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AVIO-REFUELING PROCESS SIMULATION IN AN AIRPORT ENVIRONMENT

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ABSTRACT
The process of aircraft refueling has crucial impact in the performance of an airport. It is in fact of common knowledge that one of the most important indicators for benchmarking an airport is the punctuality of flights departure. To assure high results, the airplane service activities such as passengers boarding, baggage handling and aircraft refueling must not delay one another and the overall departure time. The scope of the proposed study is to produce an instrument capable of simulating the process of the aircraft refueling in the airport environment and to consider different scenarios and evaluate their impact in the overall performance. This tool has significant relevance for the company whom process we have analyzed, allowing it to be able also to evaluate easily and in a short period of time complex changes in the process.

Keywords: aircraft refueling, process simulation, scenarios evaluation, airport.

1. INTRODUCTION

The airport is the site we are referring to, with attention to the areas used for the handling of aircrafts and service vehicles, correlated to each other in order to guarantee the effective and efficient results for aircraft landing and take-off operations. These areas include the take-off and landing runway, taxiways and lay-bys. The management phase of an aircraft transiting in an airport environment is a topic of particular interest at a scientific level and the literature offers several studies on the different activities that are carried out in this field (Ruamchat *et al.* 2017).
First of all, there is the handling of the aircraft in the moments following the landing, with the objective of transferring the aircraft from the runway to the lay-by assigned to it from the control tower, taking into account especially the traffic conditions. This extremely delicate phase must be carried out guaranteeing the maximum possible rapidity and the least bulk of the road conditions; especially for the larger types of aircraft, a parking area must be guaranteed as close as possible to the landing strip, also considering the available roads that often have to be modified to adapt to the ever-increasing size of the aircraft. Given the delicacy and importance of this phase, there are several studies in the literature that analyze it and propose different mathematical models able to efficiently coordinate these operations (Samà, D'Ariano, Corman, & Pacciarelli 2018), and which also propose models that can serve as an instrument for the optimal allocation of the stalls (Guépet, Acuna-Agost, Briant, & Gayon 2015) as an instrument serving the control tower.

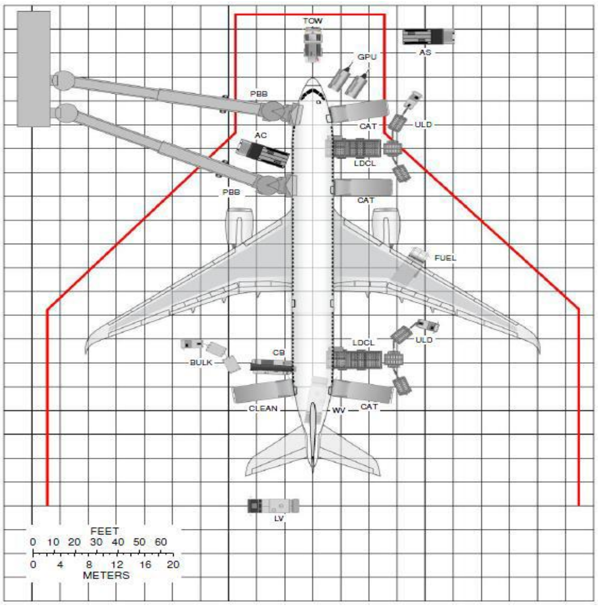

Figure 1: The "Ramp Area": diagram to illustrate the complexity of the integrated system (K.Wing, Cloutier, & Felder, 2015)

After parking the aircraft at a lay-by, also referred as "Ramp Area" (see Figure 1), the operations performed by service providers such as catering restoration, cleaning services, baggage loading and unloading, passenger descent and ascent, and refueling are activated. This area is often congested. It is due to the fact that all the airline companies are day by day more focused on being in the lay-bys the least possible amount of time, and so all the different service providers are forced to execute their activities in a small portion of time, causing a lot of traffic between themselves. The person responsible for coordinating all these operations in the ramp area is called "Ramp Agent". He/She has the role of assuring two conditions during the work of the service providers:

- Rapidity, making sure that the operators do not interfere one another.
- Safety & Security.

In the literature, many studies have focused their attention on the single activities done in the ramp area and on the overall efficiency of the coordination of these. For example, Kierzkowski & Kisiel (2017) study the passengers boarding procedure and how the human factor is crucial in the implementation of one methodology or another; others studies propose the development of simulation tools to support the analysis, for example, of the baggage handling phase and its performance (Cavada, Cortés, & Rey, 2017), the optimization of the operators used for aircraft refueling in airport parking area (Carotenuto et *al*. 2019),, or proposing refueling optimization tools capable of finding the optimum number of avio-refuelers and the best routes, given a specific market demand (Babić, 1987).
None of these, however, keeps in consideration the contemporaneity of the distinct activities, resulting in a probable underestimation of the complexity of the system. The ramp agent comes in handy right where the human factor is of primary importance and without whom the coordination of these activities would result poorly managed (Wing, Cloutier, & Felder, 2015).

2. SYSTEM DEFINITION

The proposed study was developed for a company operating at an important airport in Italy, in charge of refueling aircraft at a Ramp-Area (we will call it BlueSupply for data confidentiality). At the airport, BlueSupply owns two cisterns capable of storing 200,000L of jet-fuel and a tank truck fleet with an overall store capacity of 240,000L. It is the company duty to restore the product in the cisterns ordering it from the referenced refinery according to the estimated demand on a daily base.
The following factors in particular make the complexity of the activities done by the company grow:

- Jet-fuel decantation;
- Bridger arrival rhythm;
- Quality standards;
- Customs controls;
- Distance of the ramp areas from the trucks stand by area;
- Strict deadlines.

