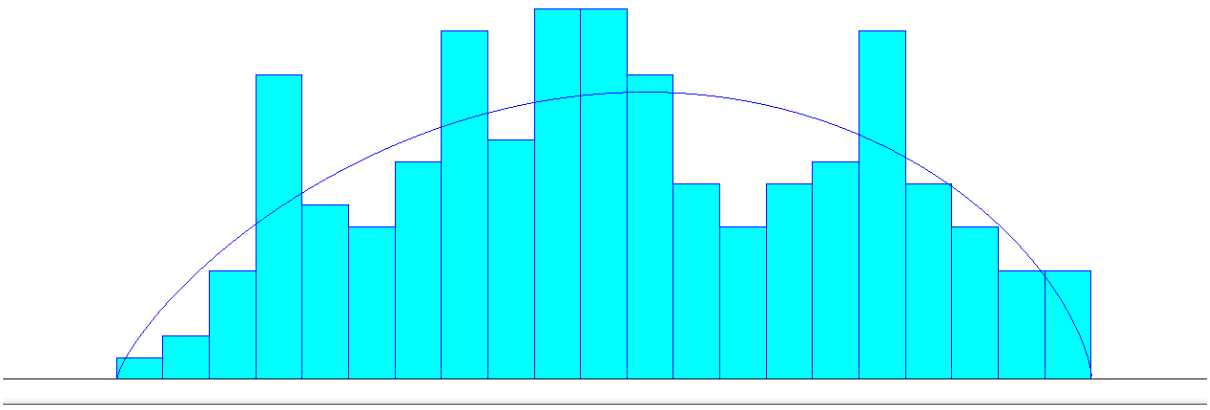


Figure 4 Input analyzer graph

The above histogram shows the best fit for the Racine terminal data on the same day. The expression was found to be 4.5 + 21 * BETA (1.76, 1.64). But the Cast terminal yard process was not recorded properly. Hence an approximate data were provided regarding maximum, minimum and mean values. Therefore, it was decided to have a triangular distribution for the data, and it is TRIA (10, 11.5, 15). Similarly, for Viau terminal, the distribution is TRIA (3.5, 7, 40.5). Correspondingly, the yard distribution was found for April 3rd data where three terminal yard data were not recorded hence the data was suggested for Cast as TRIA (10, 11.5, 15). The Racine yard delay distribution with the expression as TRIA (10, 11.5, 15). The Maisonneuve delay is TRIA (5.5, 15.9, 38.5). The yard delay for the Viau was found to be 4.5 + EXPO (16). The use of excel will be explained in the later sections.

4.3 Model Conceptualization

We have developed a conceptual model for developing the DES model using the process map. The process map explains how a truck enters the port territory and moves inside the terminals. First, the trucks arrive at the port which has a T0 gate delay, then T1 delay and staging before their respective terminals and delayed at T2 gates and then enters yard process and then into T3 gate and then moves finds the way to the exit. Figure 5 shows the typical truck transaction at the Cast terminal starting from T0 to T4. The complete high-level process map for Figure 5 movements is shown in Figure 6 below. The number of lanes at each terminal staging is not mentioned in the process map. But they are referred to in the process chart of the DES algorithm.

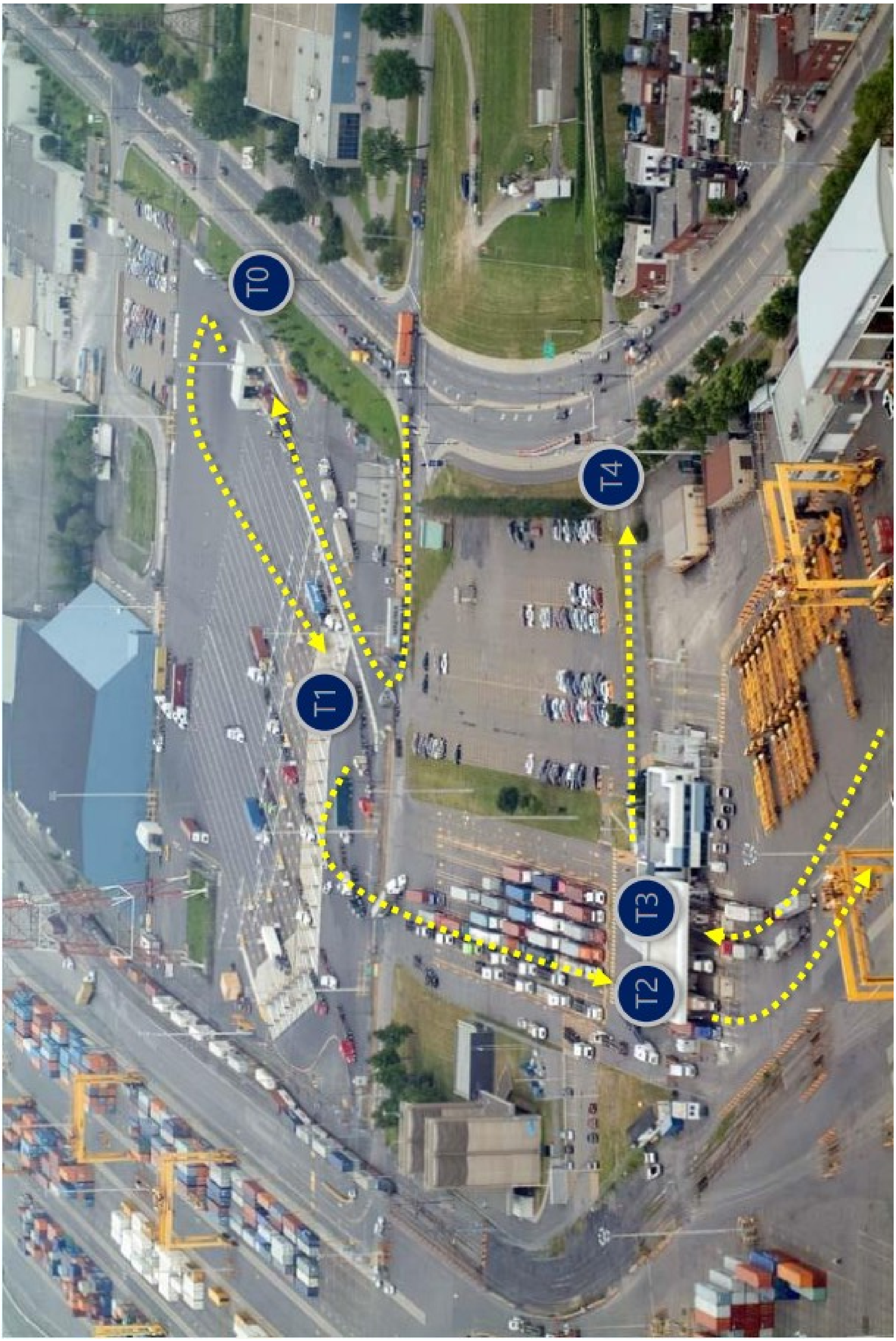


Figure 5 Typical Truck Transaction – Cast terminal

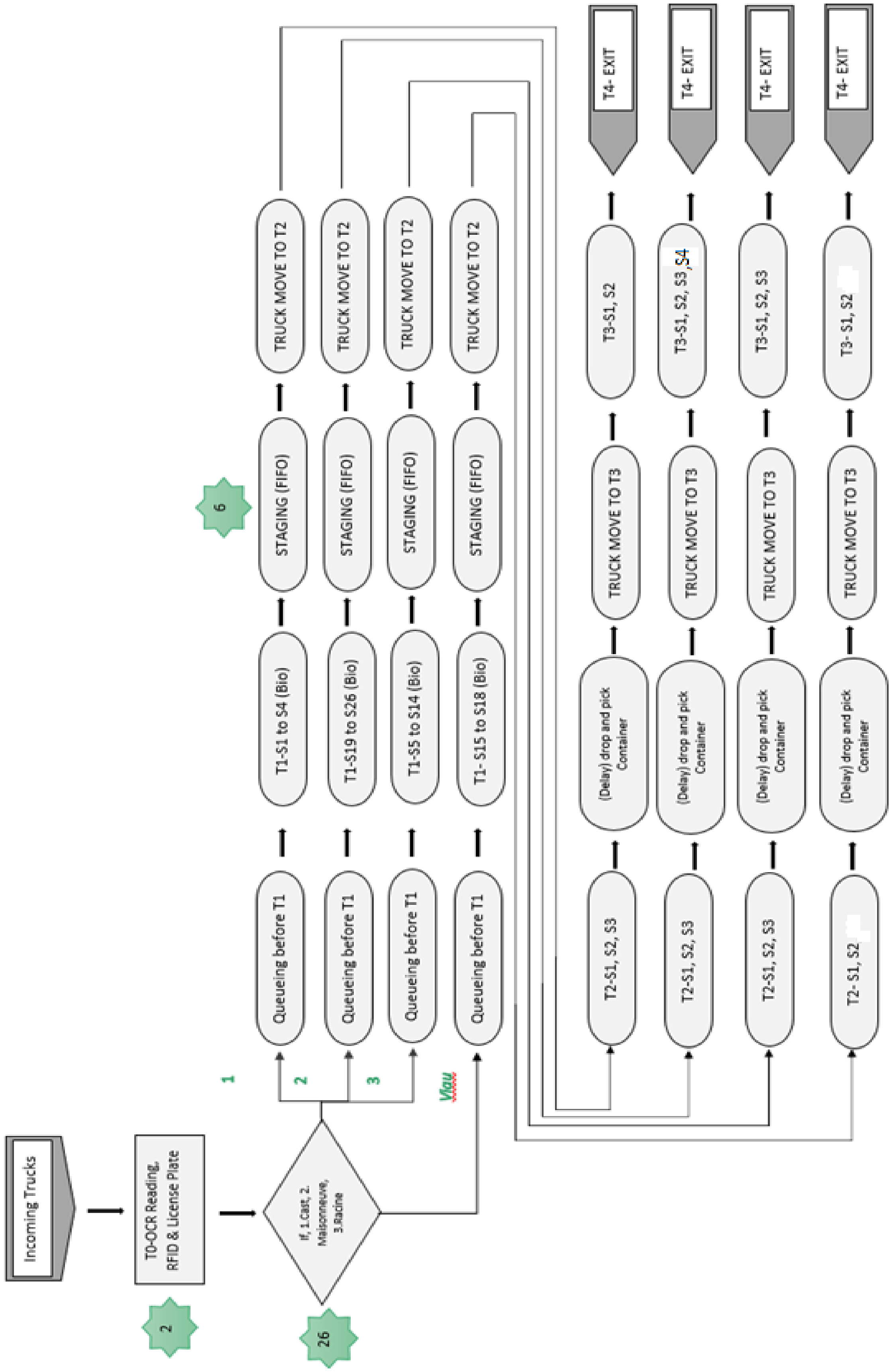


Figure 6 Process map

4.4 Model Translation

In this step, we translate the conceptual process map into a DES model. Before developing an actual DES model, an algorithm is developed, and then the DES model is developed in Arena. Microsoft Visio was utilized for developing this algorithm.

4.4.1 DES algorithm

DES algorithm is designed based on the process map of the system. It defines the movement of entities and decision in DES model. The flow of the algorithm is explained as follows:

1. The truck entities are generated all together at once.
2. Then the truck entities are assigned their type and their inter-arrival time from the table which is provided as an input to the DES model.
3. Then the Truck entities enter the first gate T0 to get served. They select the T0 queue based on the shortest queue.
4. Then these truck entities choose the second gate queue based on the specific queue assigned. The cast and the Racine truck entities are assigned lanes 1 to 14; the Maisonneuve entities are assigned to lanes from 19 to 26, the Viau entities from 15 to 18 and within the assigned lanes they select the lane based on the lane with a minimum number of entities. The second gate has 26 resources. They are called T1 gate resources.
5. Then the entities are moved to their respective terminals and enter the third gate resource T2 through separate staging before each terminal. The staging lane number varies for different terminals. The number of T2 resources differs from each terminal which can be seen in the flow diagram of figure 6.
6. The entity selects the staging lane with a minimum number in the lane.
7. The entities select the T2 resource which is empty as the capacity of the resource is 1.

8. Once the entities are served at T2 in all terminals, they move into the yard process where they are delayed for the yard operations (drop off or pick up container).
9. Upon the completion of the yard operations, the entities go through the fourth gating operation T3 to the exit which is the T4 gate.
10. They select the T3 resource base on the maximum remaining capacity. The number of T3 resources differs from terminal to terminal. This can be seen from the chart in figure 6 below.
11. Then the entity before going to the dispose module to exit they move through the record module where the entity statistics are recorded such as turn time, count.

The algorithm explained above is represented in figure 7(a) and 7(b) below:

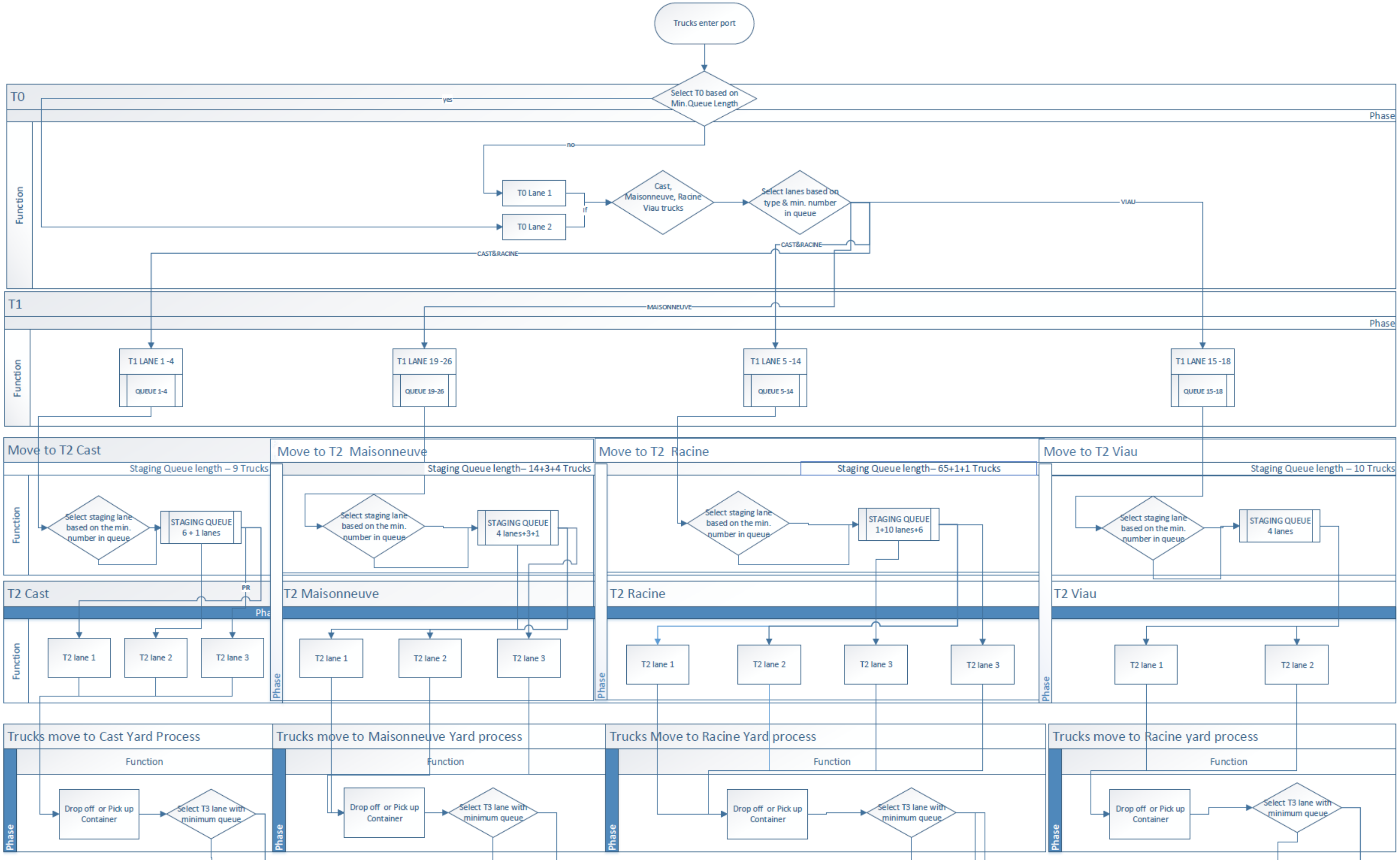
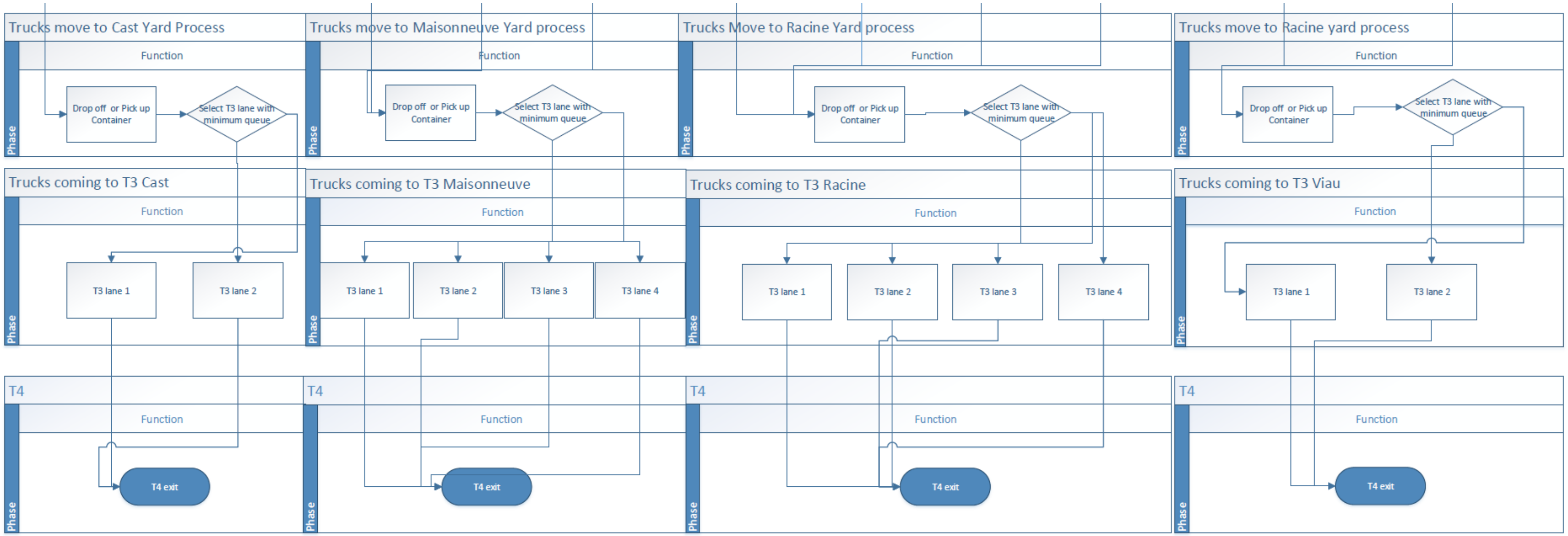


Figure 7(a) DES Algorithm



All Trucks follow FIFO queueing Policy and The queue selection is based on the minimum number in queue

Figure 7(b) DES Algorithm

4.4.2 Elements of DES model

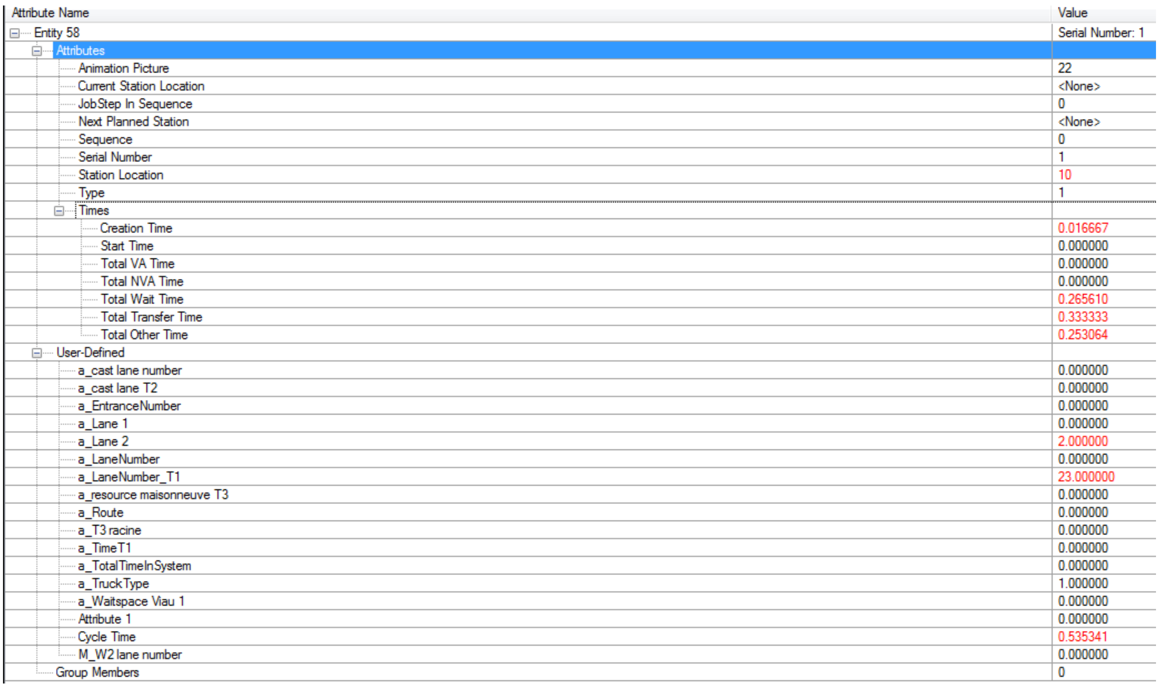
Various elements used in the DES model are explained in this section. These elements can be categorized as follows:

Type	Definition	Model elements
System	A system is a group of structures or parts that together perform vital functions to accomplish a goal.	In our case, the Montreal port trucking operations are modeled as a system composed of various modules such as truck entity creation, resource creation, assignments and so on, that work together.
Entity	An entity can be defined as an object or part. They move inside the system, and their action causes some changes in the system.	The entities in our research model are the container trucks to the port. There is only one entity which is created and assigned four attributes to differentiate between the different types of incoming trucks to the Port of Montreal.
Attribute	An attribute can be defined as the property of an entity which is always attached to the entity.	There are several attributes used in our model. Some of them are, to differentiate between different incoming trucks type attributes are assigned, truck lane number attribute, route attribute, cycle time attribute and so on. These attributes are explained in detail in the model development section.
Variables	Variables like attributes are not tied to an entity rather tied to the system. They are accessible by any entity in the system, and their value can be changed anytime.	In our model, there are several variables used in the system some of them are v_I_InterarrivalTimes, v_I_TruckType, v_TruckArrivalRow, v_I_TruckLanesMatrix, v_I_MaxTrucksInLane, v_I_MaxTrucksincastlane and so on. These variables are explained in detail in the model development section of the model.
Sets	The set module allows us to define a set of resources, counters, entity types, and sometimes entity pictures.	In our model, we use sets to define resources, queues, entity pictures and set of stations.
Events	Events are actions that change the state of the system at an instance of time. All the elements explained are elements of the basic process tab in Arena. There are also elements used from the advanced process and advanced transfer tab as follows.	Various events occur in our DES model such as the creation of truck entities, holding the entities, delaying the entities, assigning the entities, and finally recording the entity statistics and so on.

Seize	The seize module used to seize the resources according to a specific rule. The resources and queues can be defined in the seize module. The seize module used in our model is used to seize the set of resources and set of queues.	The seize module used in our model is used to seize the set of resources and set of queues.
Delay	The delay module is used to delay an entity for a specified duration of time. Several delay modules are used in our model to delay the truck entities for a specified duration of time at the gate resources.	Several delay modules are used in our model to delay the truck entities for a specified duration of time at the gate resources.
Release	The release module is used to release the seized entity from the resource. The units to be released can be defined in the release module. The release rule can be specified if there are many resources.	The release modules in our model are used to release the truck entities from the resources.
Search	The search module can be used to search a specific entity or resources. The search module can be used to search either a queue or a batch. An expression can also be defined to search.	Search module with an expression is used in our model to search the shortest queue.
Route	The route module is used to route the entity by delaying it by specifying the duration of delay and route the entity to the destination station. The delay and destination can also be an expression. A route always accompanies a station module as a destination for the entities from the route module.	The route module in our model is used for delaying the truck's route to the terminals.
Station	The station module is used as a destination for the route module. A station module consists of a single station or a set of stations defined as a set.	There are several station modules used in our DES model as a destination for the truck entities.

4.5 Verification

Verification is done to ensure that the DES model is producing the right results. The logical structure of the model is verified, and their inputs are also checked. The model was verified by running it without any simulation errors, and run to completion without any errors. The results at the end of the simulation were checked if the expected and observed values match for the modeling parameters. Table 1 shows the sensitivity of certain parameters at different parts of the terminal. Debugger tool and run controller were used to track entities, queues, and resources. With the help of debugger one entity type was selected and followed from the creation till they exit the model. It showed that the model was working as it needed to be. Hence most of the parameters such as the creation of entities from the excel data, entities choosing the right lane and resource, work in progress, current number in resource and queue, current number seized, current simulation time, can be verified from the DES model at any instant of time. A screenshot of the debug bar used to track an entity can be seen in figure 8 below.



Attribute Name	Value
Entity 58	Serial Number: 1
Attributes	
Animation Picture	22
Current Station Location	<None>
JobStep In Sequence	0
Next Planned Station	<None>
Sequence	0
Serial Number	1
Station Location	10
Type	1
Times	
Creation Time	0.016667
Start Time	0.000000
Total VA Time	0.000000
Total NVA Time	0.000000
Total Wait Time	0.265610
Total Transfer Time	0.333333
Total Other Time	0.253064
User-Defined	
a_cast lane number	0.000000
a_cast lane T2	0.000000
a_EntranceNumber	0.000000
a_Lane 1	0.000000
a_Lane 2	2.000000
a_LaneNumber	0.000000
a_LaneNumber_T1	23.000000
a_resource maisonneuve T3	0.000000
a_Route	0.000000
a_T3 racine	0.000000
a_TimeT1	0.000000
a_TotalTimeInSystem	0.000000
a_TruckType	1.000000
a_Waitspace Viau 1	0.000000
Attribute 1	0.000000
Cycle Time	0.535341
M_W2 lane number	0.000000
Group Members	0

Figure 8 Debug bar

Table 1 Verification test and results

Terminal	Gate	Test	Expected Results	Model Results	Verified
Common Entry	T0	Increase Arrivals	Increase in length of the queue	Increase in length of the queue	☑
Common Entry	T1	Increase Arrivals	Increase in congestion for prolonged period	Increase in congestion for a prolonged period	☑
Cast	T2	Increased service time	Increased waiting time at T1	Increased waiting time at T1	☑
Maisonneuve	T2	Increased Service time	Number Increase in staging queue	Number Increase in staging queue	☑
Racine	T2	Increased service time	Increased waiting time at T1 and dedicated staging lane	Increased waiting time at T1 and dedicated staging lane	☑

4.6 Validation

Validation is performed to ensure if our model results meet the operational needs of the user. There are several validation techniques such as face validity, Historical data validation, predictive validation, internal validation and so on (Sargent, 2007). Face validity and historical data validation are used in our DES study. Face validity is done by the experts checking the model. Historical data validation is comparing our simulation results with the historical data. Figure 9 shows the interactive run controller used in our DES model to check the resources, queues, entity statistics, and process.

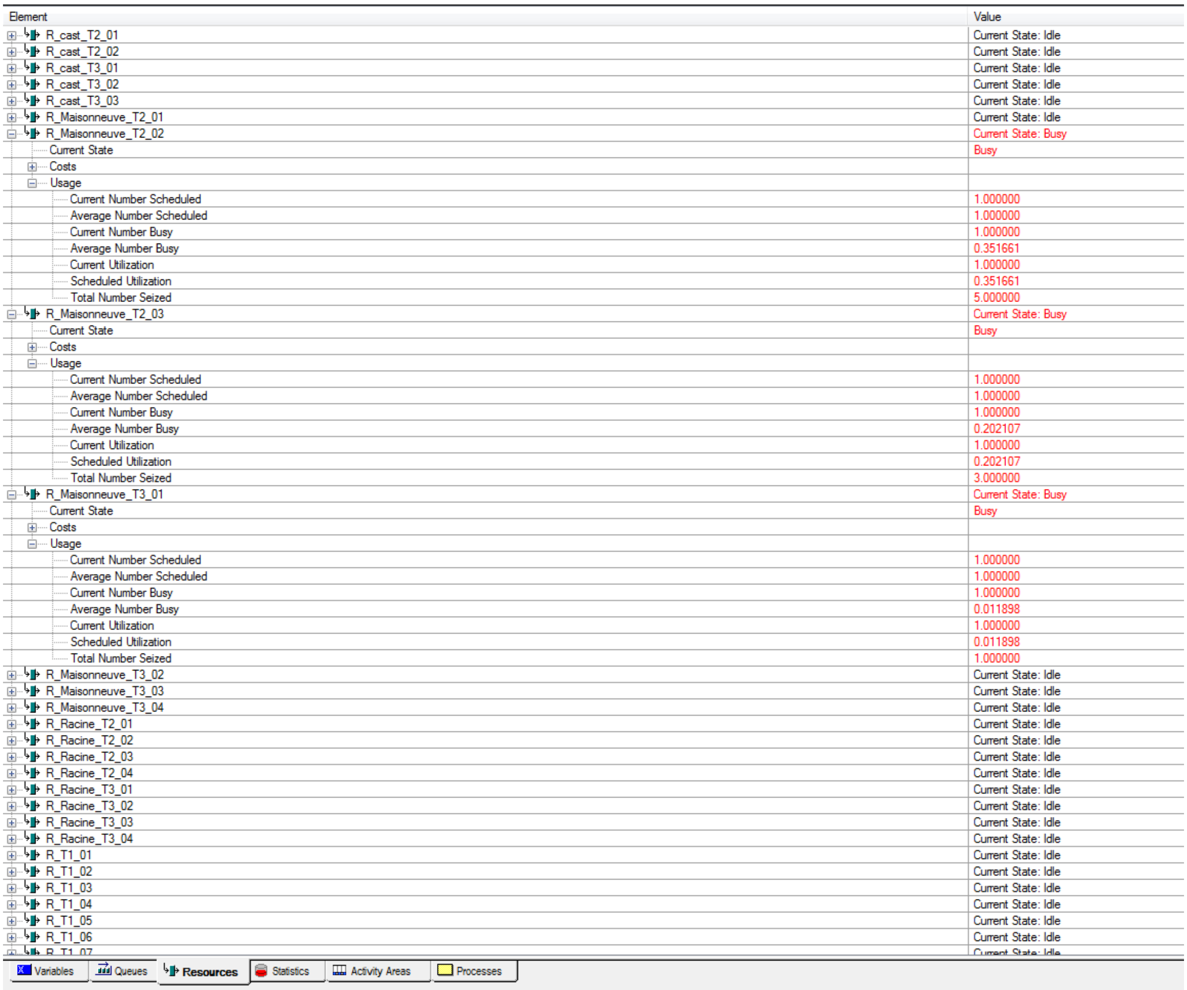


Figure 9 Debug Bar 2

4.6.1 Historical data validation

For historical data validation, data was collected from the Montreal port authority. The parameter being validated is the average truck turn time. The average turn times were calculated from the historical data, and then compared with the simulation output data as shown in Table 2 below.

Table 2 Average cycle times

Avg Cycle Time	**April 3rd (real)**	**April 3rd (Sim)**	**April 4th (real)**	**April 4th (Sim)**
Cast	*51.64*	*76.01*	*69.83*	*93.97*
Maisonneuve	*102.71*	*123.82*	*53.55*	*82.32*
Racine	*56.4*	*76.29*	*76.366*	*116.7*
Viau	*70.62*	*34.62*	*69.34*	*34.68*

The above table shows the turn times from the historical data and simulation output. The simulation results are higher than the existing system historical data. Some model constraints cause the results of the average turn time to be higher which will be discussed in output analysis.

4.6.2 Face validity

In this technique, an expert's opinion is sought to determine if the model adequately represents the real system of truck operations and verify if the output parameters of the simulation model are correct. For our simulation model, the outputs were verified with the Montreal port authorities to check if the outputs were satisfactory. The authorities approved the model after checking all the results of the DES model.

4.7 Output Analysis

The outputs of the simulation model are shown in Table 2. It clearly shows the variation in simulation output and the real system output for the selected two days. Then a detailed study was made comparing the original system with the simulation model and conclusions were made for the factors that affect the simulation time of the model.

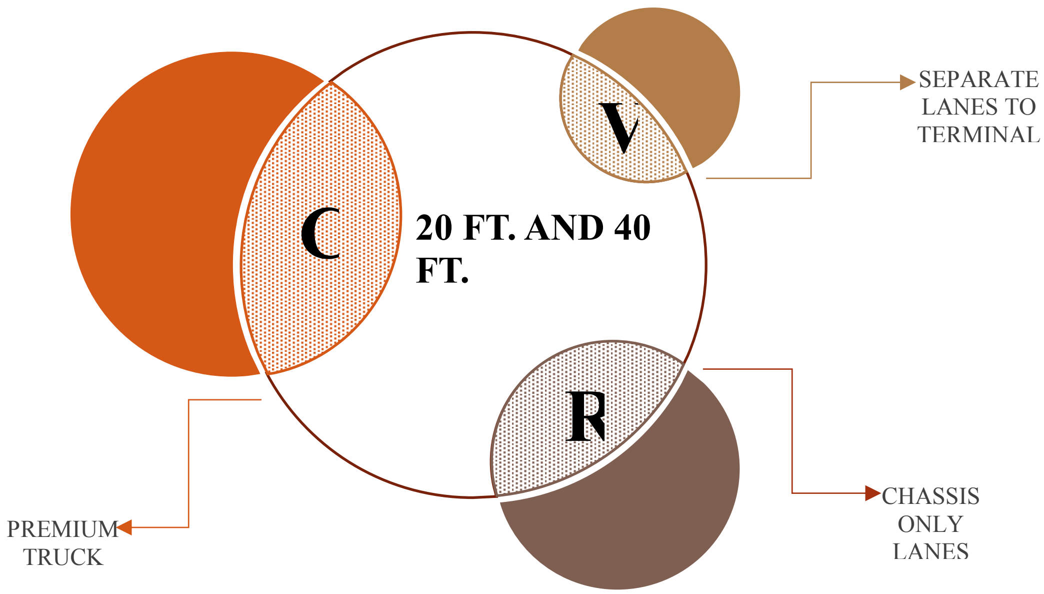


Figure 10 Causes of simulation delay

Figure 10 shows the factors responsible for the delay in the turn times of truck entity. Firstly, the model constraint which affects all the terminal results is that the real system has trucks of varying lengths with 20ft and 40ft containers. But in the model, it is very difficult or impossible to model trucks of varying lengths. Hence, only trucks of one size which is 40ft were considered and based on this length the wait spaces were created at all staging lanes inside the port territory. Due to longer trucks, there is less space in the terminal staging. Hence the average turn time is increased in the DES output. Apart from this, there are other factors which affect the turn times in the terminals. The Opt-quest results comparison is presented in the scenario analysis in chapter 5.

4.7.1 Factors influencing Cast terminal

The cast terminal in our model has only six lanes for staging compared to the real systems seven. This increases the turn time considerably and the T3 gate resource defined is only of capacity two when compared to the real systems three. The third resource was not considered because it serves only the truck entering from the 7th lane which is absent in our simulation model. The 7th lane in the staging is for the premium trucks for which we don't have historical data and also makes the design complex. Hence all the trucks were considered to be normal trucks.

4.7.2 Factors affecting Racine terminal

The Racine terminal has ten lanes along with another six lanes parallel to it for staging in the existing system in which the six lanes are dedicated for the trucks with empty chassis. In our model, we have designed only one type of truck staging which is the first ten lanes and due to the complexity of designing the other six lanes the empty chassis trucks entering the Racine terminal were neglected. As a result, all the trucks entering this terminal went through only one staging of ten lanes and therefore the Racine terminal truck average turn times are higher in the simulation model.

4.7.3 Factors affecting Viau terminal

As the Viau terminal of the real system is under construction, the DES for the Viau terminal was designed entirely with assumptions and guidance from the port authority. The DES model of the Viau terminal has a separate route to the yard terminal from the second stage T1 gating. They were designed in such a way that there is no interference by the truck entities which are moving towards other terminals. But this is not the case in the existing scenario where there are interference by the Racine trucks to some extent.

Similarly, the Maisonneuve trucks are affected by trucks of varying length which could lead to shorter turn times than considering as all the trucks longer. As the terminal staging can handle only less number of longer trucks the trucks even after completing the service at T1 gate are not going to be released which increases the turn time and also the truck output of the terminal.

The assumption of same length of trucks can also affect all other terminal trucks turn time. The alternative configurations of models are tested in the case study which reveals the mean turn time of trucks for different types of terminals.

Chapter 5

Case Study for Port of Montreal

In this chapter, we will discuss the application of the proposed DES model-based solution approach through a case study for Montreal port authority. There are various scenarios of truck arrivals tested in the Port of Montreal using our simulation model. The scenarios tested are the factors that affect the turn time either positively or negatively. Based on the results from these scenarios recommendations were made to MPA which helps them to decide to deploy any of the scenarios. The scenario analysis represents the output analysis based on different scenarios.

5.1 About Port of Montreal

Port of Montreal is a port and transshipment point located on the Lawrence River in Quebec, Canada. It is an international container port which serves Toronto, central Canada, U.S, Europe and parts of Asia. It has a shoreline of 26kms between the Victoria Bridge and Point-aux-Trembles. More than $37.5 billion in goods move through the Port of Montreal every year, and its activities generate economic benefits valued at $1.5 billion. The volume of containerized cargo handled in 2013 was 11.9 million tons. This represents 1.4 million 20-foot equivalent unit containers (TEUs).

Non-containerized general cargo traffic rose 22.7 percent to reach 159, 677 tonnes primarily due to metal products, whose volumes increased from 19,372 to 58, 664 tonnes. The amount of liquid bulk handled is 9.5 million tonnes annually. 2013 ranks among the best in the cargo category. Dry bulk traffic increased to 6.6 million tonnes, mainly due to increased shipments of iron ore, fertilizer and scrap metal. The Port of Montreal also has a Cruise terminal which has one berth welcome approximately 70,000 visitors annually. At present, the Port of Montreal has joined the sustainability race with the ports around the globe to protect the environment. It has four container terminals namely Cast, Maisonneuve, Racine, and Viau. The trucks destined to these terminals have to pass through a common entry and then divert to their respective terminals. The port on average has 1600 incoming coming trucks every day. This includes trucks with containers, empty chassis, and premium trucks. The geographical location of the port can be seen from the figure 11.

Figure 11 Port of Montreal Location

5.1.1 Common Entry for Terminals

The container trucks to all the terminals enter a common entry where there are two lanes, and there are no rules for the trucks to select the two lanes. However, the truckers select lanes only based on the minimum number of trucks in the queue. There is a gate -T0 (figure 12) at the end of these lanes where the truck driver's identification card is scanned, and license plate reader used to scan the truck registration number, along with barcode scanners and OCR to scan the container numbers.

Figure 12 T0 gate entry lanes

Once they get past the first gate, there are 26 lanes designated for the trucks according to the terminal for the second gate -T1 (figure 13). The trucks have to select the gates according to the destination terminal and again the biometrics and OCR is done in this gate. The common entry portal was a recent development in the Port of Montreal. At present, the Cast and the Racine trucks share the first 14 lanes, and the Viau has dedicated lanes from 15 to 18, and similarly, the Maisonneuve has seven dedicated lanes from 19 to 26. The service time varies for the different terminal trucks where the Cast and Racine trucks take around 20 seconds, and for the Maisonneuve/Viau, it takes a minute on an average due to the container pick up and drop details processed. As they have different terminal operators, the service time varies.

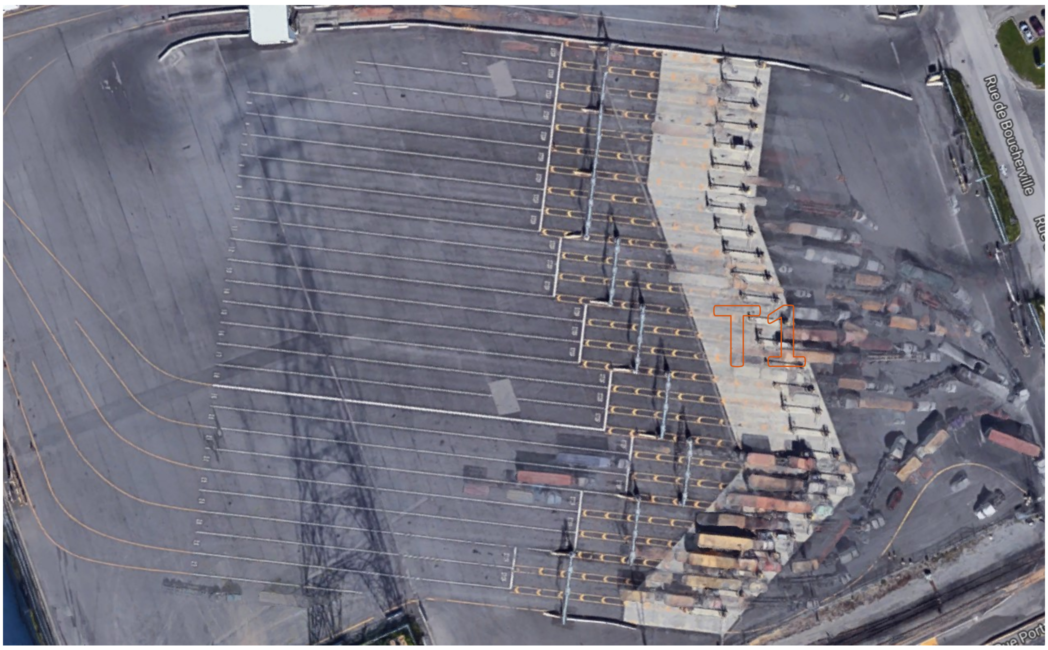


Figure 13 Common entry for terminals

5.1.2 Cast Terminal

Figure 14 Cast Staging and T2, T3 gates

Termont Montreal manages the Cast and the Racine terminals. Similarly, the Maisonneuve and the Viau terminals are operated by the MGT. Through the gate -T1 the Cast trucks move towards their terminal where they have seven lanes for staging, out of which one lane is for the premium paying customers. A maximum of forty-two trucks can be staged. Once staged, the truck driver leaves the truck for doing the paperwork and his container assignment takes usually between 2 to 5 minutes. Once the paperwork is complete, the driver gets back to the truck and moves to the next gate which is T2 where they scan the identification card for the second time and move into the yarding process. The gate -T2 has three entries for the trucks and there is gate T3 with 2 entries for their exit from the yard process. The identification card of the driver is scanned again on their exit. Both T2 and T3 gates can be seen from the figure 14. The number of T2 and T3 gates are often reconfigured between inlet and exit depending on the truck traffic.

5.1.3 Maisonneuve Terminal

Figure 15 Staging Maisonneuve Terminal

Similarly, the Maisonneuve trucks move through the respective T1 lanes and then enter the staging area which is in a different design compared to the Cast terminals. It can accommodate between 35 to 40 trucks based on the length of the trucks. There are three entries at the gate - T2 of the Maisonneuve. It takes approximately a minute to scan the Identification card and get the ticket. Once the T2 gate scanning is done, then the trucks enter the Maisonneuve terminal. On their exit, they have four entries at gate –T3 to leave the yard and then move to the exit of the port. The gate –T2 and T3 can be seen from figure 16 and staging from the figure 15.

Figure 16 T2 and T3 gates Maisonneuve

5.1.4 Racine Terminal

The Racine terminal is located at about 2 km from the common entry gating T1. It has a dedicated staging lane before T2 which is divided into 2 sections. First, they enter a single lane which can accommodate approximately 65 trucks and then there is another staging with 16 lanes with a capacity of one each. Out of 16 lanes, 10 lanes are for the incoming trucks with the containers, and the remaining 6 lanes are for the empty chassis. The trucks then enter the T2 Racine gates which have four entries and three T3 gates for exits. Once the truck is in staging paperwork process which is similar to the Cast terminal that usually takes the same time. The identification in T2 and T3 are also pretty much similar. The gates can be seen in figure 17.

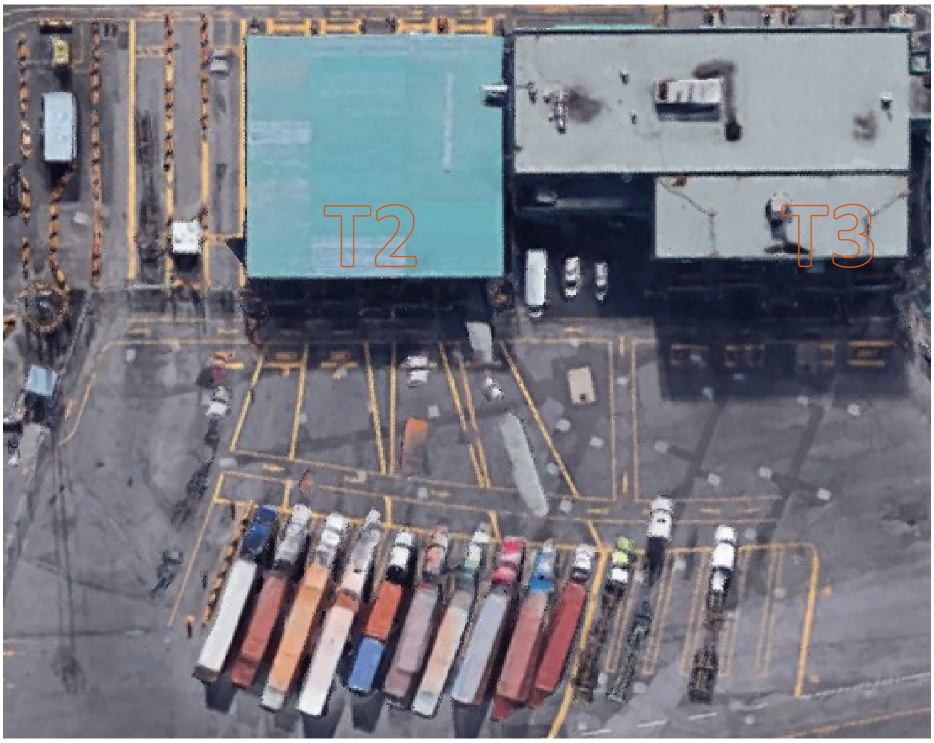


Figure 17 Racine Staging and T2, T3 Racine

5.1.5 Viau Terminal

The Viau trucks once passing the T1 gate, then they travel approximately 4 km to reach their terminal staging. As the terminal staging is not yet built and is under construction, our model focuses on the data collected on the Viau capacity and gates from MPA. The data collected shows that the Viau staging can hold a maximum of 20 trucks approximately and they have two entries for the gates at T2. The Viau terminal has a dedicated lane after the Maisonneuve terminal. Until Maisonneuve terminal, the Racine trucks and Viau trucks share the same lane. The Viau terminal is under construction (figure 18) and the terminal is designed with a staging capacity of 20 and two entries for T2 and T3 gates. The port has different exits and it is let to the truckers to select the choice of exit for the departure. There are no dedicated exits for any terminal. Our model focuses only on one exit per terminal. No two terminal trucks can share the same exit.

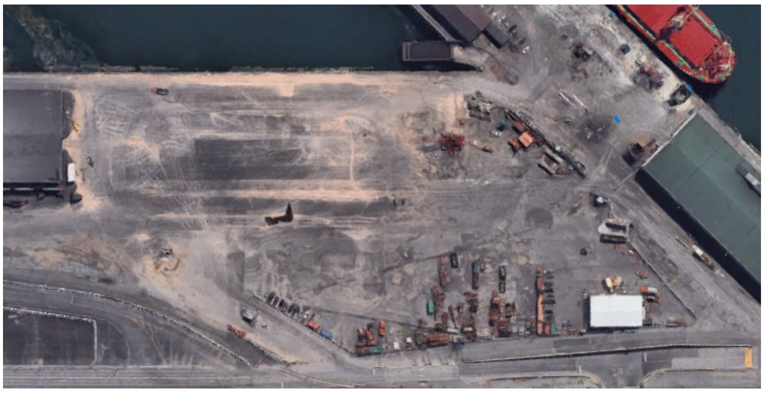


Figure 18 Viau Terminal under construction

5.2 Challenges faced by the Port of Montreal

Port of Montreal is facing few challenges which are listed below,

- Controlling the level of greenhouse emissions.
- Maintaining a smooth flow of trucks inside the port
- Increased average turn time due to the idling of trucks.
- Congestion in Maisonneuve terminal staging.
- Difficulty in managing increased truck arrivals.

5.3 Proposed Solutions

The following solutions or alternative scenarios were proposed based on the review of the literature and the understanding of the operations at the Port of Montreal.

- Extended gate hours.
- Suggested arrival patterns.
- T1 gate structure policy.
- Improved Technology

Hence all these solutions or the scenarios are tested separately, and the results are interpreted. The results are then analyzed using process analyzer, and the graphs are plotted.

5.3.1 Simulating Extended Gate Hours

5.3.1.1 Input Data

As it is complicated to develop a model for verifying all the data only two days data were taken into consideration for testing. April 3rd and 4th truck data were selected because April 3rd closely represents other days of the month in terms of truck numbers and they also had a distinct arrival pattern from the rest of the month. April 4th had the maximum number of truck arrivals of the month and as on this day there was a high congestion in the terminal there was a long queue developed outside T0 which could be verified to check the model.

Table 3 shows the total number of container truck arrivals to each terminal within one-hour intervals from 6.00 am to 5.00 pm. At the very beginning of the port opening at 6.00 am to 7.00 am as the Cast and Racine terminals are closed there are usually no trucks to these terminals.

Table 3 Truck arrival data

APRIL 3 2017	Cast	Racine	Maisonn	Viau	Sum
6.00 - 7.00 am	2	0	35	6	**43**
7.00 - 8.00 am	61	51	55	9	**176**
8.00 - 9.00 am	45	64	70	15	**194**
9.00 - 10.00 am	55	39	77	15	**186**
10.00 - 11.00 am	68	65	68	20	**221**
11.00 - 12.00 am	77	71	76	19	**243**
12.00 - 1.00 pm	85	72	65	18	**240**
1.00 - 2.00 pm	66	59	60	12	**197**
2.00 - 3.00 pm	42	37	65	13	**157**
3.00 - 4.00 pm	8	8	51	1	**68**
4.00 - 5.00 pm	4	1	19	1	**25**
					0
Total	**513**	**467**	**641**	**129**	**1750**

In Table 3, it is clear that there are two trucks which came into the port between 6.00 and 7.00 am to Cast and Racine. These two trucks entered at 6.59 am. So, they were included in the first-hour bracket. The total number of trucks that entered is 1750. Arrival pattern in figure 19.

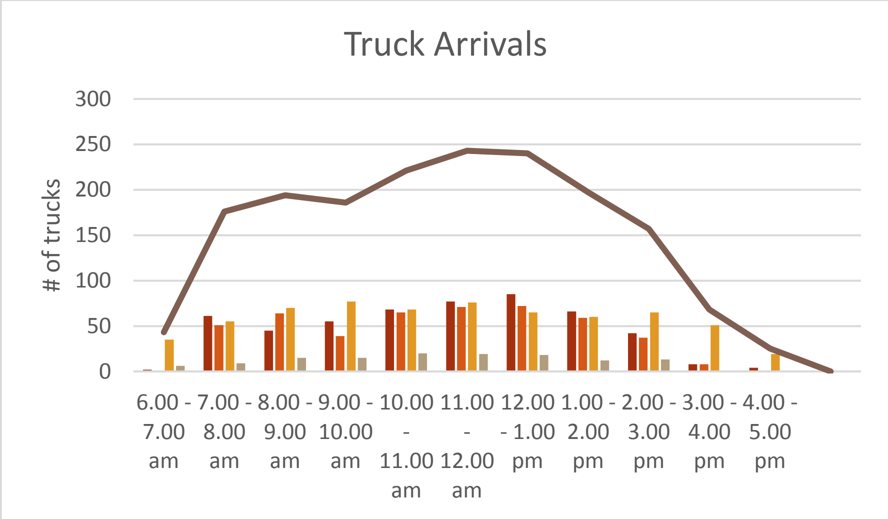


Figure 19 Arrival pattern April 3rd

In order to test for extended gate hours, the existing truck data was modified after discussing with the port authorities. The data was modified for Cast and Racine trucks in the early first hour. In the new table the total number of trucks were balanced to 1750 as the original data assuming the peak hour shift in the arrivals. This is done by replacing another high peak two hour intervals from 11am to 1pm. The replaced data was taken from another days truck arrivals and their inter arrivals were replaced with the original data to have an original representation of the real world arrivals. The modified data table is shown below, and their corresponding graph is plotted to visualize the inter-arrival pattern. The modified data (table 4) and their pattern (figure 20).

Table 4 Truck arrival data

APRIL 3 2017	Cast	Racine	Maisonneu	Viau	Sum
6.00 - 7.00 am	56	42	51	8	**157**
7.00 - 8.00 am	61	51	55	9	**176**
8.00 - 9.00 am	45	64	70	15	**194**
9.00 - 10.00 am	55	39	77	15	**186**
10.00 - 11.00 am	68	65	68	20	**221**
11.00 - 12.00 am	69	41	63	15	**188**
12.00 - 1.00 pm	57	65	37	22	**181**
1.00 - 2.00 pm	66	59	60	12	**197**
2.00 - 3.00 pm	42	37	65	13	**157**
3.00 - 4.00 pm	8	8	51	1	**68**
4.00 - 5.00 pm	4	1	19	1	**25**
					0
Total	**531**	**472**	**616**	**131**	**1750**

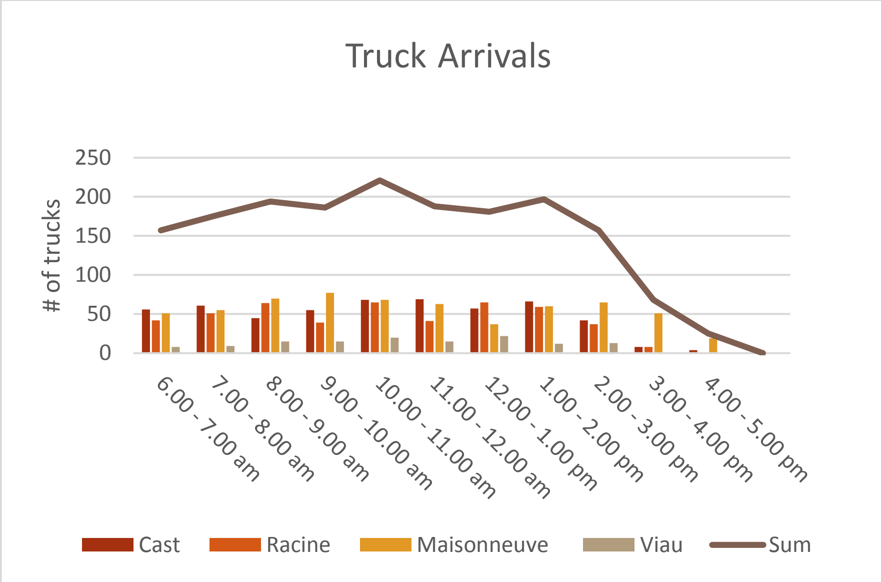


Figure 20 Arrival pattern April 3rd

In the new modified table, there are 56 Cast trucks, 42 Racine trucks and rest are Maisonneuve and Viau trucks. Three rows are marked in yellow to show the changes made from the original data. These data are taken from a different day to balance the overall number of trucks as the original data.

5.3.1.2 Model Execution

As we mentioned earlier, among the four terminals the Cast and Racine terminals operate from 7.00 am unlike the other terminals which open at 6.00 am. Hence extending the gate hours for the Cast and Racine may reduce the congestion at the entry gates and in turn reduces the turn time. New data for the extended gate hours was discussed with the port authorities and used as inputs to the same model. Two models were developed to test and compare the results. The first model was tested with historical data as input with original April 3rd inter-arrivals and the second model with a modified April 3rd inter-arrival with trucks entering all the terminals from 6.00 am. The model was executed using the excel inputs for both the original scenario and the extended scenario. Similarly, all the other inputs were also modified from excel sheet.

5.3.1.3 Results

Both these input data are tested in the Arena, and the results can be seen below in the form of bar graph.

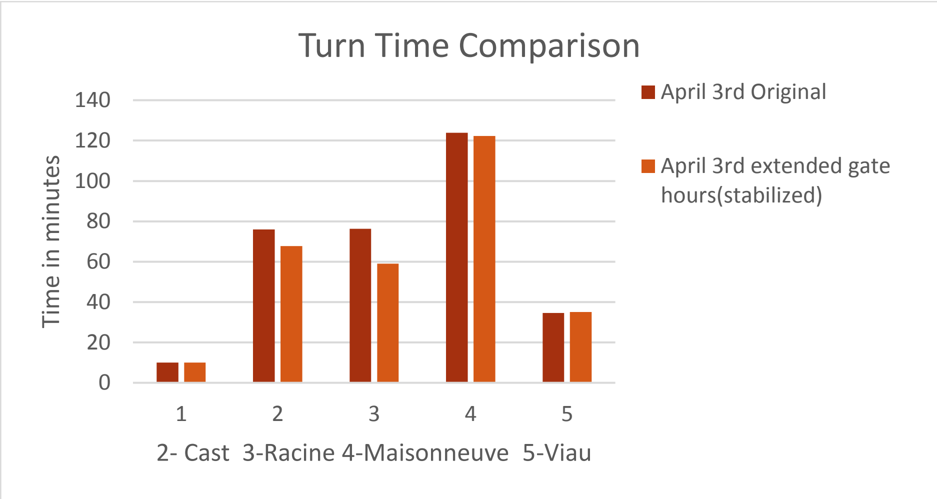


Figure 21 Results Turn time

The above graph (figure 21) shows the simulation results with ten replications for turn times of Cast, Maisonneuve, Racine and Viau terminals. It can be clearly seen that the turn time for the Cast and Racine terminals are decreased from 76.019 to 67.802 and 76.297 to 59.079 respectively. This shows an 11.85% decrease in turn time for the Cast and 22.57% Racine respectively. This will not have a great impact on the turn time of trucks to the other two terminals. Hence it is evident from the results that extended gate hours is an important factor which has a great impact on the turn times of the Cast and Racine terminals. It can also help in shifting the peak hour congestion of trucks to off-peak hours. There is also another data tested within next part without assuming any shift in the peak hour to check the impact of EG.

5.3.2 Simulating Arrival patterns of trucks:

To test if the arrival pattern per hour of truck affects the turn time. Two models were tested as below:

1. Steady-state arrivals vs. April 4th with extended gate hours vs. April 4th original
2. April 4th original vs. Reverse arrivals of April 4th original

5.3.2.1 Steady State Arrivals vs. April 4th with extended gate hours

Input data

With the guidance of the port authorities, data was created with a maximum of 171 trucks arriving every hour adding to a total of 1881 trucks from 6.00 am to 5.00 pm (table 7). This 171 was taken from another day data of just 1hr interval and the same data was used for arrivals every hour. The particular one hour interval was selected due to the fact that this data when added represented the average total number of trucks entering the respective terminals. For example, 52, 53, 43 23 are the data selected which added for intervals from 6am to 5pm gives a total of 572 cast, 583 racine, 473 maisonneuve and 253 viau trucks. These totals are close to the average number of trucks entering the port on a usual day. Hence this particular data was selected. This is compared to April 4th with extended gate hours with peak hour shift turn time results as they have a high number of arrivals every hour which is higher than 171. Here in this extended gate hour data peak hour shift is not assumed and hence the total truck arrivals are higher than original. The original input data on April 4th was also tested for comparisons of the output. This data is seen from table 6 and their arrivals can be seen from the graph (figure 22).

Table 5 April 4th with extended gate hours

APRIL 4 2017	Cast	Racine	Maisonneu	Viau	Sum
6.00 - 7.00 am	69	30	72	12	**183**
7.00 - 8.00 am	99	95	75	13	**282**
8.00 - 9.00 am	75	41	77	30	**223**
9.00 - 10.00 am	57	65	37	22	**181**
10.00 - 11.00 am	65	56	47	11	**179**
11.00 - 12.00 am	62	77	61	39	**239**
12.00 - 1.00 pm	70	75	52	27	**224**
1.00 - 2.00 pm	96	66	59	26	**247**
2.00 - 3.00 pm	19	65	40	18	**142**
3.00 - 4.00 pm	56	28	2	0	**86**
4.00 - 5.00 pm	3	6	0	0	**9**
Total					**0**
	671	**604**	**522**	**198**	**1995**

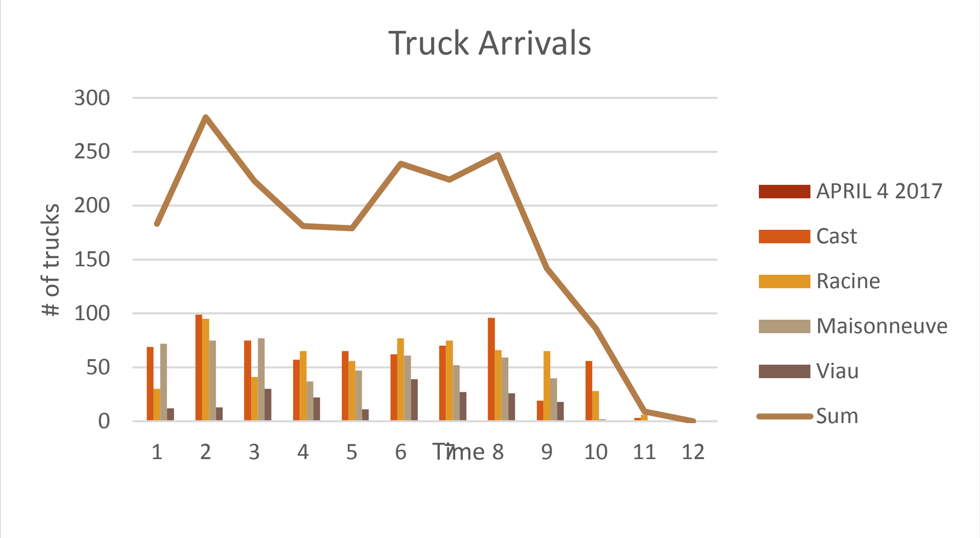


Figure 22 Arrival Pattern per hour April 4th (EX)

Table 6 April 4th without extended gate hours

APRIL 4 201	Cast	Racine	Maisonneuv	Viau	Sum
6.00 - 7.00 am	0	0	58	18	**76**
7.00 - 8.00 am	99	95	75	13	**282**
8.00 - 9.00 am	75	41	77	30	**223**
9.00 - 10.00 am	57	65	37	22	**181**
10.00 - 11.00 am	65	56	47	11	**179**
11.00 - 12.00 am	62	77	61	39	**239**
12.00 - 1.00 pm	70	75	52	27	**224**
1.00 - 2.00 pm	96	66	59	26	**247**
2.00 - 3.00 pm	19	65	40	18	**142**
3.00 - 4.00 pm	56	28	2	0	**86**
4.00 - 5.00 pm	3	6	0	0	**9**
	602	**574**	**508**	**204**	**1888**

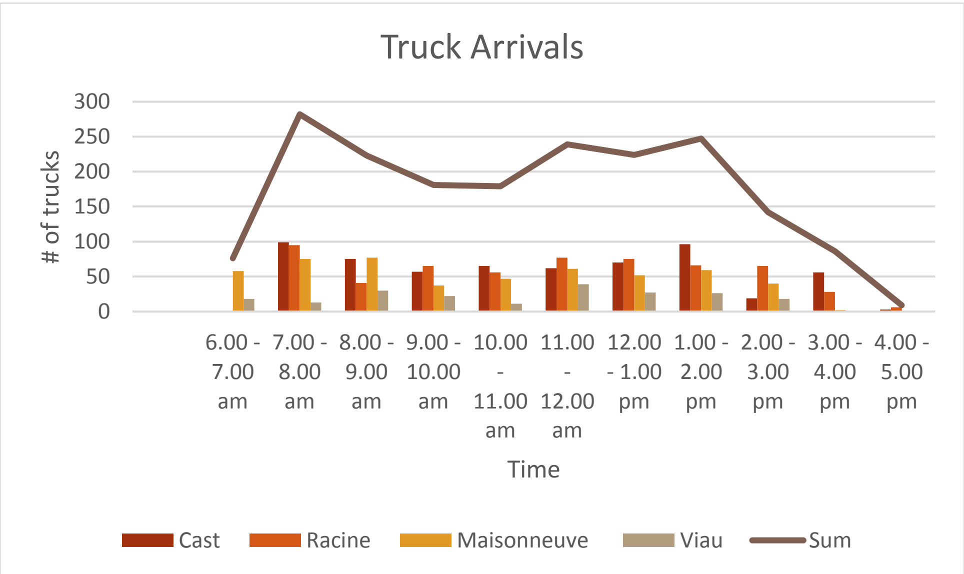


Figure 23 Arrival Pattern per hour April 4th (Original)

The above graph (figure 23) shows the arrival pattern of trucks every hour, and this helps to visualize the shape of the arrival pattern. The data for April 4th without extended gate hours is given in table 6 above. The graph of the steady state (figure 24) is a straight line which means every hour has a constant number of arrivals. Here it can also mean that the arrivals are capped at a certain number. The cap here for total number every hour is 171 and the similarly for Cast, Racine, Maisonneuve, and Viau would be 52, 53, 43 23.

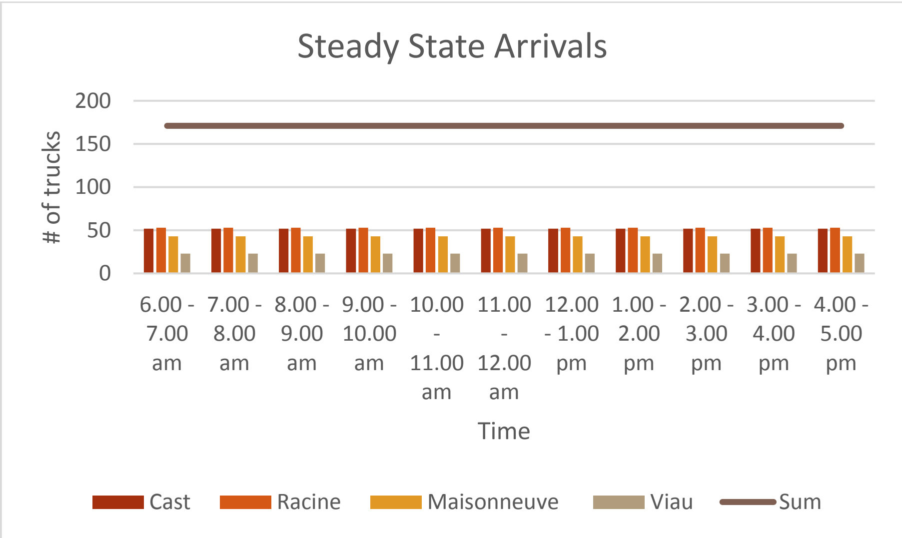


Figure 24 Arrival pattern steady state

Model Execution

The model inputs were modified in the excel data input where new inter arrivals are calculated for the new inputs of April 4th with extended gate hours and the newly developed steady state arrivals. The main objective of this model is to find the effect of constant arrivals on the average turn time and find the effect of a decreased level of Maisonneuve trucks on the average turn time of Maisonneuve terminal. We will also compare an extended gate hour scenario with no peak arrival shift for the purpose of finding the arrival patterns effect on the turn times.

Results

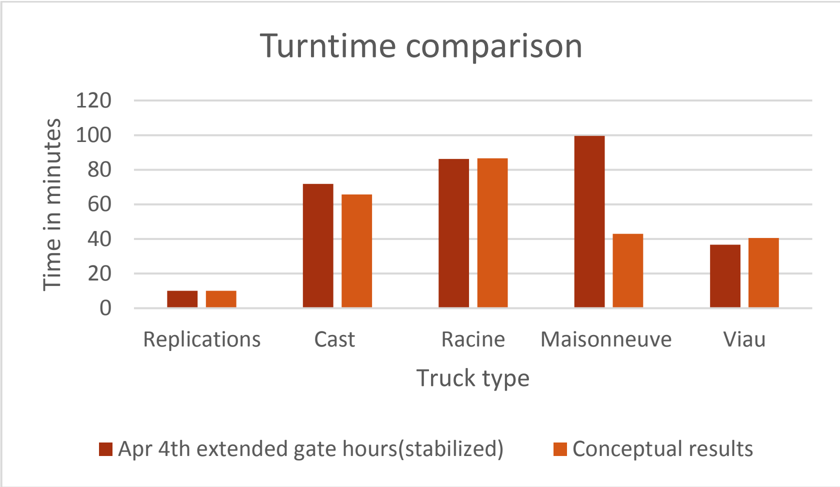


Figure 25 Results Turn time

The above graph (figure 25) shows the results of the average turn time comparison of steady-state arrivals and the April 4th data with extended hours with peak hour shift from the simulation. The results show the Cast, Maisonneuve, Racine and Viau truck average turn times. The Cast and Racine turn times are pretty much the same, but the Maisonneuve turn time is reduced to a greater extent. On April 4th the Maisonneuve turn time is 99.606 and in the conceptual constant arrival model, the average turn time is 44.926. Hence a 54.9% decrease in the turn time is seen in the Maisonneuve terminal. This is evident that Maisonneuve terminal cannot process high levels of truck numbers with reduced turn times.

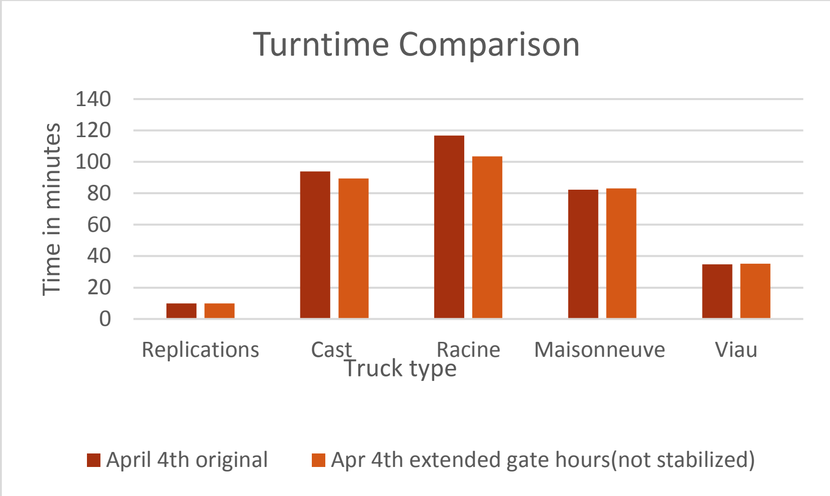


Figure 26 Results Turn time

In the case of constant arrivals when Maisonneuve trucks are capped at 43 an hour they have a greater impact in the turn times. Hence it can be concluded from this model that type of arrivals does affect the average turn times. The number of trucks per hour should also be capped at a certain number at the Maisonneuve terminal. However, it is not necessary to cap the Cast trucks and the Racine trucks as it does not have a high impact on their turn time. This proves that reducing the number of trucks in the Maisonneuve terminal will solve the ports existing issue of congestion faced in the staging area of the Maisonneuve terminal. The results from the figure 26 show that extended gate hours with no peak hour shift arrival data also impact the turn times to a greater extent. Even with the added truck arrivals the turn time are significantly lower than the original. We are concentrating only on the Cast and Racine trucks.

5.3.2.2 April 4th original vs. Reverse arrivals of April 4th

Input Data

Reversed arrivals mean the arrivals of the truck data are reversed for the purpose of simulation. So, the order of the truck arrivals is in such a way that the trucks at the end of the day enters the port during the opening hours of the day and so on. The April 4th data are reversed which can be seen from the table 8 below and the corresponding arrival pattern can be seen from the figure 27.

Table 7 Truck arrivals

APRIL 4 2017	Cast	Racine	Maisonn	Viau	Sum
Total					0
4.00 - 5.00 pm	3	6	0	0	9
6.00 - 7.00 am	0	0	58	18	76
3.00 - 4.00 pm	56	28	2	0	86
2.00 - 3.00 pm	19	65	40	18	142
10.00 - 11.00 am	65	56	47	11	179
9.00 - 10.00 am	57	65	37	22	181
8.00 - 9.00 am	75	41	77	30	223
12.00 - 1.00 pm	70	75	52	27	224
11.00 - 12.00 am	62	77	61	39	239
1.00 - 2.00 pm	96	66	59	26	247
7.00 - 8.00 am	99	95	75	13	282
	503	479	433	191	1888

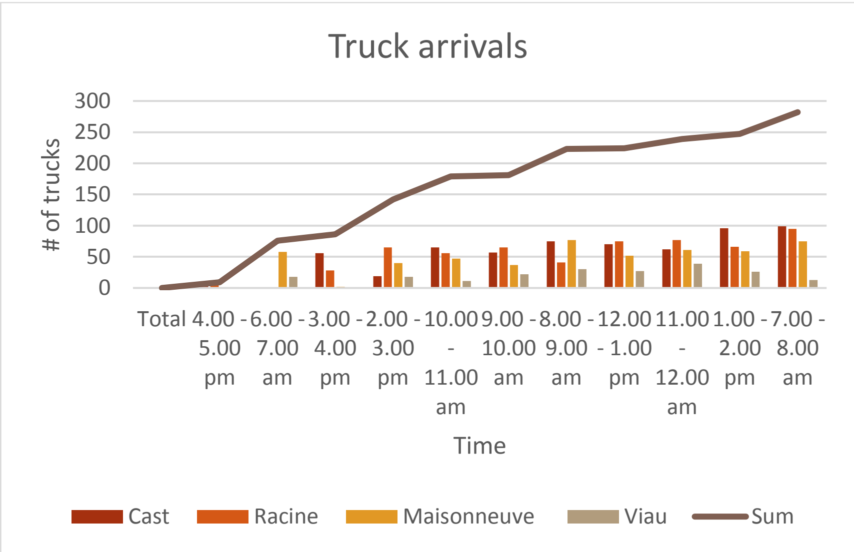


Figure 27 Arrival pattern April 4th reversed data

Model Execution

The model inputs have to be modified with the new interarrivals and the excel inter arrivals input are updated and a new file is updated inside the ARENA file module. The matrix values are changed accordingly. This is done for all the tests where the input data are changed. This helps us in finding if an increasing trend in the arrival pattern affects the truck turn time. Then the model is simulated and the graphs are plotted with the opt quest of Arena.

Results

Once this model is simulated, the turn times are reduced for all three terminals excluding the Viau terminal when compared to the original April 4th data. It is evident from the turn time graph (figure 28) that an increasing trend in arrival patterns affect the turn times. The original data of April 4th without extended gate hours was simulated as the same data is reversed and compared. Increasing arrivals have a significant impact on turn times. The April 4th data which has a more of decreasing trend affect the turn time as there is more congestion at the entry gates during the early hours of the day. Hence it can be concluded sustaining the level of incoming container truck arrivals into the port is very important. Even though this is not an accurate comparison, it helps in understanding the impact of arrival pattern on turn time of trucks.

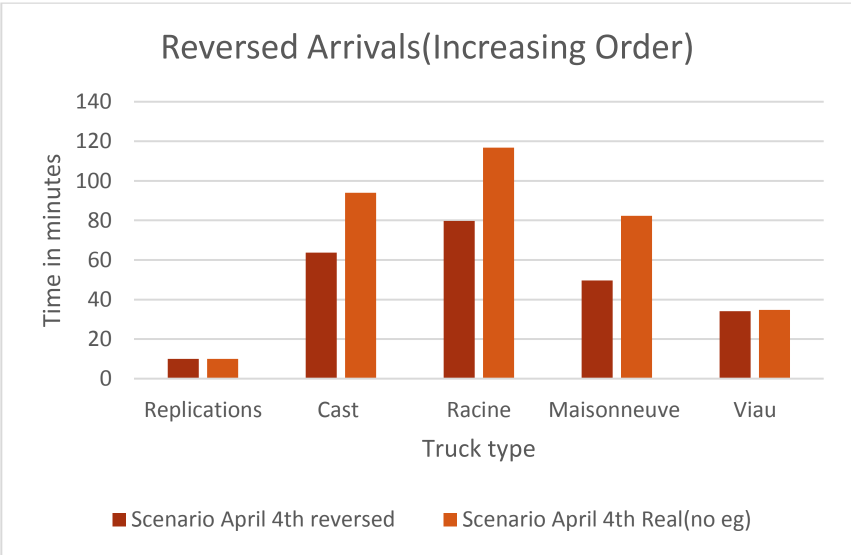


Figure 28 Turn times results in comparison

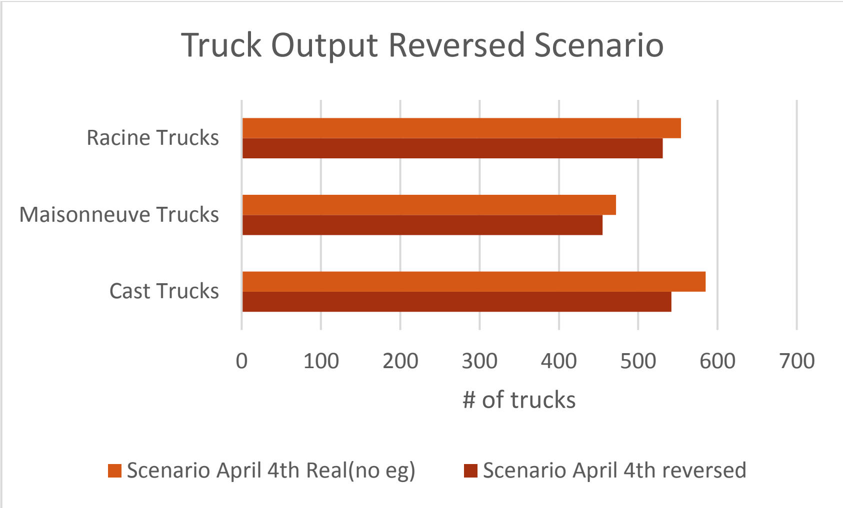
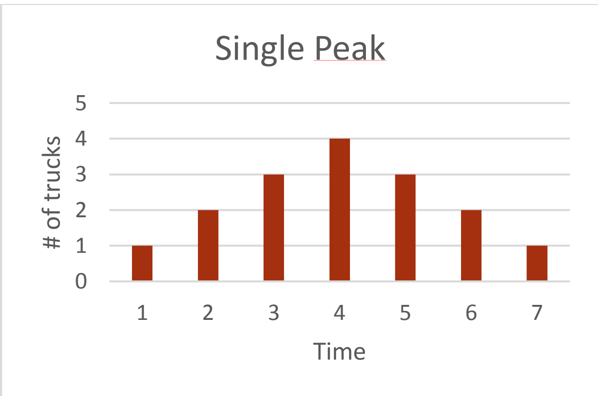
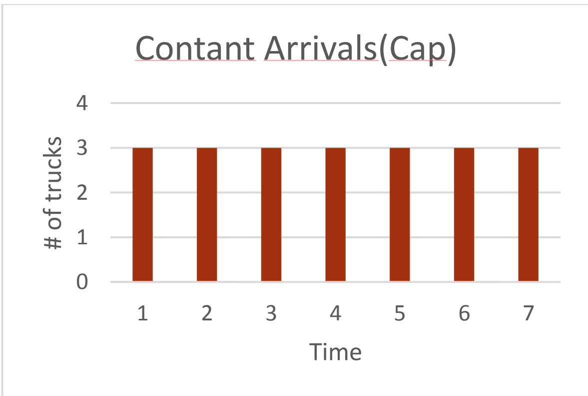


Figure 29 Truck output comparison

As the reversed arrival data had a lot of trucks entering at the end of the day the number of output truck data was studied which showed fewer output trucks than the original April 4th which can be seen from the graph (figure 29). But the goal of this model is to understand how an upward trend affects the turn times.

It can be concluded from the above scenarios, that the following arrival patterns have a positive impact on the average turn time. However, the arrivals can never be in a completely decreasing trend which is going to affect the turn times. The different forms of arrival patterns which has positive impact on the turn times can be seen in the figure below. There were several other data simulated and we came to a conclusion of the following graphs (figure 30). This graph is approximate representation of the shape of arrivals.





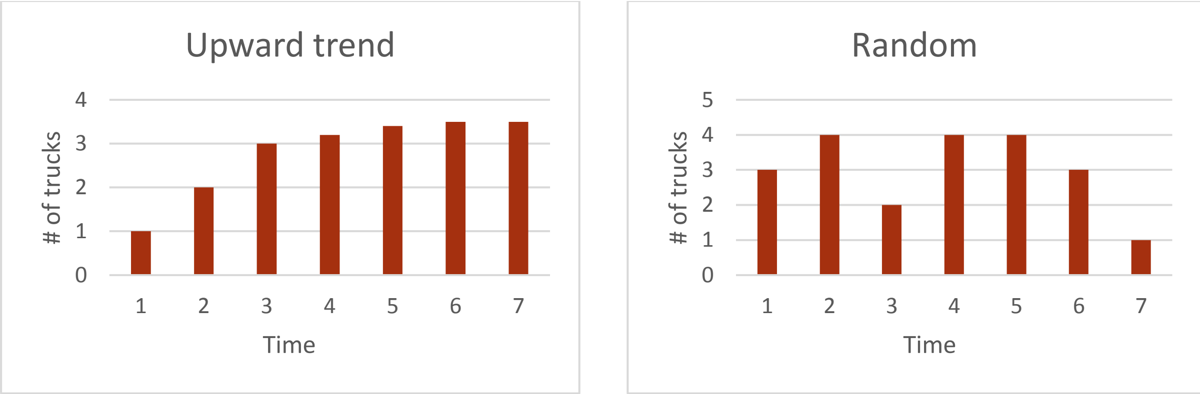


Figure 30 Recommended arrival patterns

5.3.3 Simulating different T1 Gate Structure Policies

Input Data

As mentioned earlier, the 26 lanes in the second stage gating T1 has some policy for the incoming trucks to select the gate numbers according to their destination terminal. The Maisonneuve terminal and Viau terminals have a fixed gating lane policy at T1. However, it is not the case for Cast and Racine trucks where they share the 14 lanes irrespective of any specific policy separately for each type. Hence, Cast and Racine terminal truck lane policy analysis is done to find the best policy, which means to analyze by assigning different lane numbers as inputs in the arena excel input data for Cast and Racine trucks. To analyze this a matrix (table 9) was developed in excel for the inputs. The table below shows a sample policy (4, 10). Arena takes 1 as true and 0 as false. Truck type 1 can move between lanes 19 to 26 which is denoted with 1 and rest 0, Truck type 2 can move between lanes 15 to 18, Truck type 3 can move between lanes 1 and 4, Truck type 4 can move between lanes 5 and 14. The policies are changed by changing the 0's and 1's in the respective columns. The results of the different policies tested are given below in the form of bar chart (figure 31).

Table 8 Truck Lane Matrix

lanes	1	2	3	4
1	0	0	1	0
2	0	0	1	0
3	0	0	1	0
4	0	0	1	0
5	0	0	0	1
6	0	0	0	1
7	0	0	0	1
8	0	0	0	1
9	0	0	0	1
10	0	0	0	1
11	0	0	0	1
12	0	0	0	1
13	0	0	0	1
14	0	0	0	1
15	0	1	0	0
16	0	1	0	0
17	0	1	0	0
18	0	1	0	0
19	1	0	0	0
20	1	0	0	0
21	1	0	0	0
22	1	0	0	0
23	1	0	0	0
24	1	0	0	0
25	1	0	0	0
26	1	0	0	0

Model Execution

The model is updated in Arena using the file module and the matrix is updated once again and we are going to change the input inter arrivals of all the data tested before for April 3rd and April 4th. The model is run for 10 replications and outputs are verified with the previous results. These models are again run using Opt quest in Arena which again runs 10 replications and gives the same results of all the data which is then plotted and compared. The results of the comparison are discussed in the results.

Results

The bar graph (figure 31) shows the average cast truck turn time results of different policies on two separate days that were tested with the original data. The term normal in the graph represents the present scenario in which the Cast and Racine share the 14 lanes.

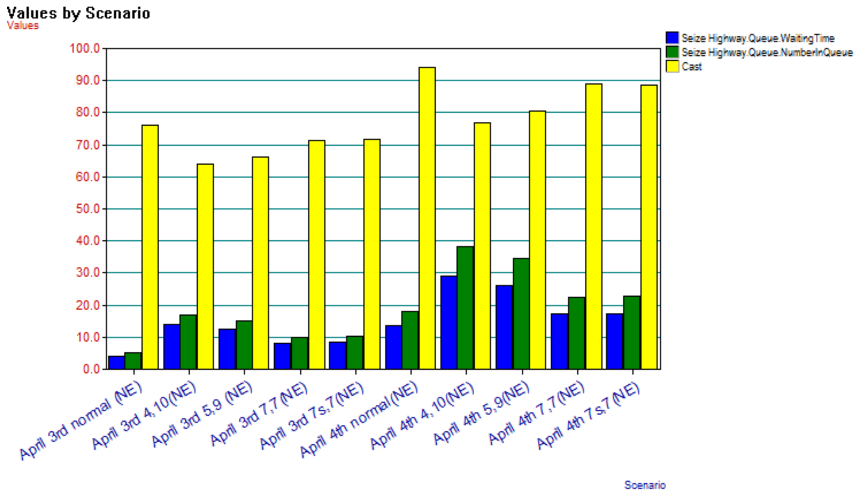


Figure 31 Turn times of Cast with different gate policies

It is evident from the resultant graph that the best policy to get a reduced turn time would be 4, 10, i.e., assigning the first four lanes for the cast and ten lanes for the Racine. This is evident from turn times on both the days which was tested. The results for the Racine turn times can be seen from the bar chart below (figure 32). The lane policy 7s, 7 represents seven shared lanes and the remaining seven lanes dedicated to Racine.

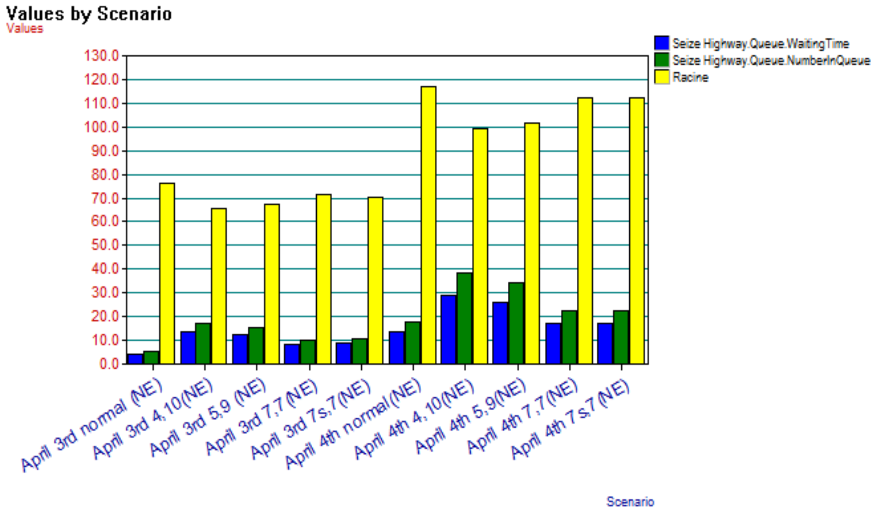


Figure 32 Turn times of Racine with different gate policies

It can be concluded that the 4, 10 lane policy is the best policy to reduce the turn times of the trucks at any arrival pattern which is evident from two different data. We are not taking into account of the queue waiting time and queue length before the entry gate T0 as we are considering only one type of truck where all are considered to be of the same length 40ft. This result may seem pretty high than usual mainly for the maximum waiting time. But our focus here is only on the average turn time. There are several factors that affect the entities in real time were acceleration, deceleration, braking and driver concentration plays a major role. Because the turn times are calculated after T0 till T4 this is not much concentrated.

5.3.4 Simulating Advanced technology in Cast and Racine

As mentioned earlier, Cast and Racine terminals are the ones which employ humans at their T2 gates to do the paperwork. However, this is done with an automatically at T1 gates for the Maisonneuve and Viau Terminals. Hence, the Maisonneuve and Viau trucks have an increased service time at T1 gates compared to Cast and Racine.

Input Data

To simulate this scenario the T2 paperwork resources in the simulation model of Racine and Cast are set to Zero and the T1 gate service time is replaced by the time of Maisonneuve and Viau. So, the model has all truck types with the same T1 gate service times which is deterministic. As excel input modeling was employed, it was easier to change the time of the Cast and Racine gate resource service time. The new service times were updated in excel input data.

Model Execution

Before executing the model, the matrix for the new inputs from the advanced process were checked for the update in Arena. Then the capacity of the resource set for the Cast and Racine is changed to zero and also the delay at the paperwork resource is changed to zero. In this way, both of these terminals work as the Maisonneuve and the Viau terminal. Then the model is run with the same number of replications as before.

Results

The outcomes of the simulation are shown in below graphs. It was tested only for the April 3rd data due to the complexity of the model changes to be established where both data of April 3rd with and without extended gating of the increased number of trucks are tested.

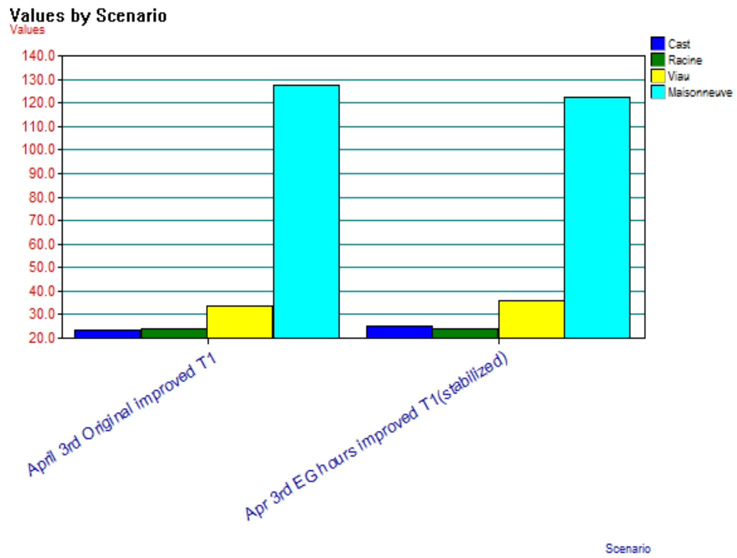


Figure 33 Turn time results for upgraded terminals

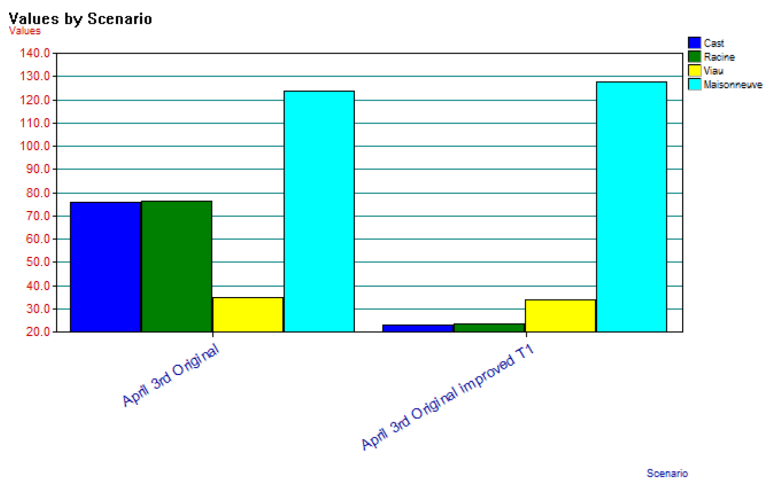


Figure 34 Turn time comparison

Table 9 Average turn time

	Cast	Racine	Maisonneuve	Viau
April 3rd Original	*76.019*	*76.297*	*123.822*	*34.627*
April 3rd Original improved T1	*23.207*	*23.699*	*127.586*	*33.821*

From the results of the simulation model, it is evident from the graph (figure 33 and figure 34) that with the improved technology in Cast and Racine terminals the turn times of their trucks can be significantly reduced. For this, the original simulation results of April 3rd is compared to the improved technology model. The average turn time of Cast truck is reduced by 69.48%, and the Racine trucks are reduced by 68.94% when compared. But it is not certainly going to have such an impact if implemented as we have only 6 lanes designed in the Cast staging and deterministic values are used at the T1 resources, we can conclude that a 30% - 40% change may occur in the real-time which results in an average of at least 25% decrease in the average turn times. In order to verify this, the Maisonneuve terminals were altered in their model similar to the Cast by degrading with an assumption of manual work before T2 and with different service times before T1 which should us a significant increase in the service times by approximately 30%. This is interpreted in table 11 below.

Table 10 Average turn time

	Cast	Racine	Maisonneuve	Viau
April 3rd Original	*76.019*	*76.297*	*123.822*	*34.627*
April 3rd Degraded T1	*23.207*	*23.699*	***175.623***	*33.821*

Hence it can be concluded that improving technology has a significant impact on the average turn time of the trucks in the port. This, in turn, helps in reducing the greenhouse emissions to a greater extent.

Output comparison

The model was run for 10 replications to find the grand mean of the key output parameter. The number of replications were stopped at 10 beyond which the variation in the output was least. Below are the simulation results before implementation of any strategies,

Table 11 Simulation results without any test scenarios

Data	Truck type	Average turn time (Minutes)
April 3rd	*Cast*	*76.019*
	Racine	*76.297*
April 4th	*Cast*	*96.979*
	Racine	*116.752*
Conceptual model data	*Maisonneuve*	*99.606*

Below are the simulation results after implementation of any strategies,

Table 12 Simulation results with test scenarios

S.No	Test scenarios	Truck type	Average turn time (Minutes)	Percentage reduction
1.	**Extended Gating April 3rd (stabilized)**	*Cast*	*67.802*	*11.85%*
		Racine	*59.079*	*22.57%*
	Extended Gating April 4th (Non- stabilized)	*Cast*	*89.407*	*4.86%*
		Racine	*103.522*	*11.33%*
2.	**Steady state arrivals (Conceptual model)**	*Maisonneuve*	*42.926*	*56.90%*
3.	**Upgrading technology**	*Cast*	*23.207*	*69.48%*
		Racine	*24.699*	*68.94%*
4.	**Gate lane (4,10) policy**	*Cast*	*63.975*	*15.84%*
		Racine	*65.317*	*14.39%*

Table 13 Simulation outputs of Average turn time for different gate policies

Policy	Replicat ions	Cast	Maisonn euve	Racine	Viau	Percentage Reduction
April 3rd normal (NE)	*10*	*76.019*	*123.822*	*76.297*	*34.627*	*Existing scenario*
April 3rd 4,10(NE)	*10*	*63.975*	*117.767*	*65.317*	*35.337*	*C - 15.84%* *R – 14.39%*
April 3rd 5,9 (NE)	*10*	*66.06*	*117.98*	*67.147*	*34.939*	*C – 13.1%* *R – 11.9%*
April 3rd 7,7(NE)	*10*	*71.433*	*120.289*	*71.301*	*35.269*	*C – 6.03%* *R – 6.54%*
April 3rd 7s,7(NE)	*10*	*71.7*	*122.102*	*70.417*	*34.104*	*C – 5.68%* *R – 7.70%*
April 4th normal(NE)	*10*	*93.979*	*82.32*	*116.752*	*34.69*	*Existing scenario*
April 4th 4,10(NE)	*10*	*76.79*	*70.78*	*98.979*	*35.874*	*C - 20.81%* *R – 15.22%*
April 4th 5,9(NE)	*10*	*80.376*	*71.792*	*101.584*	*35.546*	*C – 17.12%* *R – 12.9%*
April 4th 7,7(NE)	*10*	*88.921*	*80.235*	*112.529*	*34.167*	*C – 8.30%* *R – 3.61%*
April 4th 7s,7(NE)	*10*	*88.659*	*78.791*	*112.506*	*34.157*	*C – 8.57%* *R – 3.63%*

Note: NE in the above table 14 represents no extended gate hours have been applied.

5.4 Recommendations

Based on the simulation results, following recommendations are made to MPA.

- Firstly, extending the gate hours by opening all the four terminals at 6 am could reduce the peak hour congestion inside the terminal and hence has a significant impact on the turn time of the trucks inside the terminal. There is a high probability that the peak hour arrivals could shift to off-peak hours.
- Secondly, the Maisonneuve terminal is admitting trucks beyond its capacity and hence there is much congestion inside the port territory. This leads to an increase in the turn

time of the Maisonneuve trucks. Hence, it is recommended that the number of Maisonneuve trucks entering the terminal every hour should be capped at 45(threshold). This could have a significant impact on congestion inside the port territory and also improve the turn times of the Maisonneuve trucks.

- Thirdly, we observe from the analysis that the arrival patterns have a great impact on the turn times of the trucks. Hence it should be ensured that the truck arrivals are random, and it is based on the recommended arrival patterns. If the arrival pattern is not controlled, then it is suggested that the number of truck arrivals during the early morning peak hours should be capped. At least the first three hours should be controlled with no more than 180 trucks including all truck types. An Appointment system should be developed where there should be one-hour intervals where the total for one hour is fixed. So, the truckers can choose a slot for arriving during the first three hours.
- Fourthly, having the best lane policy at the T1 gates are very important to reduce the average turn time of the Cast and the Racine trucks. This is not going to have any impact on the Maisonneuve and the Viau trucks key parameters. The main objective is to reduce congestion before T1 and have a smooth flow of trucks inside the port territory. This, in turn, reduces the idling time of trucks before T1 and reduced the non-value added greenhouse emissions.
- Finally, if the existing technology is improved in the Cast and Racine terminals like the Maisonneuve and Viau terminal the turn times and congestion can be reduced to a greater extent. From the analysis results, it can be seen at least 25% of the average turn time of the Cast and Racine trucks can be reduced, and it is expected that the congestion is also reduced.

Following any of the above recommendations would reduce the turn times of trucks which would, in turn, reduce the non- value added greenhouse gas emissions.

Chapter 6

Model Development in Arena

In this chapter, we discuss the development of the proposed Discrete Event Simulation model in Arena™ Simulation Software, various flowchart modules, and Spreadsheets, the attributes, and variables along with the working of the simulation model. Before going into the model, we will discuss the assumptions that were considered in building the Simulation Model.

6.1 Assumptions

Several assumptions were considered while developing the simulation model as listed below:

1. The waiting spaces in every lane inside the port are designed as resources.
2. The service times are mostly stochastic with a few exceptions of deterministic inputs.
3. All the incoming container trucks are considered to be of the same length, unlike the real scenario.
4. All the terminals yards are provided with a separate lane for their truck movements after T1.
5. To simplify the model, all the trucks were considered to be standard ones of the same length and no premium trucks, empty chassis trucks were designed.
6. It is assumed that the cast staging has only six lanes instead of 7 in the case of the real scenario. Premium trucks use 7th staging lane in the port.
7. The Racine terminal staging was also simplified from 6 lanes for empty chassis and ten lanes for the regular trucks with containers, by neglecting the empty chassis lanes.

8. The speed of trucks was given regarding time, which was calculated based on the distance traveled.

6.2 Model explanation

The model consists of various flowchart modules, excel data and they can be divided into mainly four parts as follows:

1.Creation of Incoming Trucks Using the Excel Data.
2. Designing the T0 Gates.
3. Designing the T1 Gates.
4. Designing of individual terminals which includes Cast, Maisonneuve, Racine, and Viau.

6.2.1 Creation of Incoming Trucks Using Excel Data

The entire model is designed based on the concept of overlapping resources. As there are only limited wait spaces available before all the resources inside the terminals, a buffer resource is defined. In this case, the entity retains control of the first resource until there is a space in the buffer. The entity then retains its control of buffer resource until it can seize the resource at the following operation. Controlling the seizing and releasing of resources in this way a controlled blocking effect for the entity flow through the system is created.

Incoming trucks are not created at random instead historical real-time data was given as input for the truck entity generation. This was made possible by entering the inter-arrival time data in the form of an Excel data sheet, and figure shows creating a separate variable for this data in the variable spreadsheet module. All the Excel inputs are given in advanced process file module which is apparent from figure 6.1. In the case of inter-arrival times separate recordsets were created, and then variables are generated based on this record sets. Corresponding rows and columns are specified depending on the number of trucks. Then the corresponding truck type is mentioned in a separate column and variable is created as before (figure 6.2).

File - Advanced Process

	Name	Access Type	Operating System File Name	End of File Action	Initialize Option	Recordsets
1	File_Inputs	Microsoft Excel (*.xlsx)	C:\Users\v_alages\Desktop\v\Thesis files\conceptual model\Data For Tesing With Arena use this (20th april)conceptual.xlsx	Dispose	Hold	7 rows
	Double-click here to add a new row.					

Figure 6.1 File module

Variable - Basic Process

	Name	Rows	Columns	Data Type	Clear Option	File Name	Recordset	File Read Time	Initial Values
1	v_I_InterarrivalTimes	1710		Real	None	File_Inputs	Recordset_I_InterarrivalTimes	BeginSimulation	0 rows
2	v_I_TruckType	1710		Real	None	File_Inputs	Recordset_I_TruckType	BeginSimulation	0 rows

Figure 6.2 Variables for truck type and inter-arrival

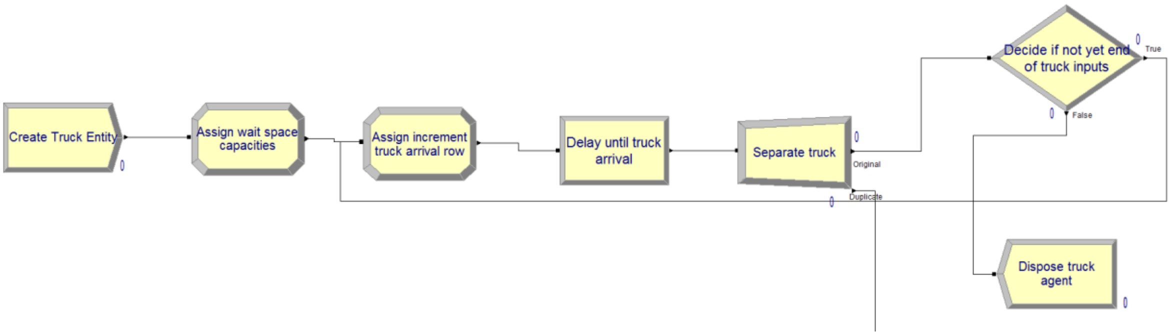


Figure 6.3 Creation of input entities

The above Figure 6.3 shows that the complete truck creation which consists of a create module which creates one truck entity randomly once at 0.0 minutes. Figure 6.4 shows the Create block. This entity would go to the assign module where several assignments are given to this entity.

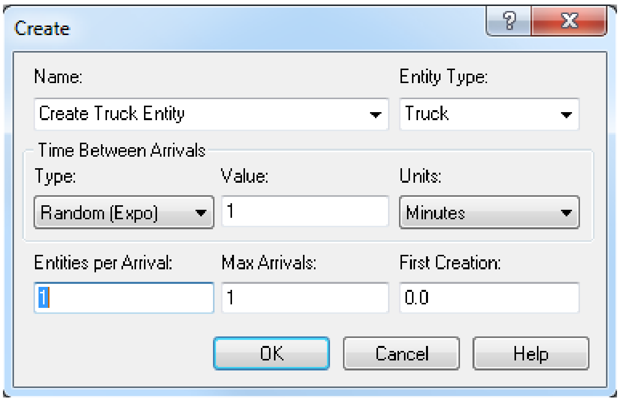


Figure 6.4 Create module

Figure 6.5 shows the dialog box of assign module where a variable is created as v_TruckArrivalRow for the incoming truck, and they are incremented by one each time the entity enters the assign module, and it becomes v_TruckArrivalRow + 1. An Attribute is assigned to the same entity as a_TruckType which is given the value as v_I_TruckType (v_TruckArrivalRow). This takes the attribute truck type from the variable v_I_TruckType of the stored excel data corresponding to the variable v_TruckArrivalRow value, as there are four types of incoming truck entities a_TruckType is used. Finally, entity picture is assigned depending on the attribute a_Truck Type.

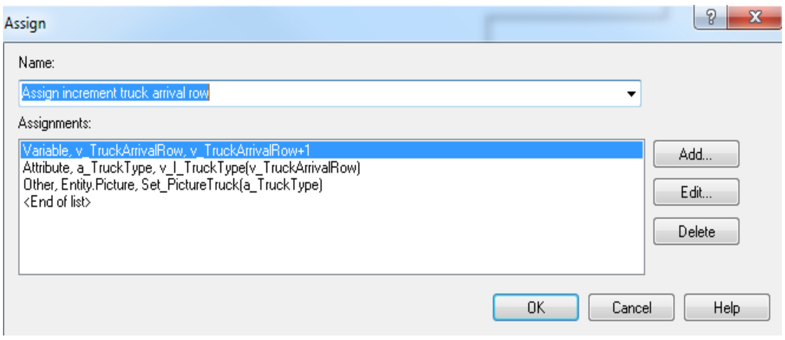


Figure 6.5 Assign module

The dialog box below (figure 6.6) shows the delay module where the delay time is given as v_I_InterarrivalTimes (v_TruckArrivalRow). v_I_InterarrivalTimes represents the Inter-arrival variable which reads the inter-arrival time from the recordset corresponding to the variable v_TruckArrivalRow value. The unit of inter-arrival is in seconds. Therefore, each time the entity comes into the delay module it is given delay time depending on the v_TruckArrivalRow variable value.

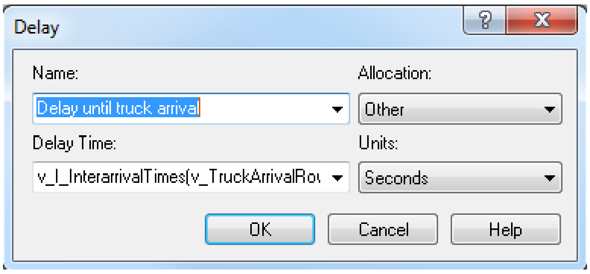


Figure 6.6 Delay module

Once the entity is assigned the inter-arrival delay in the delay module, it enters the separate module (figure 6.7) where the entity is duplicated again and enters the assign increment truck arrival row module where all the assignments are done as the previous entity and the next inter-arrival delay is given in the delay module and again duplicated. This is continued until all the trucks from the excel input data arrive.

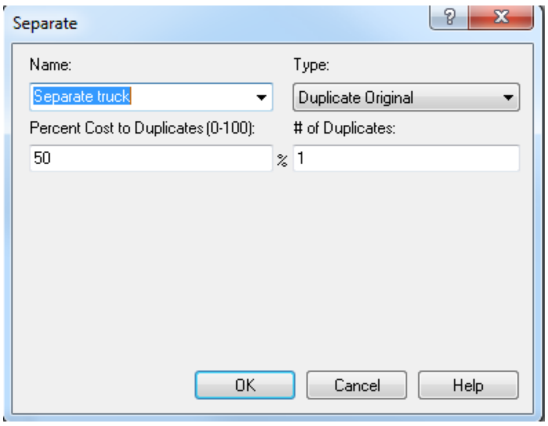


Figure 6.7 Separate module

To stop the creation of trucks, exactly at the end point of data, a decide module (figure 6.8) is used with an expression as v_TruckArrivalRow < UBOUNDROW ("v_I_InterarrivalTimes"). This expression shows if the variable value v_TruckArrivalRow is lower than the number of rows in the variable v_I_InterarrivalTimes then send the entity into the system or else dispose of the entity which ultimately stops the creation of trucks with zero entities to duplicate.

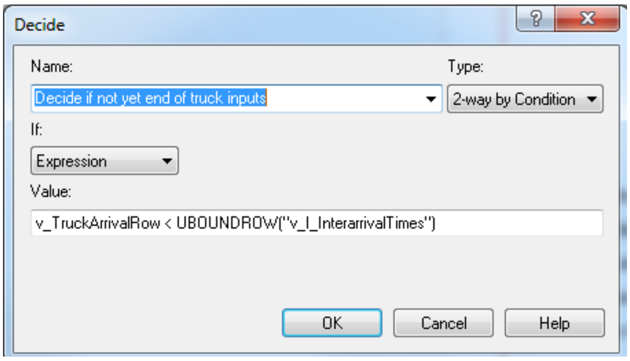


Figure 6.8 Decide module

If the entities are still available, the creation of truck entities continues by duplicating, then assigning and delaying and so on. All the tests were conducted based on the same technique for reading and assigning the values.

6.2.2 Designing the T0 Gates

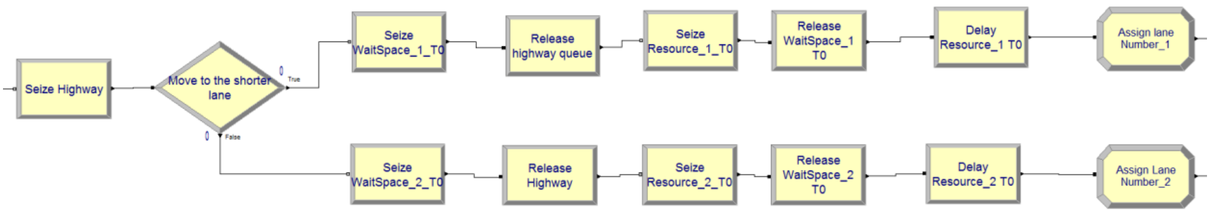


Figure 6.9 T0 gate modules

The above figure 6.9 shows the complete T0 gate design with its components such as the queue and resources. Before the truck entity enters the port territory, it comes on a single lane through the highway. Hence a seize module (figure 6.10) with a buffer resource was used to design the highway queue. Seize Highway. Queue represents the trucks that wait in this queue.

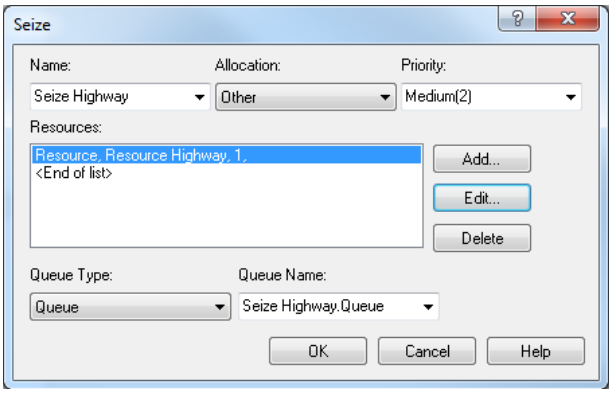


Figure 6.10 Seize module

Once the truck entity enters the port territory, it has two queues before the T0 gates. The queue is selected based on the minimum number in either resource. The condition NR(R_WaitSpace_1_T0) < NR(R_WaitSpace_2_T0) is given in the decide module (figure 6.11). If the number in the resource wait space 1 is lower than the resource wait space two then move to seize waitspace 1 or else move to seize waitspace 2.

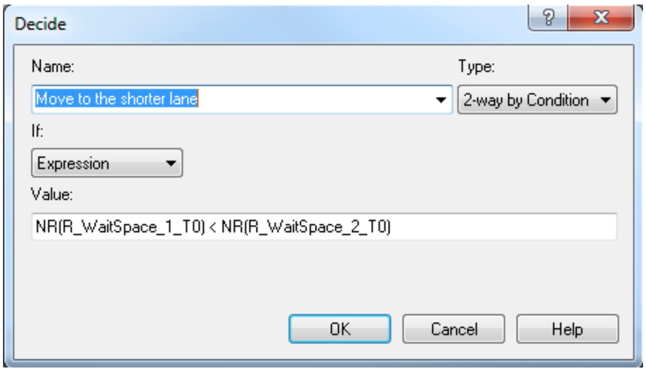
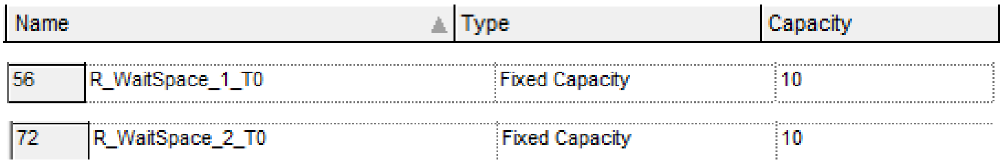


Figure 6.11 Decide module

The two queues before the gates T0 are designed with a fixed capacity of 10 Trucks. Here each of the ten waitspace for the trucks is designed as a separate resource which is the buffer without delay and acts as a queue. The seize module dialog box can be seen in figure 6.13. Figure 6.12 shows the waitspace capacity of these resources which are fixed at 10.



Name		Type	Capacity
56	R_WaitSpace_1_T0	Fixed Capacity	10
72	R_WaitSpace_2_T0	Fixed Capacity	10

Figure 6.12 Define capacity

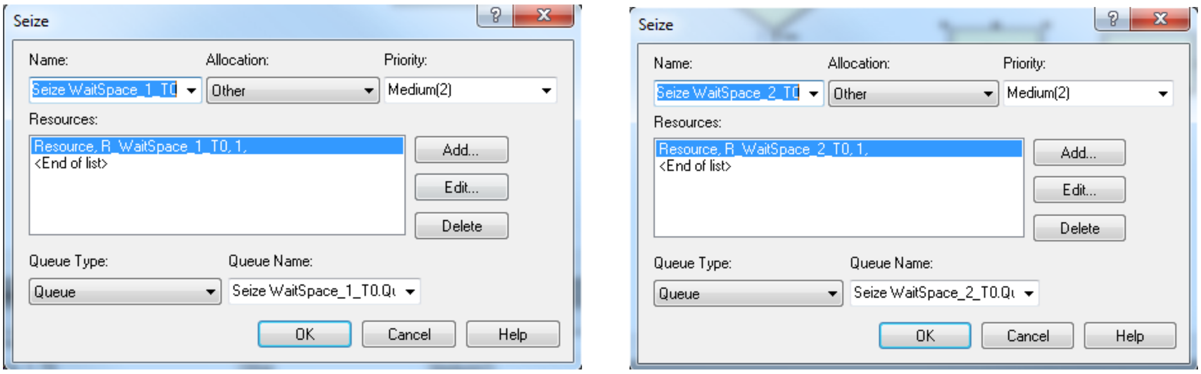


Figure 6.13 Seize modules for wait spaces

Once the entity finds an empty waitspace resource, then it seizes that waitspace and only if the entity seizes the resource the entity in the highway queue is released. Release modules (figure 6.14) are used separately for different queues.

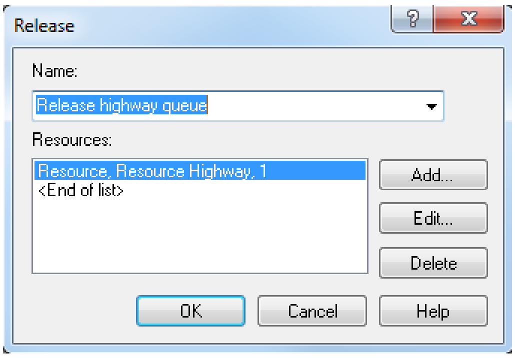


Figure 6.14 Release module for highway

If any of the resource T0 is empty, then the truck entities seize the resource from their corresponding queues. Until the Resource T0 is seized, the truck entity is not released from the waitspace buffer resource. Seize modules (figure 6.15) are used to seize the truck entities. The T0 resource capacity is given as one as it can process one resource at a time.

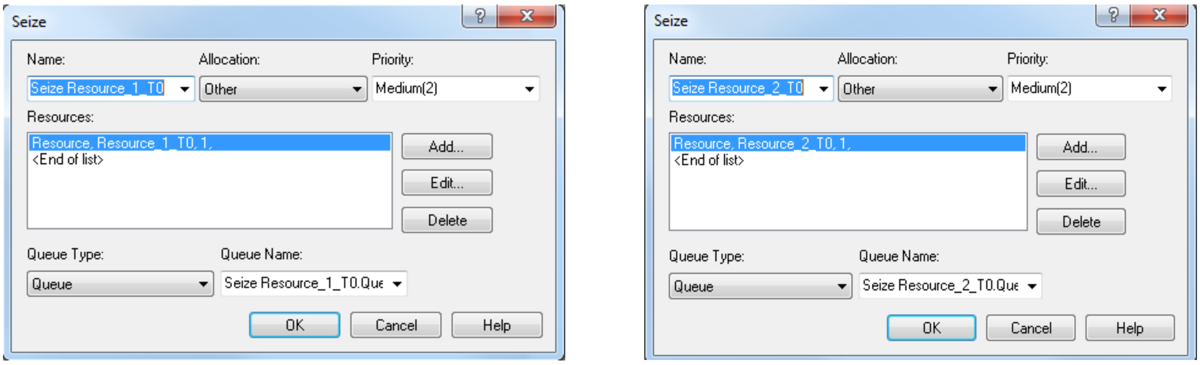


Figure 6.15 Seize modules for resources

Similarly, two release modules release the waitspace buffer resources once the entities seize the resource at Gate T0. The entities are delayed using delay modules at the resource T0 with a triangular distribution of value TRIA (14, 18, 20). The unit is in seconds. The entities coming out of the Resource T0 are assigned lane numbers using assign modules (figure 6.16) to identify later the queue through which the truck entities came through. Then a time stamp module (figure 6.16) is used to calculate the cycle time of the entity which passes through it. Later at the end of the model before the dispose module a record module is used to record this cycle time and report the time.

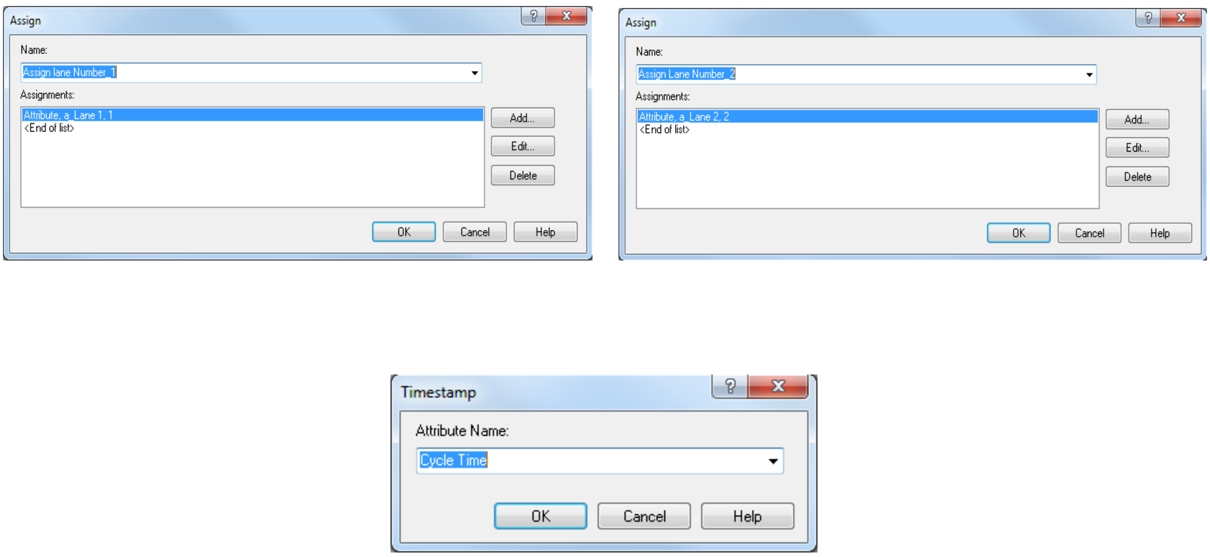


Figure 6.16 Assign modules, Timestamp module

6.2.3 Designing the T1 Gates

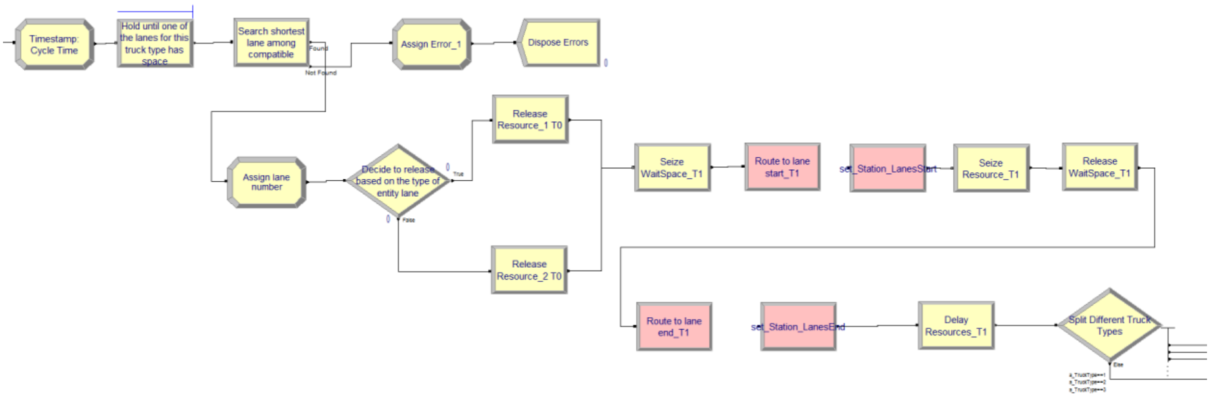


Figure 6.17 T1 gate modules

The figure 6.17, shows the complete T1 gate design and its components. The entity after exiting the timestamp module enters the hold module (figure 6.18) which has the condition as below:

(NR(R_WaitSpace_T1_01)<MR(R_WaitSpace_T1_01) && v_I_TruckLanesMatrix(1,a_TruckType))

|| (NR(R_WaitSpace_T1_02)<MR(R_WaitSpace_T1_02) && v_I_TruckLanesMatrix(2,a_TruckType))

|| (NR(R_WaitSpace_T1_03)<MR(R_WaitSpace_T1_03) && v_I_TruckLanesMatrix(3,a_TruckType))

|| (NR(R_WaitSpace_T1_04)<MR(R_WaitSpace_T1_04) && v_I_TruckLanesMatrix(4,a_TruckType))

|| (NR(R_WaitSpace_T1_05)<MR(R_WaitSpace_T1_05) && v_I_TruckLanesMatrix(5,a_TruckType))

|| (NR(R_WaitSpace_T1_06)<MR(R_WaitSpace_T1_06) && v_I_TruckLanesMatrix(6,a_TruckType))

|| (NR(R_WaitSpace_T1_07)<MR(R_WaitSpace_T1_07) && v_I_TruckLanesMatrix(7,a_TruckType))

|| (NR(R_WaitSpace_T1_08)<MR(R_WaitSpace_T1_08) && v_I_TruckLanesMatrix(8,a_TruckType))

|| (NR(R_WaitSpace_T1_09)<MR(R_WaitSpace_T1_09) && v_I_TruckLanesMatrix(9,a_TruckType))

|| (NR(R_WaitSpace_T1_10)<MR(R_WaitSpace_T1_10) && v_I_TruckLanesMatrix(10,a_TruckType))

|| (NR(R_WaitSpace_T1_11)<MR(R_WaitSpace_T1_11) && v_I_TruckLanesMatrix(11,a_TruckType))

|| (NR(R_WaitSpace_T1_12)<MR(R_WaitSpace_T1_12) && v_I_TruckLanesMatrix(12,a_TruckType))

|| (NR(R_WaitSpace_T1_13)<MR(R_WaitSpace_T1_13) && v_I_TruckLanesMatrix(13,a_TruckType))

|| (NR(R_WaitSpace_T1_14)<MR(R_WaitSpace_T1_14) && v_I_TruckLanesMatrix(14,a_TruckType))

|| (NR(R_WaitSpace_T1_15)<MR(R_WaitSpace_T1_15) && v_I_TruckLanesMatrix(15,a_TruckType))

|| (NR(R_WaitSpace_T1_16)<MR(R_WaitSpace_T1_16) && v_I_TruckLanesMatrix(16,a_TruckType))

|| (NR(R_WaitSpace_T1_17)<MR(R_WaitSpace_T1_17) && v_I_TruckLanesMatrix(17,a_TruckType))

|| (NR(R_WaitSpace_T1_18)<MR(R_WaitSpace_T1_18) && v_I_TruckLanesMatrix(18,a_TruckType))

|| (NR(R_WaitSpace_T1_19)<MR(R_WaitSpace_T1_19) && v_I_TruckLanesMatrix(19,a_TruckType))

|| (NR(R_WaitSpace_T1_20)<MR(R_WaitSpace_T1_20) && v_I_TruckLanesMatrix(20,a_TruckType))

|| (NR(R_WaitSpace_T1_21)<MR(R_WaitSpace_T1_21) && v_I_TruckLanesMatrix(21,a_TruckType))

|| (NR(R_WaitSpace_T1_22)<MR(R_WaitSpace_T1_22) && v_I_TruckLanesMatrix(22,a_TruckType))

|| (NR(R_WaitSpace_T1_23)<MR(R_WaitSpace_T1_23) && v_I_TruckLanesMatrix(23,a_TruckType))

|| (NR(R_WaitSpace_T1_24)<MR(R_WaitSpace_T1_24) && v_I_TruckLanesMatrix(24,a_TruckType))

|| (NR(R_WaitSpace_T1_25)<MR(R_WaitSpace_T1_25) && v_I_TruckLanesMatrix(25,a_TruckType))

|| (NR(R_WaitSpace_T1_26)<MR(R_WaitSpace_T1_26) && v_I_TruckLanesMatrix(26,a_TruckType))

The entities exit the hold module only if any of the above conditions are satisfied. This condition represents the 26 lanes before 26 resources at T1 Gate. The figure 30 below shows Hold module.

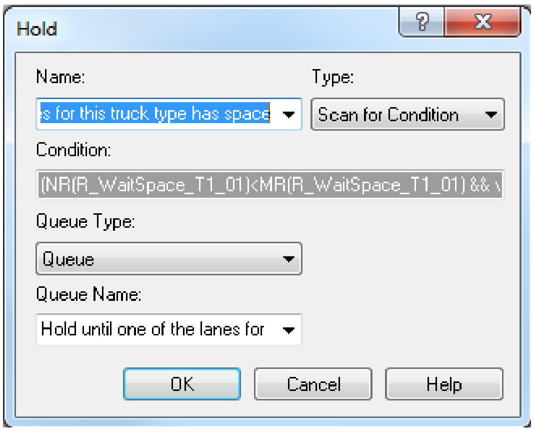


Figure 6.18 Hold module

(NR(R_WaitSpace_T1_01)<MR(R_WaitSpace_T1_01) &&

v_I_TruckLanesMatrix(1,a_TruckType))

The above equation shows that if the number of waitspace in the first lane is less than the maximum number scheduled and also checks the truck lane matrix according to the attribute truck type. It checks if the particular entity which enters the module belongs to that specific gate lane and if not then it goes through the next condition and checks until 26th lane. Only when a condition is satisfied the truck entity leaves the hold module and enters the search module (figure 6.19) which has a condition which helps in finding the lane with a maximum number of empty spaces from the truck lane matrix. That starting value is from 01 to 26 as the truck entity has to search between 26 lanes.

The search module condition is given below:

MAX(MR(Set R_WaitSpace_T1(J))-NR(Set R_WaitSpace_T1(J)) -999999*(v_I_TruckLanesMatrix(J,a_TruckType)==0))

This is a maximizing condition, when the current number in the set waitspace T1(J) is subtracted from the number scheduled of the same set and a high value such as 999999 was selected randomly and multiplied with the value of the condition (v_I_TruckLanesMatrix(J,a_TruckType)==0)) which is either 1 or 0. If the value is 1 and the condition becomes false which will be zero multiplied with a constant 999999 is again zero, and the rest of the condition remains. This is continued for all the lanes of the specific type, and the MAX in the condition chooses the lane with a maximum waitspace available. But if the value is 0 then the statement becomes true, and one will be multiplied by the constant number which becomes a very high value. The final value will be negative. Hence this will be neglected.

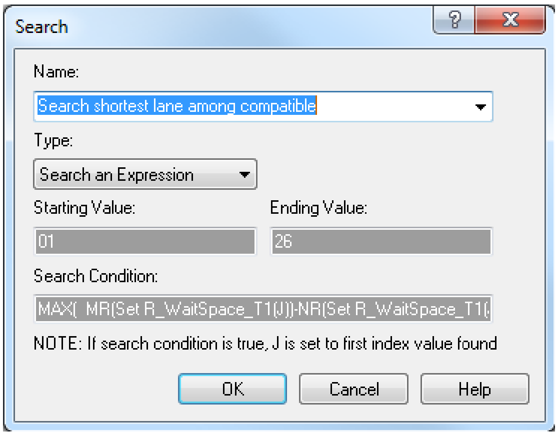


Figure 6.19 Search module

If in any case the condition is not satisfied then that entity passes through the not found exit and is assigned an error variable and disposed of immediately. The entities from the found output of the search module enter the T1 Gate for the 2nd stage processing. Before the entity seizes the resource, they are assigned the lane number with an attribute as a_Lanenumber and with a value, J using an assign module (figure 6.20). J Represents the index with a temporary value.

Once the value J is assigned, then they enter the decide module depending on the attribute lane number 1 and 2 through which they enter the release module where the truck entities at Gate T0 is released. This releases the particular resources Resource_1_T0 and Resource_2_T0 using a release module.

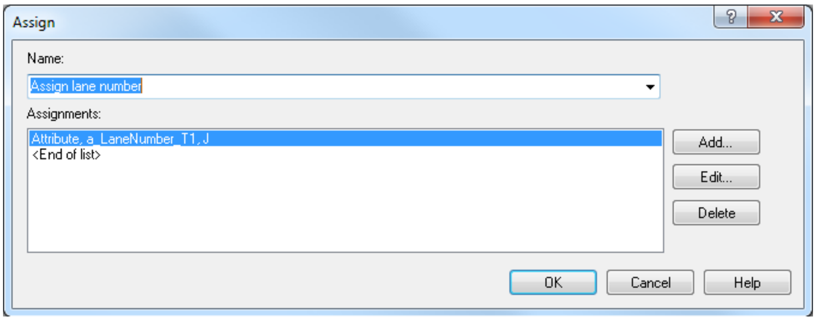


Figure 6.20 Assign module

The truck entity which is released from T0 enters the seize module where it seizes the waitspace resource. A set of 26 resources is created using SET from the basic process tab. The waitpace resources are selected based on specific member rule with the index as a_LaneNumber_T1. The queue for this seize is a set of 26 queues. Once it seizes a particular resource then travels for 20 seconds through route module and enters station module (figure 6.21). The station module has a set of 26 members for all the lanes with different resources.

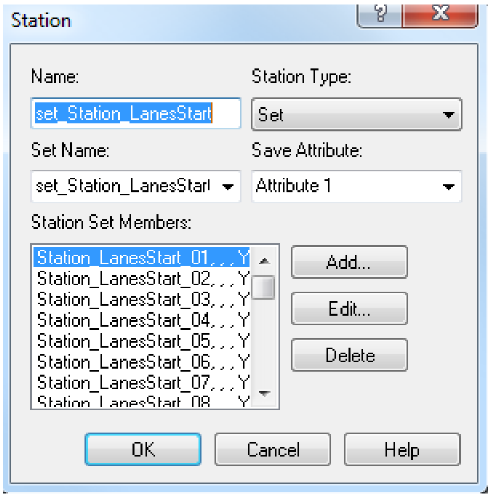


Figure 6.21 Station module

The truck entity then seizes the resource at T1 gate. Only when the resource is seized the entity is released from the waitspace resource using a release module (figure 6.22)). The release rule here is a specific member with the index as a_LaneNumber_T1 which can be seen from the figure 6.22.

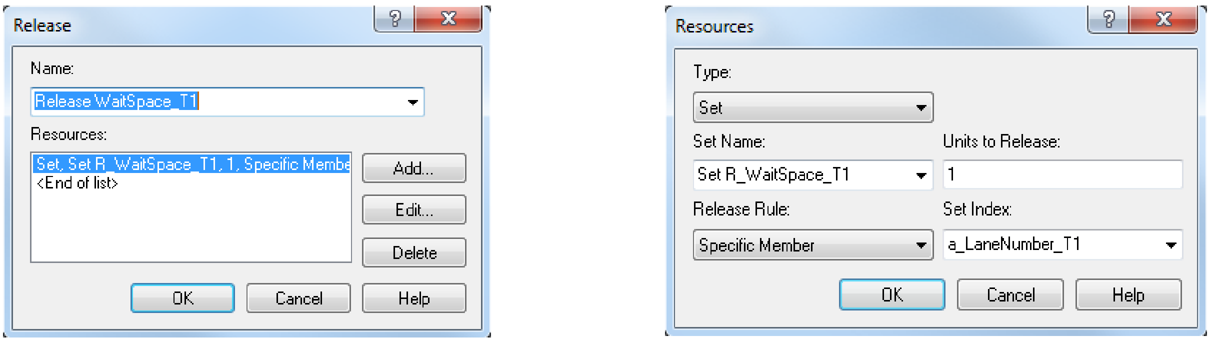


Figure 6.22 Release module, Resources

The entity then enters another route and station modules with a travel time delay(figure 6.23) of 15 seconds in the route and then it reaches the resource at T1 gates and a delay expression as Delay T1(a_LaneNumber_T1) are entered. An expression is created as Delay T1, and a recordset is created from the Excel input data. The delay time is applied depending on the attribute (a_LaneNumber_T1).

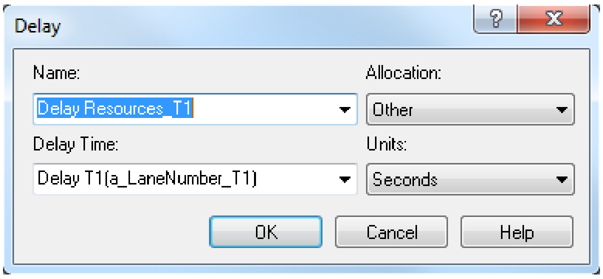


Figure 6.23 Delay module

The entity then enters into a decide module (figure 6.24) which separates them according to the truck type based on a specific attribute and directs them into their respective terminals. N-way by the condition is used to specify the conditions.

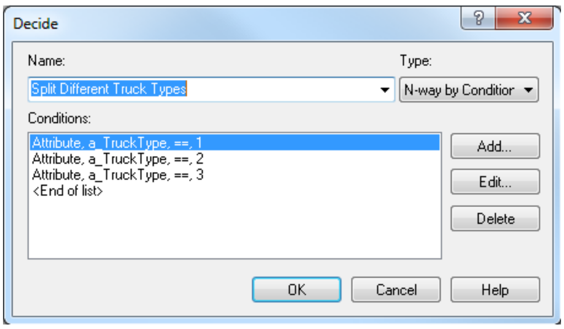


Figure 6.24 Decide module

6.2.4 Designing the Cast Terminal

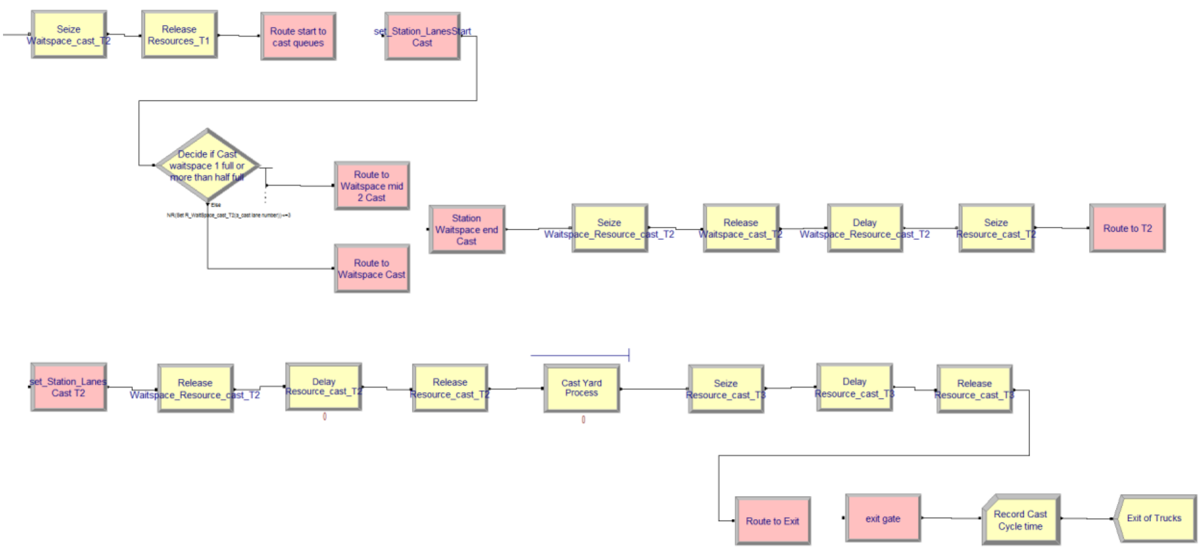


Figure 6.25 Cast terminal modules

The Cast terminal (figure 6.25) is designed with six staging lanes having a capacity of 7 waitspaces each and the paperwork authorities are designed as resources with a delay. T2 Gates have two resources as mentioned earlier. Yard process has 15 resources to load and unload the containers.

From the decide module the cast entity enters the seize module(figure 6.26) where it seizes the waitspace resources and once the entity seizes the waitspace resource they are released from the resource set T1 (Set R_T1) using a release module (figure 6.27). They are released based on a specific member rule according to the index a_LaneNumber_T1. A set of resources (Set R_WaitSpace_cast_T2) and queues are created for the waispaces. The waitspaces are seized according to the largest remaining capacity in the available lanes, and they are saved with an attribute a_cast lane number. Then they travel for 20 seconds (route module delay) to reach the staging using a route and station module. A set of stations is created at the beginning of the staging with an expression set_Station_LanesStart Cast (a_cast lane number). This expression helps to select the station according to the attribute. The Station module can be seen in the figure 6.28 below.

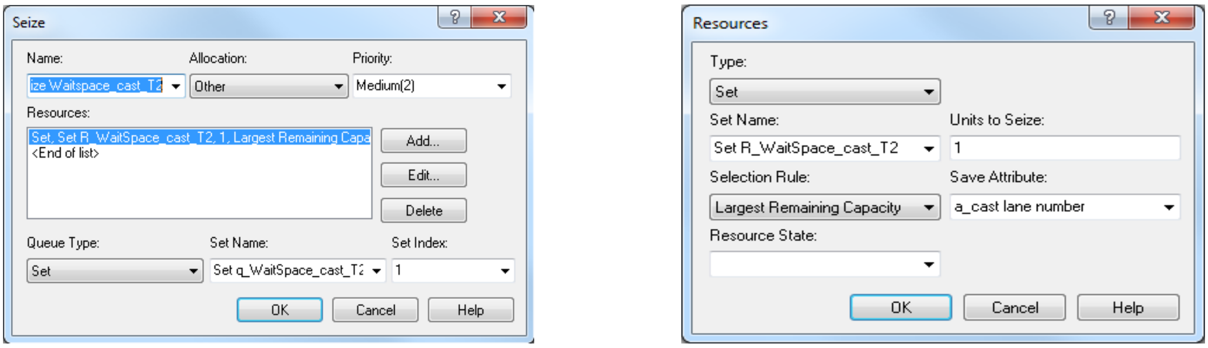


Figure 6.26 Seize module, Resources

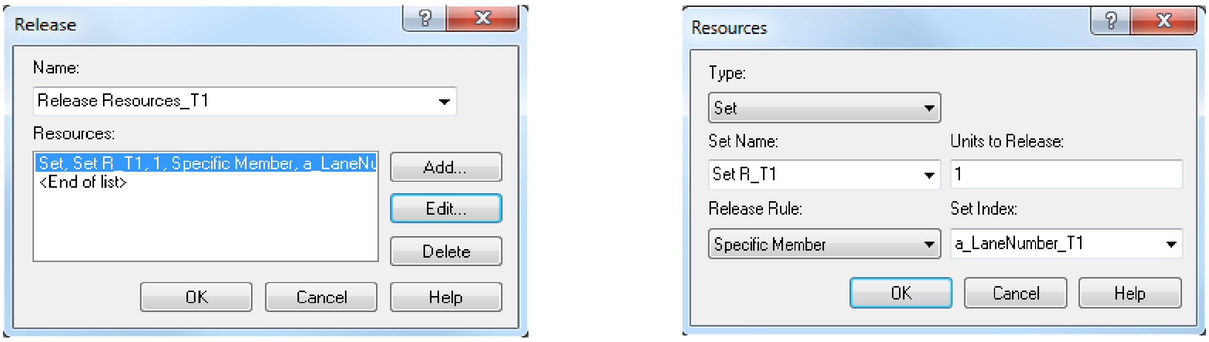


Figure 6.27 Release module, Resource define module

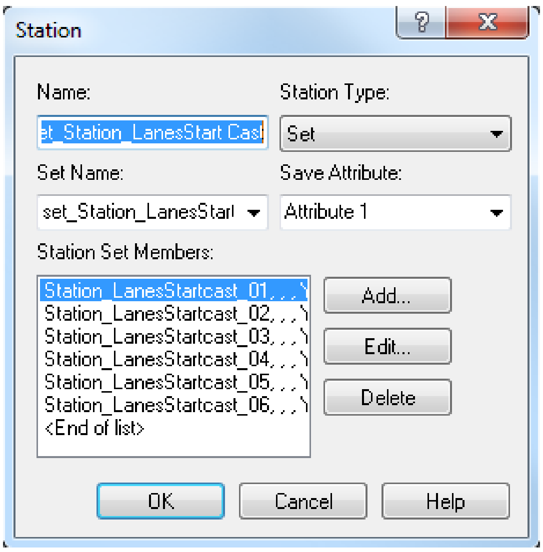


Figure 6.28 Station module

The truck entity then passes through a decide module which decides if the number in set waitspace resources is less than or equal to 3 and then routes them with a 6-second delay using a route module or else routes them with a 0-second delay. The condition NR (Set R_WaitSpace_cast_T2 (a_cast lane number)) <=3 is used in the decide module (figure 6.29)

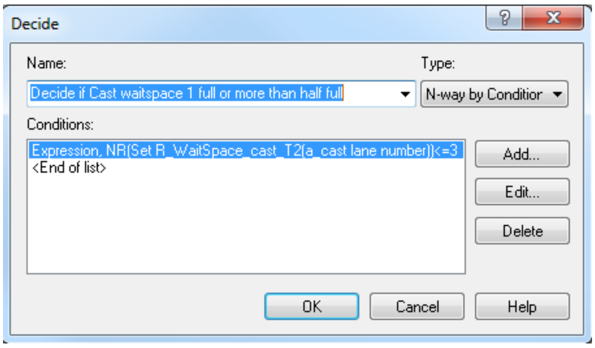


Figure 6.29 Decide module

Two route modules are used to satisfy this condition. An expression is used in the route module for the entity destination station based on the waitpace attribute. The expression is Station Waitspace Cast (a_cast lane number). The same set of station members is created for the destination as created before the decide module. This can be seen in the figure 6.30 below:

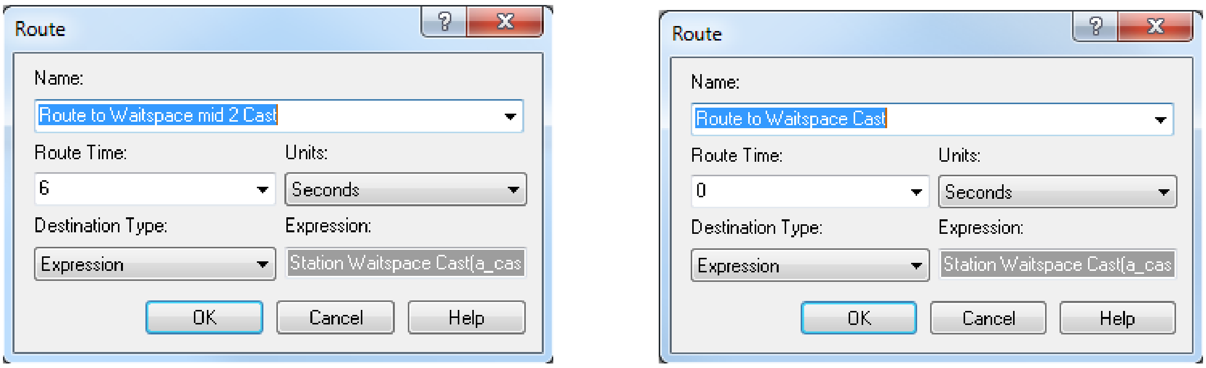


Figure 6.30 Route modules

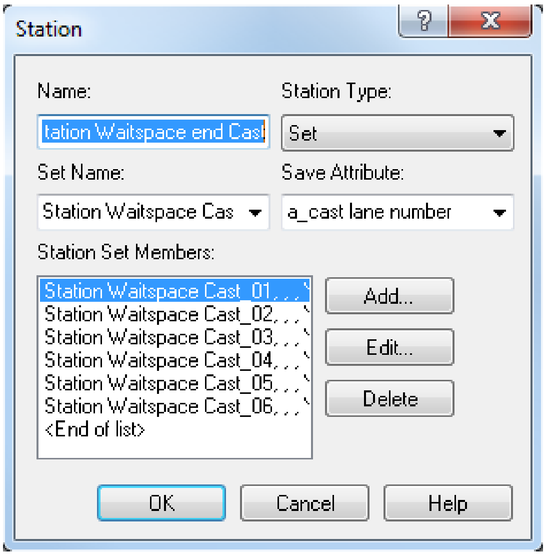


Figure 6.31 Station module

Once the entity passes through the station (figure 6.31), then it passes through another seize module to seize the paperwork resource. A set of resources Set R_WaitSpace_Resource_cast_T2 and queues are created. The resources are seized based on the largest remaining capacity using the seize module. When an entity seizes the resource, they are released from the waitspace buffer resource (Waitspace_cast_T2). The release rule used here is to release the first member seized using a release module. Then they are delayed using a delay module with a TRIA (2, 3, 4) minutes.

After the delay module, the entity seizes the resource at T2 Gate using the seize module. A set of 2 resources (Set R_cast_T2) and queues are created. The seize rule used here is preferred order. Then they are passed through a route and station module (figure 6.32) for 15 seconds according to the attribute a_cast lane T2. Again a set of stations are created as before, and the entity chooses the station based on the attribute a_cast lane T2.

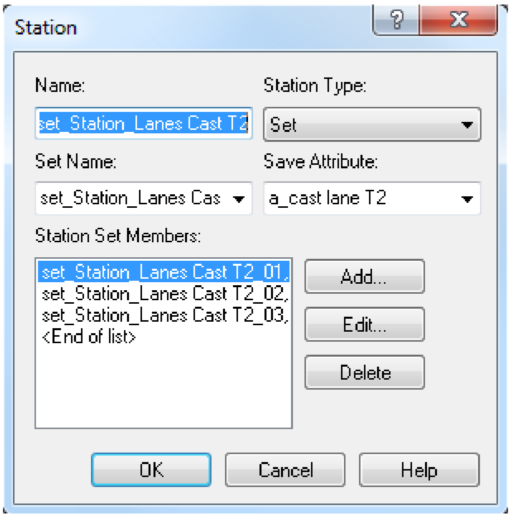


Figure 6.32 Station module

The entity then goes through a release module where the entity is released from the previous resource, and then they are delayed at the T2 gate resources with TRIA (50, 75, 90) seconds using a delay module. After the delay, they are released using a release module with the release rule as the first member seized. They move into the process module (figure 6.33) which represents the Cast yard process. This seizes, delays and releases the entity in the same module as the action selected is "Size Delay Release" and the resources are added.

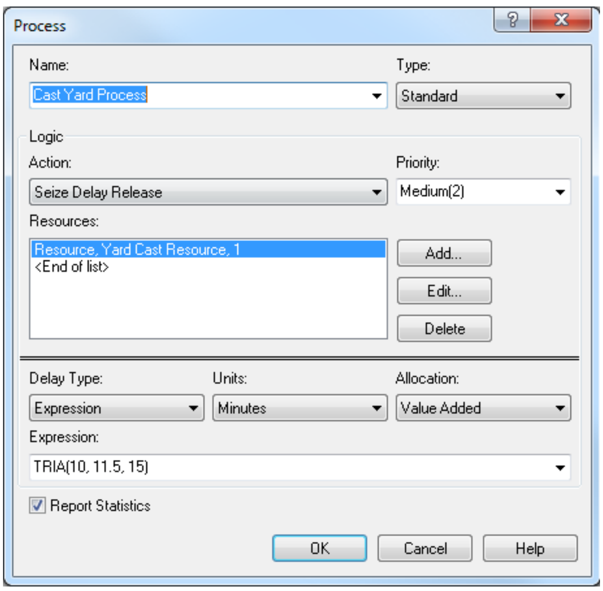


Figure 6.33 Process module

The entity in the process module is delayed according to a triangular distribution of TRIA (10, 11.5, and 15). Once the entity is released from the process module, they then seize the resource at T3 gate using a seize module. They have a set of resources(Set R_cast_T3), and queues and the resources are selected in preferred order rule where the entity always selects the first available member. After the entity is seized, they are delayed using a delay module (figure 6.34) for TRIA (50, 75, 90) seconds. Immediately after the delay, they are released using a release module (figure 6.34). The release rule would be to release the first member seized at resource T3 (Set R_cast_T3). They travel through a route module to exit the terminal using a dispose module. As the time after T3 is not taken into account, it is given as 0 minutes.

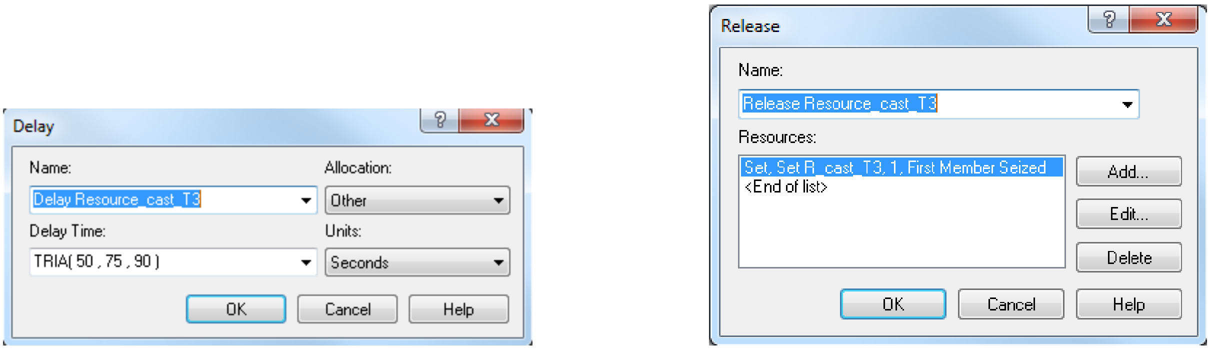


Figure 6.34 Delay module, Release module

A record module is used to measure the entity statistics and the cycle time of the entity in the system. The number of the entity entering the record module can also be counted using a count function in the record module. Finally, they enter the dispose module to exit the system.

6.2.5 Designing the Maisonneuve Terminal

The Maisonneuve terminal has different staging levels with varying capacities. Again overlapping resources are being used to design the resources and queues. The truck entity after exiting the decide module depending on the attribute type enters the Maisonneuve terminal (figure 6.35) where it enters a seize module which represents the buffer waitspace resour ces to be seized. These buffer waitspaces here are 14 hence the resource capacity is defined as 14. These 14 spots are seized based on first come first serve basis.

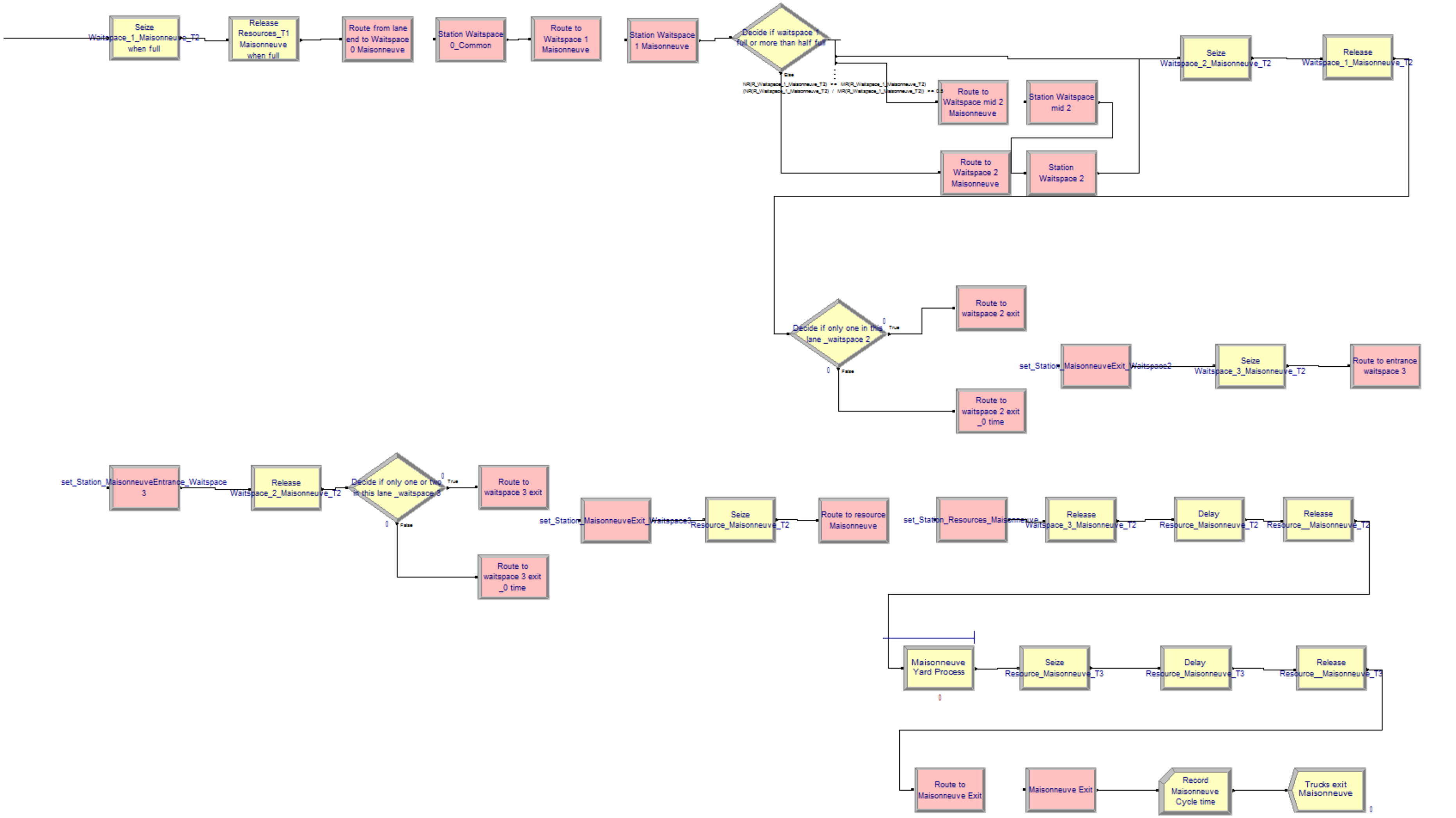


Figure 6.35 Maisonneuve Terminal modules

The buffer resource here is R_Waitspace_1_Maisonneuve_T2. As mentioned earlier the staging in Maisonneuve is split into three levels. Now the truck entity enters into the next staging level with a different set of resources with different capacities. But before seizing the next staging queue, the entity passes through a release module which releases the truck entity from the T1 Maisonneuve gate resource (Set R_T1). They are released based on a specific member rule with set lane index as a_LaneNumber_T1. As the 1st staging has only one queue a single resource with a capacity of 14 is defined in the seize module.

Once any of the waitpace one is seized the truck entity checks the current number of buffer resources seized and before seizing the 2nd staging waitspace buffer resource the truck entity enters two route modules for a duration of 20 and 10 seconds respectively. Instead of one route module, two are used for animation. Once they exit the station waitspace 1 module they enter the decide module (figure 6.36) to check the following two conditions:

1. NR(R_Waitspace_1_Maisonneuve_T2) >= MR(R_Waitspace_1_Maisonneuve_T2)

   The above condition says that if the current number of resources in R_Waitspace_1_Maisonneuve_T2 is greater than or equal to the current number scheduled, then the next entity simply seizes the available buffer waitspace resource.
2. (NR(R_Waitspace_1_Maisonneuve_T2) / MR(R_Waitspace_1_Maisonneuve_T2)) >= 0.5

   If the current number of buffer resource waitspace is greater than 50 percent, then they should travel for 15 seconds through a route module and station module.

If the entity passes through the false exit of the decide module, then they should travel for 38 seconds through another route module and station module. One station module is linked with another, so they have a common station module through different routes.

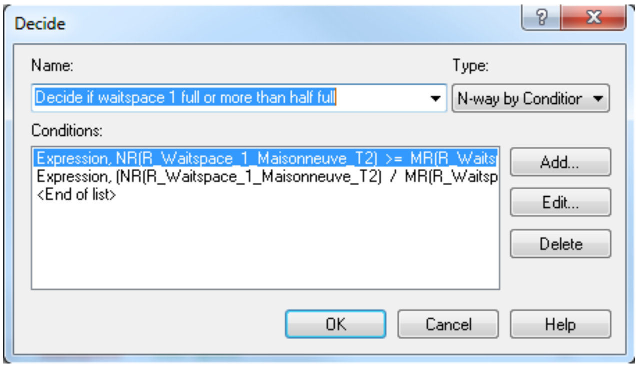


Figure 6.36 Decide module

Once the truck entity exits the station module, it passes through seize module (figure 6.37) where it seizes the 2nd staging waitspace resources (Set R_Waitspace_2_Maisonneuve_T2). The seize rule used is largest remaining capacity. The capacity of each waitspace lane is three which is defined in the capacity spreadsheet. Once the entity seizes this waitspace resource, they are released from the previous waitspace resource using a release module. Then the entity before seizing the 3rd stage waitspace they enter a decide module which checks the current number in the resources and depending on the current number they are directed to different route modules to reach a common station module before the next seize module.

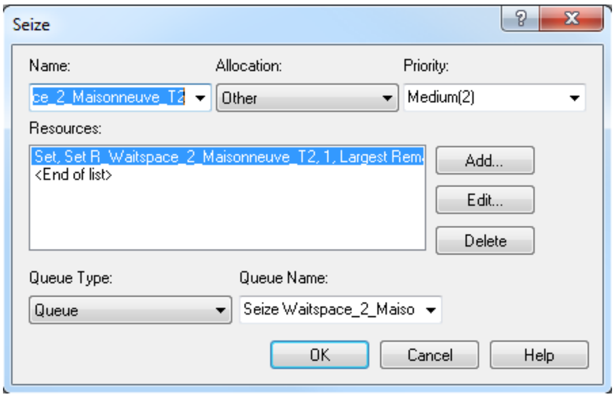


Figure 6.37 Seize module

The decide module (figure 6.38) has the following condition:

NR(Set R_Waitspace_2_Maisonneuve_T2(M_W2 lane number))==1

If the current number in the set resource waitspace is equal to 1, then they exit and pass through a route module of duration 15 seconds.

If not they pass through another route module with a duration of zero seconds. The entity travels through to the station members in the station module based on the attribute (M_W2 lane number) because the upcoming waitspace also has three lanes. The entities strictly follow the same path till they reach the T2 gate resource. The entities from both the route modules (figure 6.39) enter a common station module (figure 6.40) with a set of 3 members which represents the three lanes.

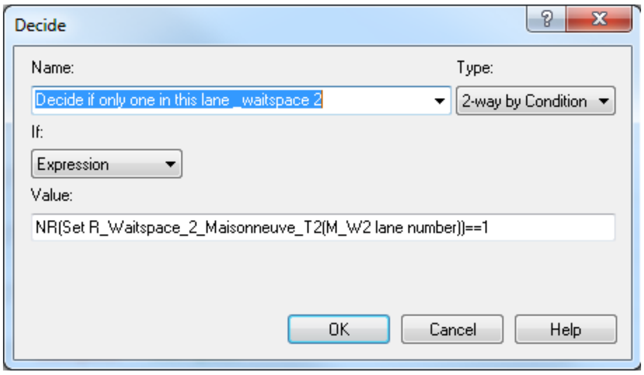


Figure 6.38 Decide module

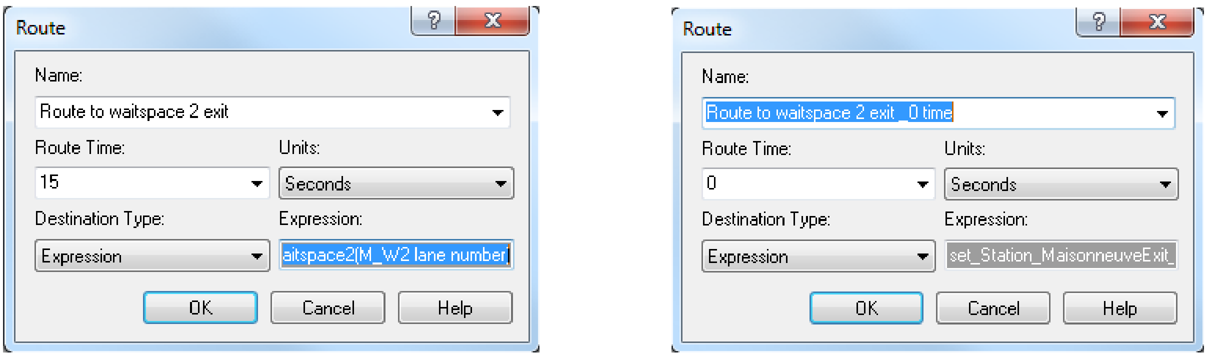


Figure 6.39 Route modules

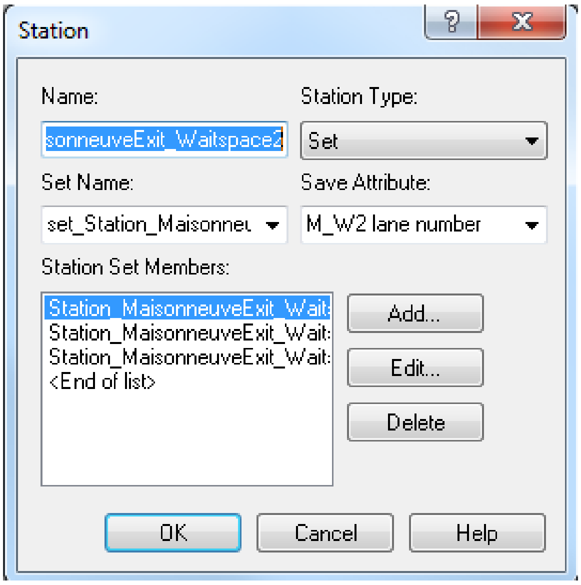


Figure 6.40 Station module

The truck entity exits the station module and then enters a seize module where it seizes a set of waitspace resources and a set of queues based on the specific member rule. The capacity of these resources is defined in resource capacity as 4 in each lane. After exiting the seize module they enter a route module for a duration of 5 seconds with the same attribute and reach a station with a set of 3 members.

As the entity seizes a waitspace they are released from the previous waitspace resource using a release module right after the station module. Once seized the entity enters a decide module(figure 6.41) where it checks for a specific condition and directs then to the two route modules accordingly. The decide condition is as follows:

NR(Set R_Waitspace_3_Maisonneuve_T2(M_W2 lane number))<=2

If the current number in the set resource is less than or equal to 2, then the entity moves to the route with 20 seconds delay, or else they pass through a route with zero delays. They take the same attribute to travel to the station members. A common station module(figure 6.42) is defined with three members with the same attribute as before.

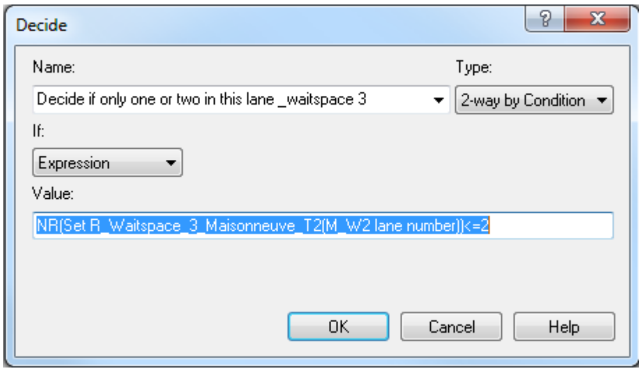


Figure 6.41 Decide module

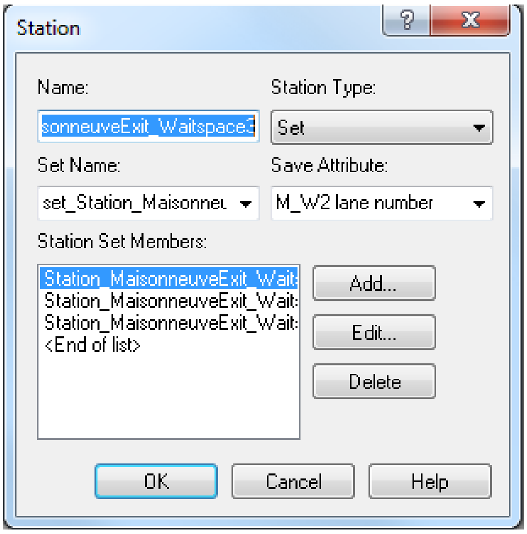


Figure 6.42 Station module

Then the entity enters another seize module where it seizes T2 gate resources(Set R_Maisonneuve_T2) with the same rule of a specific member with the same attribute. If they seize the T2 resource set, then they enter a route module for a duration of 10 seconds with the same attribute to reach the station module with three members. As the entities seized the resource, they are released using release module from the previous waitspaces with the release rule as a specific member with the index M_W2 lane number.

The truck entity is then delayed using delay module at the resource for 1.5 minutes. Then the truck entity enters the release module which releases the entity from the resource(Set R_Maisonneuve_T2) after the delay based on the release rule of the specific member with the same index. The entity enters the process module (figure 6.43) which represents the yard process with a delay [5.5 + LOGN(15.2, 11.7)]. The time unit is in minutes.

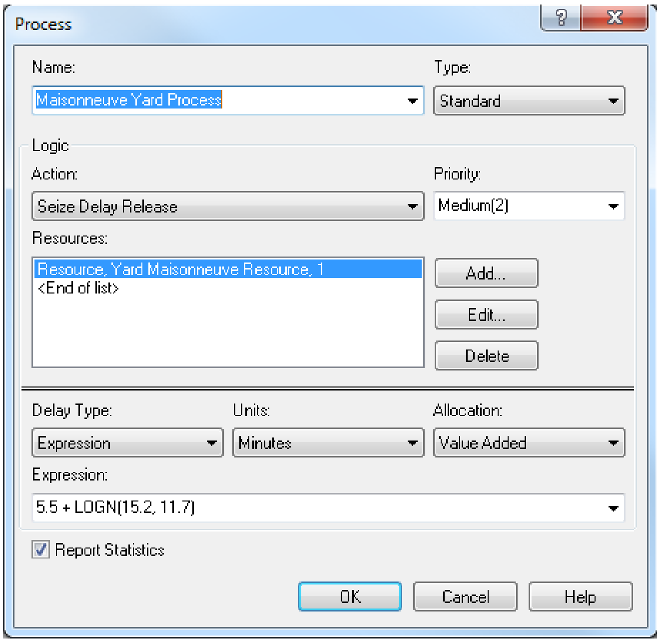


Figure 6.43 Process module

When the entity exits the process module, they enter the seize module(figure 6.44) with a set of resources(Set R_Maisonneuve_T3) and a set of queues defined in a set. The selection rule is based on the largest remaining capacity and saved in an attribute(a_resource Maisonneuve T3). The entity then passes through a delay module where they are delayed by 1.5 minutes again and then released by passing into release module based on the rule specific member seized into the resource set based on the index defined (a_resource Maisonneuve T3).

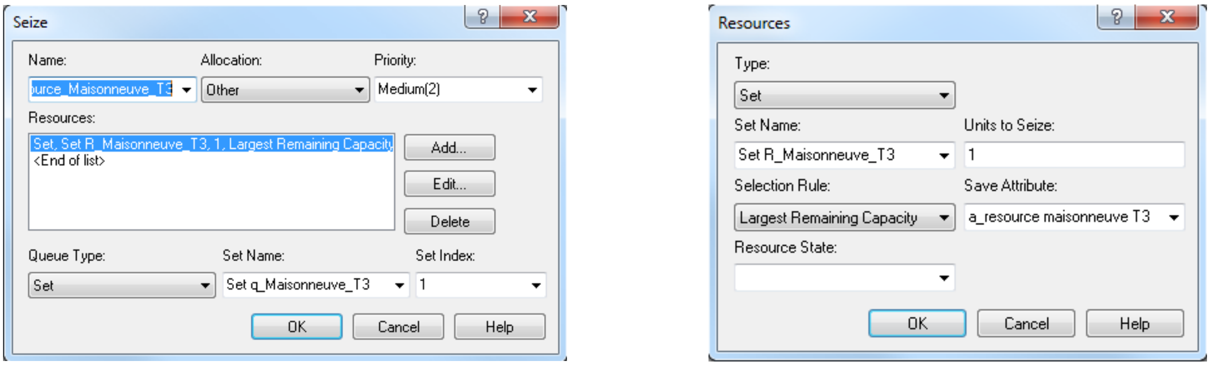


Figure 6.44 Seize module, Define Resources

Then a record module (figure 6.45) is used to record the entity statistics, cycle time and count the number of trucks. The entity then passes through the dispose module(figure 6.69) which disposes the entity from the system.

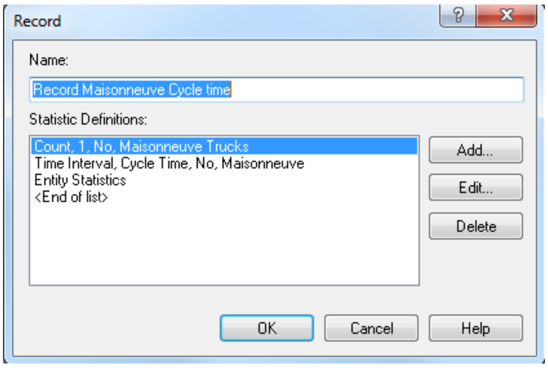


Figure 6.45 Record module

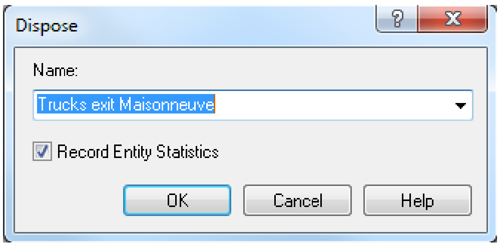


Figure 6.46 Dispose module

6.2.6 Designing the Racine Terminal

The Racine terminal (fiure 6.47) had two waitspaces before the T2 gate resources. The entity exits the decide the module and enters the seize module(figure 6.48) where the entity seizes the waitspace resource(R_Waitspace_1_Racine_T2). Only one resource is defined with a capacity of 65. Until a space in the resource is occupied the entity from the T1 gate resource is not released. They are released using a release module and the resources(Set R_T1) are released based on the release rule of a specific member according to the index a_LaneNumber_T1.

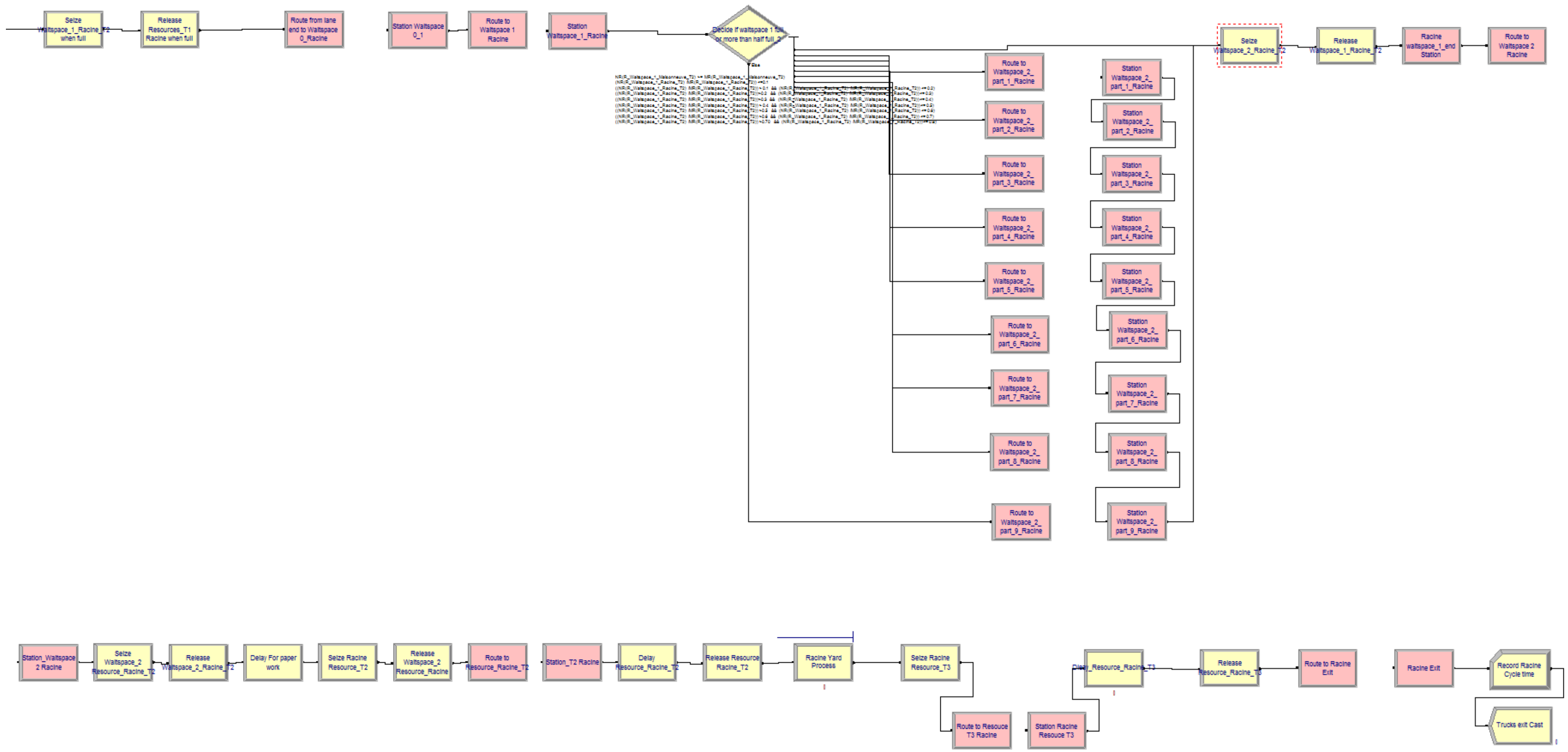


Figure 6.47 Racine Terminal modules

There are 65 spaces available for the entities before T2 Racine gate resource. To model the manner, the entities travel the same route; they have been delayed with varying delay times depending on the distance they have to travel based on the current number seized. This is made possible by decide module where there are several conditions and the entity passing through acts as per the conditions.

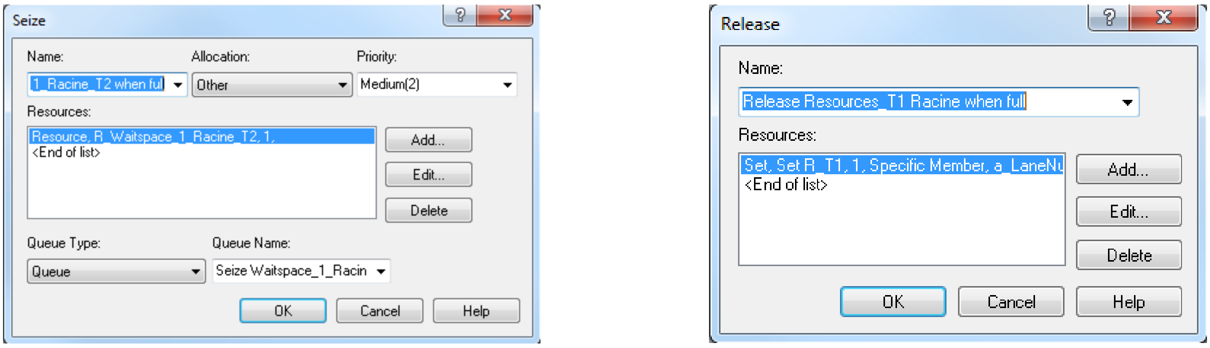


Figure 6.48 Seize module, Release module

The entity once released from the release module enters a route module where it is delayed for 15 seconds and again into another route module for 84 seconds. They pass through station module from which it enters a decide module where it decides the route the entity should take based on the condition inside the decide module (figure 6.49). The following are the conditions inside the decide module:

NR(R_Waitspace_1_Maisonneuve_T2) >= MR(R_Waitspace_1_Maisonneuve_T2)

The condition above tells that if the current number in the waitspace resource is greater or equal to the number scheduled then the entity enters the next seize module. The conditions below are connected to different routes.

(NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) <=0.1

((NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) > 0.1 && (NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) <= 0.2)

((NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2))>0.2 && (NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2))<= 0.3)

((NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2))>0.3 && (NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2))<= 0.4)

((NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) > 0.4 && (NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2))<= 0.5)

((NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) >0.5 && (NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) <= 0.6)

((NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) >0.6 && (NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) <= 0.7)

((NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2)) >0.70 && (NR(R_Waitspace_1_Racine_T2) /MR(R_Waitspace_1_Racine_T2))<= 0.8)

All the conditions above clearly shows that if the current number in waitspace resource is lesser than 10%, greater than 10% and less than 20%, greater than 20% and lesser than or equal to 30%, greater than 30% and lesser than or equal to 40%, greater than 40% and lesser than or equal to 50%, greater than 50% and lesser than or equal to 60%, greater than 60% and lesser than or equal to 70%, greater than 70% and lesser than or equal to 80% then they are directed to the true side of the decide module, and if all the above conditions are not satisfied then they are directed to the false side of the decide module, and they enter a route module with a different delay times. All the delay time are based on the distance traveled.

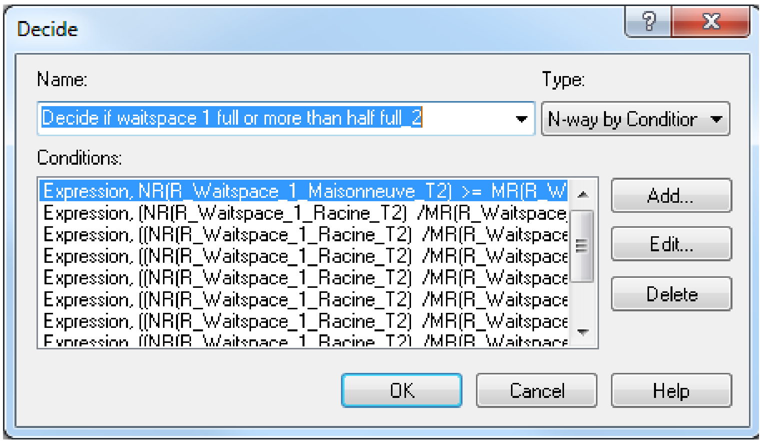


Figure 6.49 Decide module

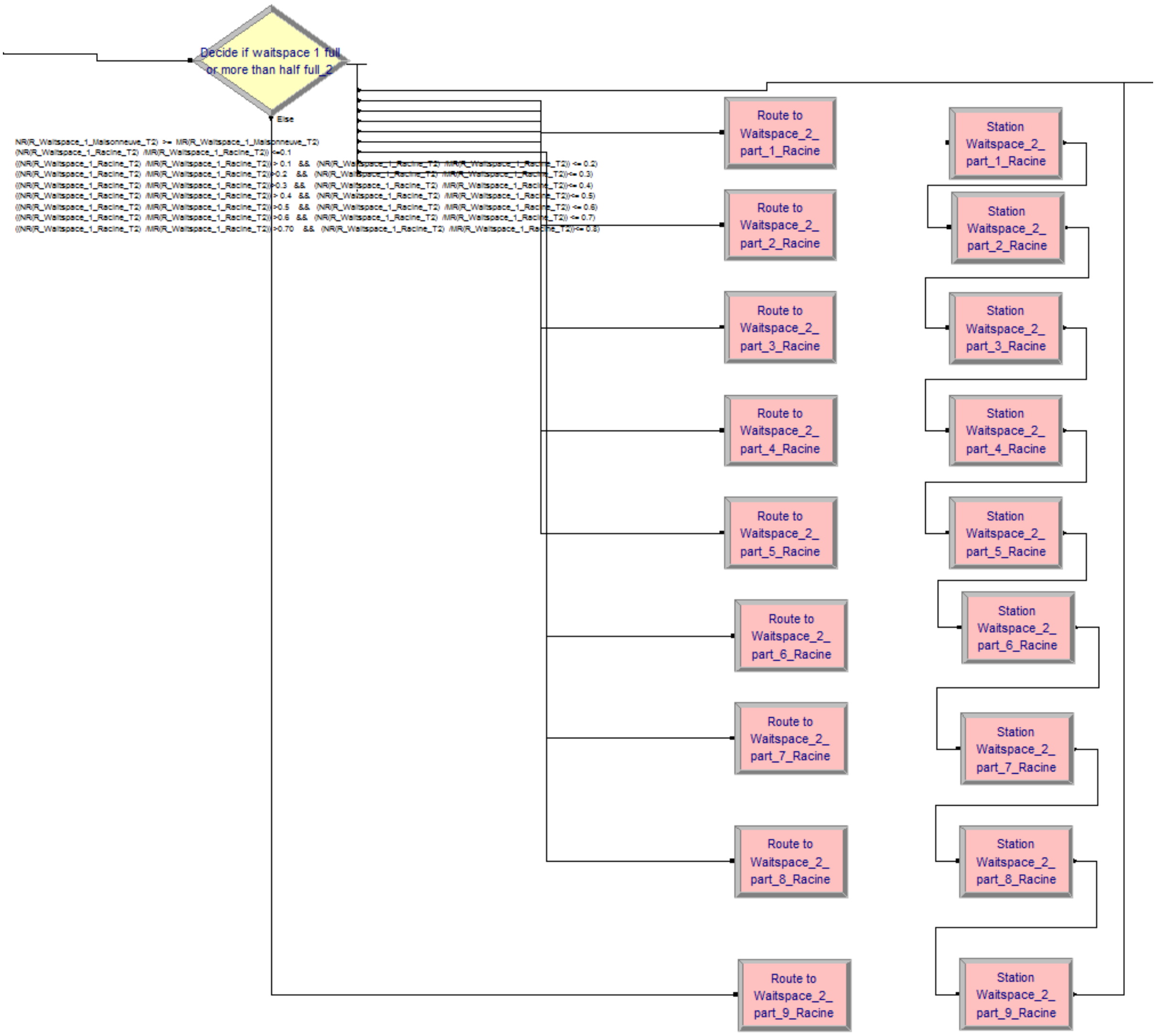


Figure 6.50 Station and Route modules

The above figure 6.50 shows the decide module with the different conditions and the different route modules with their corresponding station modules. Here all the station modules are interconnected to one single station module. Once the entity exits the station module, they enter the seize module (figure 6.51) where they seize a set of 10 resources(Set R_Waitspace_2_Racine_T2) based on the selection rule of largest remaining capacity. The resource capacities were assigned as one. A set of queues is also created.

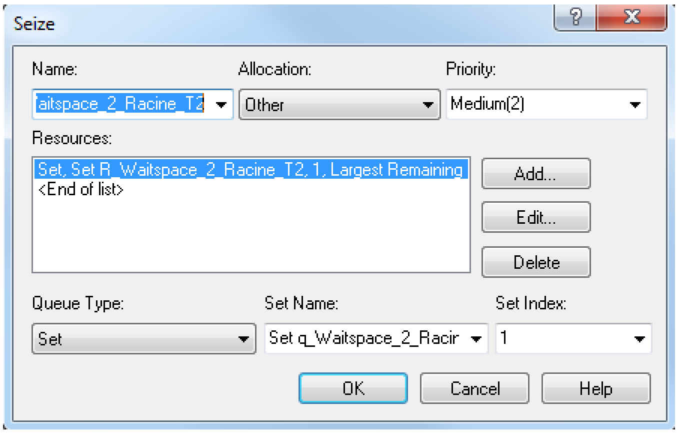


Figure 6.51 Seize module

The entity after seizing one of the resources then enter into the release module where they release the entity from the buffer waitspace resource. The entity is released from the resource(R_Waitspace_1_Racine_T2). One unit is released from the resource.

The entity is then delayed for a duration of 10 seconds using a route module, and they reach the next station waitspace using a station module. The entity then passes through the seize module (figure 6.52) where it seizes the set resource(Set R_Waitspace Resource_2_Racine_T2) which consists of 10 resources with a capacity one each. The entity seizes the resource in preferred order. Once the entity seizes the resource, they are released from the waispace one resource. Once seized they are delayed for TRIA(180, 200, 240) seconds. This delay represents the paperwork time.

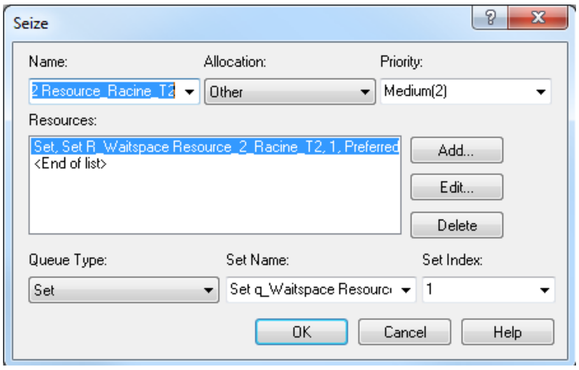


Figure 6.52 Seize module

However, after the delay, the entity enters the seize module (figure 6.53) where the truck entity seizes the T2 gate resource(Set R_Racine_T2), and once the resource at T2 gates is seized, they are released from the previous waitspace resource. They are seized based on the cyclical rule, where the entity cycles through the available members. A queue set has been defined for all the resources. Once a resource is seized then the entity is released from the previous waitspace 2 using a release module. Once seized they are delayed using a delay module with a delay of TRIA(60, 80, 100) seconds. Before the entity travels to the resource delay, they go through a route module for 10 seconds to reach a set of station members which represents the resources at T2 gates.

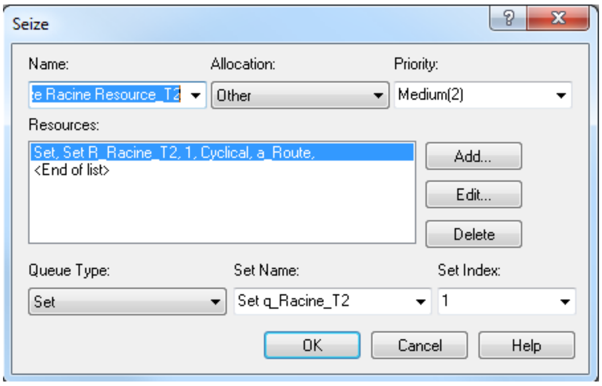


Figure 6.53 Seize module

The truck entity after the delay is released into the process module using a release module which releases the resource(Set R_Racine_T2) using the release rule of the first member seized.

One unit is set to release. The Process module then delays the truck entity for a delay time of [4.5 + 21 * BETA(1.76, 1.64)] minutes based on the result from the input analyzer. This process module (figure 6.54) represents the Racine yard process.

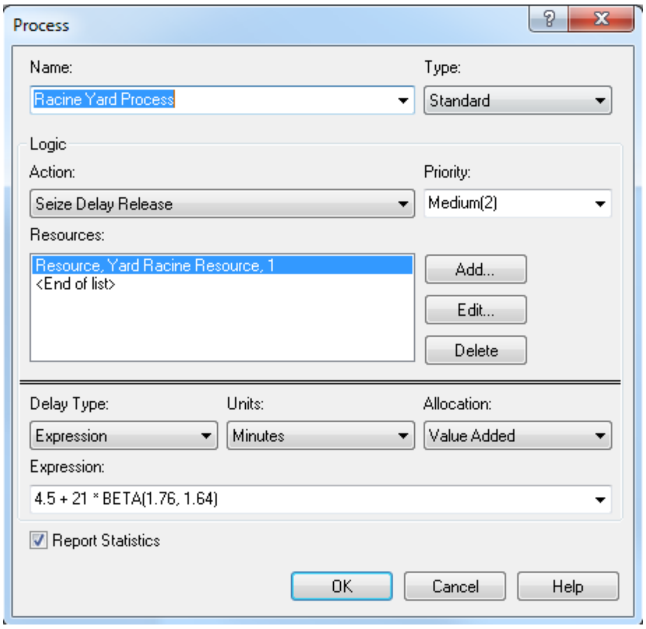


Figure 6.54 Process module

The entity which leaves the process module enters the seize module (figure 6.55) where it seizes the resources(Set R_Racine_T3) based on the cyclical rule. They arrive in a single queue and seize the resource. Before delaying the truck entity at T3 gate resource, they enter the route module for 20 seconds and then enters a station module with a set of members defined according to the attribute a_T3 Racine.

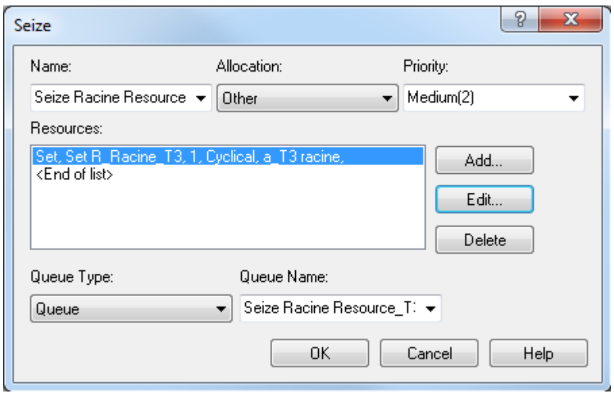


Figure 6.55 Seize module

From the station module, the entity enters the process module (figure 6.56) where the action was set to delay the entity, and they are delayed for a duration of TRIA(90,120,125) seconds.

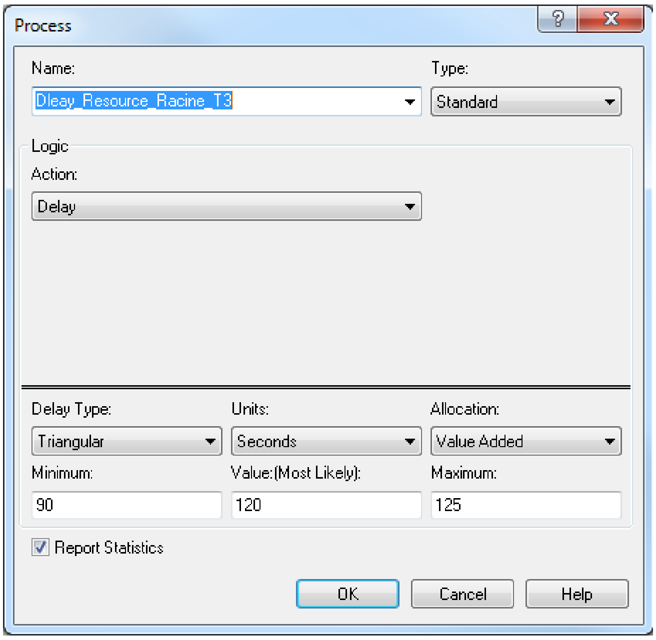


Figure 6.56 Process module

Immediately after the delay, the entity is released using a release module from the resource(Set R_Racine_T3). The release condition was set as the first member seized. The number of units released is set to 1. Then the entity enters a route and a station module which delays the entity by zero minutes and finally enters a record module (figure 6.57) before entering a dispose module and exits the system.

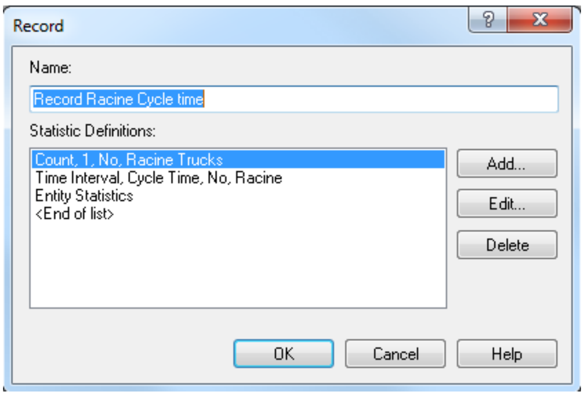


Figure 6.57 Record module

The record module is used here to count the number of Racine truck entities, the cycle time of Racine truck entity and the entity statistics.

6.2.7 Designing the Viau Terminal

The Viau terminal (figure 6.58) was also designed with the concept of overlapping resources. As the existing Viau terminal was under construction at the port of Montreal there are some assumptions that were considered to model the terminal resources and staging, it was designed with three-lane staging before the T2 and T3 with ten waitspaces each. This means it can handle ten truck entities or ten waitspaces are available for the entities.

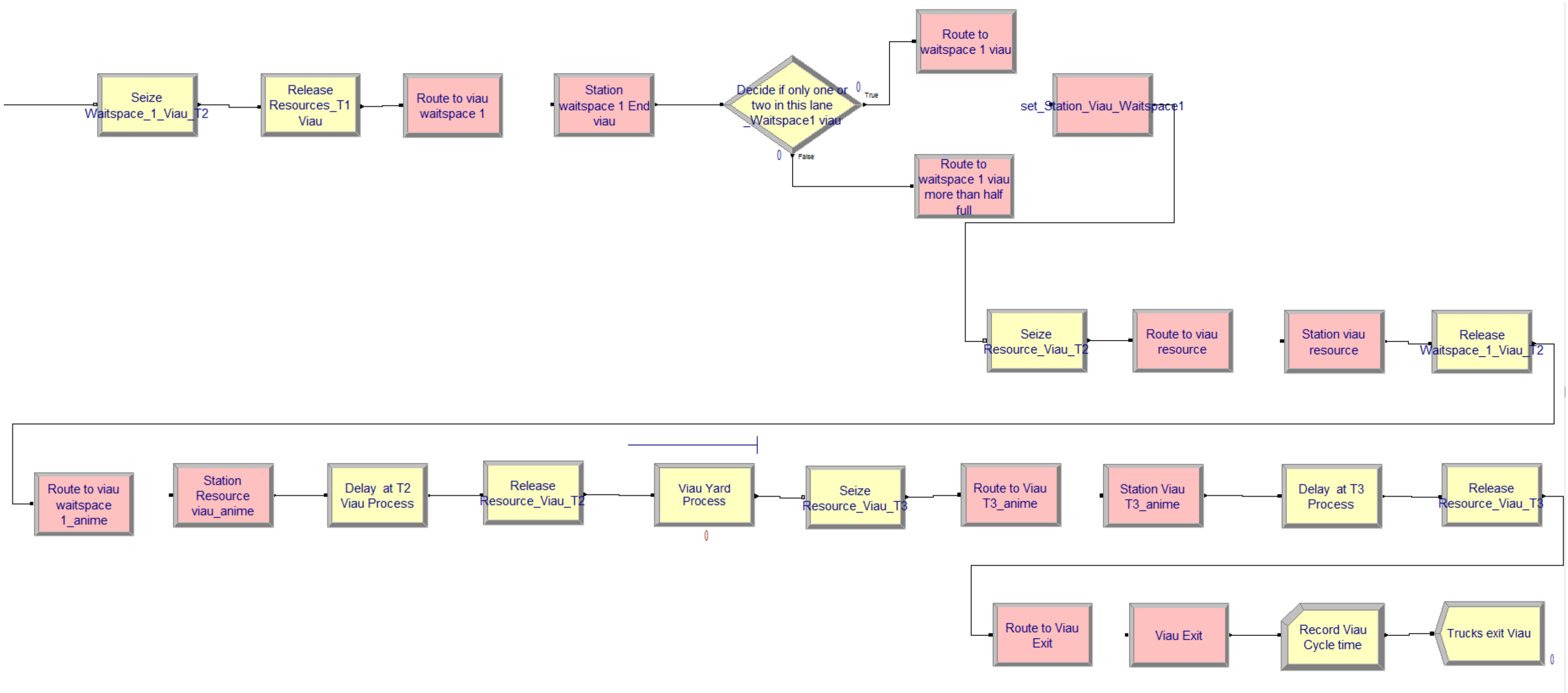


Figure 6.58 Viau terminal modules

The truck entity with attribute a_TruckType=2 enters the seize module (figure 6.59) of the Viau terminal where the truck entity seizes the resources(Set R_Waitspace_1_Viau_T2). The seize rule is largest remaining capacity, and an attribute is saved as a_Waitspace Viau 1. Once the Truck entity seizes the waitspace resources, then they are released from the T1 resources(Set R_T1) with set index a_LaneNumber_T1. The release rule is a specific member.

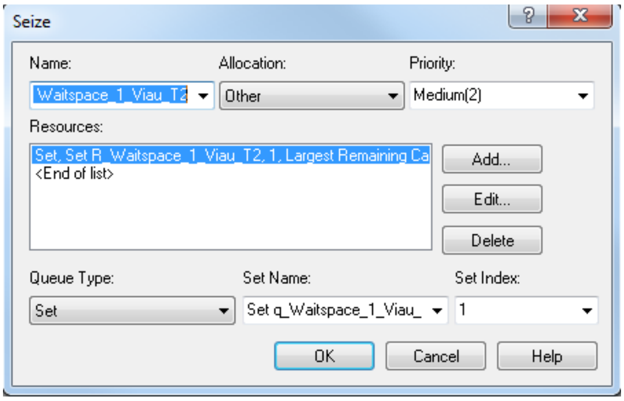


Figure 6.59 Seize module

The truck entity then enters a route module where a delay of 480 seconds is applied to the trucks, and a set of two members are created in the corresponding station module. Once the entity exits the station module the seized truck entity checks for a condition using a decide module (figure 6.60) as,

NR(Set R_Waitspace_1_Viau_T2(a_Waitspace Viau 1))<=5

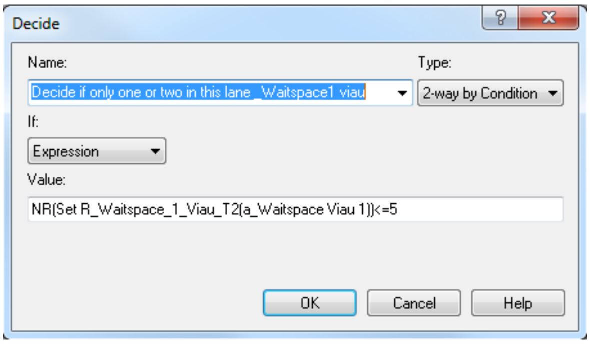


Figure 6.60 Decide module

This shows that if the current number in the resource Set R_Waitspace_1_Viau_T2 according to the attribute is less than or equal to 5, then the entity is directed towards the true exit or else to the false exit. As a set is defined, its attribute is taken into account. The entity that exits to the true side enters a route module where a delay of 30 seconds is added, and the destination station is specified with the attribute. The false exit enters a route with a zero delay and both the entities enter the same station module with a set of two members defined. Then the entity enters the seize module for seizing the T2 gate resources Set R_Viau_T2 with the same attribute that was defined before. The seize rule was preferred order. The units to seize was 1.

Once seized the entity then enters a delay module (figure 6.61) where the entity is delayed for 1.5 minutes. Once they are delayed the entity enters the release module (figure 6.62) where Set R_Viau_T2 is released and units to be released is set to 1. The release rule here would be a specific member with the set index as a_Waitspace Viau 1.

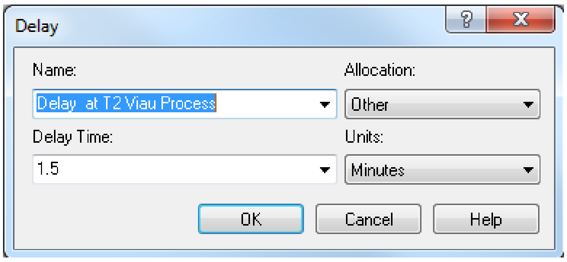


Figure 6.61 Delay module

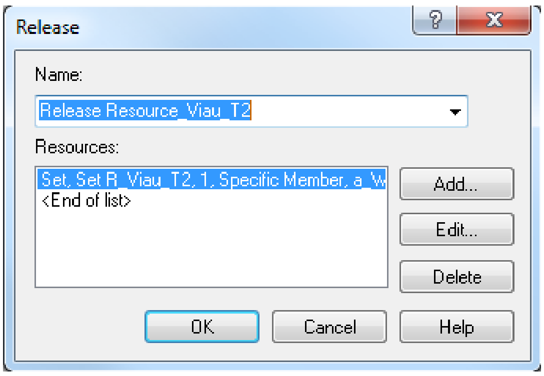


Figure 6.62 Release module

If the entity is released, they enter the process module (figure 6.63) in which the action is set to seize delay release. The resources are defined in add resource and the units to seize/release is set to 1. The dealy for the entity is given as TRIA(3.5, 7, 40.5) minutes.

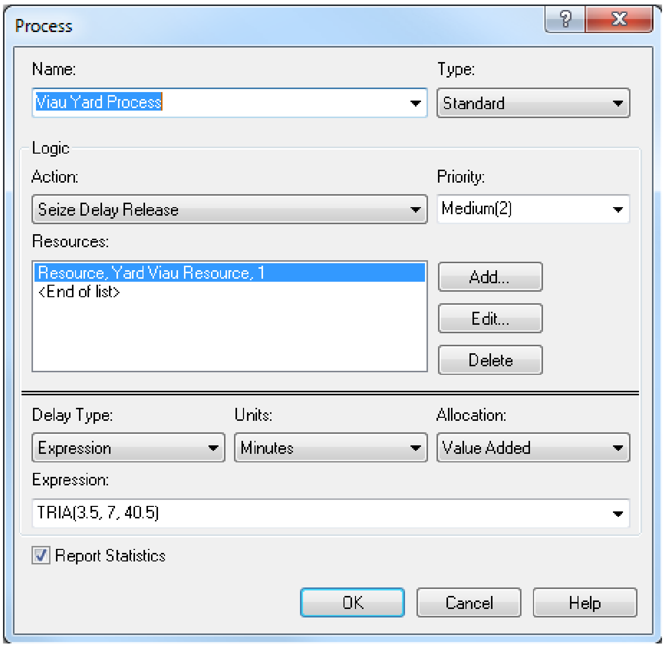


Figure 6.63 Process module

The entity then passes through the seize module where it seizes the T3 gate resources(Set R_Viau_T3). The resources are seized in preferred order. The entity then enters a delay module where they are delayed for 75 seconds. The entities are then released from the resources(Set R_Viau_T3) using a release module (figure 6.64) with the rule as the first member seized.

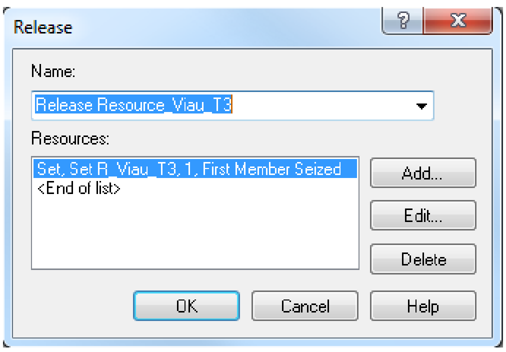


Figure 6.64 Release module

Then they enter the record module where the entity statistics, Viau truck entity count and cycle time of the Viau entity is recorded. Then the entities are then disposed from the system using a dispose module.

Chapter 7

Conclusions and future work

7.1 Conclusions

In this thesis, we investigate the problem of reducing turn times of port trucking operations and proposed a discrete event simulation model to investigate various congestion mitigation scenarios. Examples of these scenarios are extended gate hours, change in arrival patterns, gate lane change policy, and use of technology at container terminals. A case study of Green harbor trucking initiative at the Port of Montreal is done.

The simulation was run for 24 hours, and ten replications were done. All the tested scenario showed a significant reduction in the turn time. The output shows that decreasing the number of incoming Maisonneuve trucks per hour to 43 could reduce the average turn time of the Maisonneuve truck by at least 50%. Improving the technology of the Racine and Cast could lead to an improvement in turn times by at least 25%. Having a proper gate lane policy for Cast and Racine is very important and the simulation results show (4, 10) lane policy is the best policy. Change in arrival patterns could also bring a positive impact to the system in terms of turn time.

The proposed model can serve as a useful tool for decision makers at Montreal Port Authority to assess scenarios to reduce turn times which in turn would reduce the truck idleness, congestion inside the port territory, and reduction of greenhouse gas emissions.

7.2 Future work

Based on the current work, several future research extensions are possible.

1. Cost considerations could be integrated into the current model to assess the cost associated with the labor, inventory space, and other continuous improvements made in the port operations.
2. There are some limitations to the model due to the lack of data availability. Since many assumptions such as one size truck, limited staging lanes, and container chassis were considered, the model became more constrained in the level of detail it provides. It could be improved by integrating the exact number of staging lanes, considering premium trucks with the cost associated with it, empty chassis, both length of chassis, and creating perfect routes and trying to include velocity. Few constraints were due to the software.
3. The Viau terminal should be updated with respect to the existing system. The route for Viau trucks to the Viau terminal should be accurately defined. Train inference delays should be taken into account.
4. Failures of the automated systems should be considered.
5. Development of an accurate model could help in precisely developing an appointment system. A Large set of long-term data should be considered and a questionnaire should be developed with the trucks drivers about their views on an appointment system.

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