2.1. Jet-fuel decantation

The handled fuel-oil product is called Jet A1, and it is a type of fuel-oil used in the aviation field. For its nature, it is crucial for safety and security reason that jet fuel is left still for a significant amount of time every time it is moved from any source to any destination. In particular, the referenced periods are of two kinds:

1. 2 hours after transferring jet fuel into the cisterns.
2. 10 minutes every time it is moved from or to the tank trucks.

It is not sufficient to have the right capacity of storing, but what is crucial is the right choice of the times when the operators replenish the trucks from the cisterns.

2.2. Bridger arrival rhythm

With the word bridger, we are referring to the truck that carries the product ordered from the refinery to the depot. In the scenario that is presented in the referenced depot, every bridger has a capacity of approximately 35,000L and the number of bridgers arriving every day varies accordingly to the estimated demand.
Given the decantation time durations, it is fundamental to choose the right cistern in which transfer the product brought, because if a correct choice is not taken, the situation where both cisterns are inaccessible might occur.

2.3. Quality standards

As well as for the decantation time periods and the correct management of the bridgers, a considerable amount of effort is spent in the activity of assuring high levels of quality of the jet-fuel. What must be verified in different parts of the supply chain is the respect of the following factors:

- Absence of water in the product;
- Absence of debris (clear and bright);
- Correct density;
- Correct electric conductibility;

The achieving of determined standards allows the company to assure the minimum possible risk in terms of accidentality inside the airport (episodes of combustion) and during the flights (episodes of water icing inside the aircraft tanks at high altitude). A lot of time is spent in the verification of this standards.

2.4. Customs controls

Given the position of the reference company's depot, which is outside the airport area used for the aircrafts handling and for the carrying out of the airplanes services (called "Air Side"), it is a strict obligation that of assuring high standards of security through the customs controls of everyone going into this area from outside. This results in generating lot of traffic in this area for high levels of demand.

2.5. Distance of the ramp areas from the trucks stand by area

As for the airport structural and procedural limitations, the refuelers are obliged to come back to stand by in an area far from the lay-bys waiting there for the request for refueling of an airplane captain. This limitation shrinks the overall throughput capacity given the fact that every operator spends an average time of 4 minutes every time he has to go from the standby area to the ramp area, and vice versa.

2.6. Strict deadlines

As it is widely known, flight departing times are a factor of extreme relevance for an airline company performance, and for this, it is not tolerated any delays due to the services activities. For this reason, not only the refueling operations must assure high standards of quality in terms of service and product, but they have to be made in the shortest possible amount of time and as soon as possible after the request of the captain.

3. CURRENT SCENARIO

In the airport we are referring to, it is not present only the company whom process we have analyzed, but there are two other companies (owning two other depots) that also perform the aircraft refueling activity.
The first two most important aspects characterizing the system that have been considered are the following:

1. The three existing companies do not share the clients but each one of them has a unique set of airline companies to serve. A client can anyway be refueled by another company in situations of emergency.
2. With the current resources at hand, company BlueSupply is not capable of meeting all the demands of its clients. For this reason, it gives in outsourcing a part of its set of clients to the other two company.

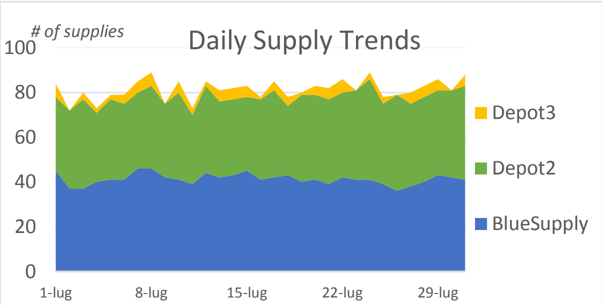

Figure 2: Daily Supplies Trend Distribution

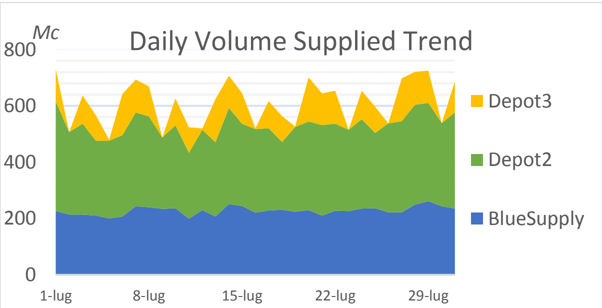

Figure 3: Daily Volume Supplied Trend Distribution

Figure 2 and Figure 3 show the number of supplies and the amount of jet-fuel refueled, respectively, day by day during a typical month. Figure 2 shows that BlueSupply (in blue in the chart) is capable of meeting only about half of the demand of its clients.

4. SIMULATION APPROACH

The proposed study wants to offer a tool capable of simulating the as-is process in a way that it can be used at a strategic level for evaluating how the system reacts to the change of exogenous and structural factors previously considered at a managerial stage.
For our scope, we utilized the discrete events simulation software Arena (Kelton, Sadowski, & Zupick, 2014) that, thanks to a user-friendly interface, permits also to non-expert users to interact with it and evaluate different scenarios. Moved by the above reasons, we have followed the following steps:

- Development and implementation of the simulation model for the as-is process and validation of it;
- Evaluation of the impact that changes in exogenous factors can bring to the performance;
- Evaluation of the impact that changes in structural factors can bring to the performance.

5. THE AS-IS MODEL

For the representation of the process and for having a better vision of the overall system simulation, we have split the whole process in six different areas that are linked together in the model. These are:

- Aircraft arrival and stand-by;
- Depot management;
- Customs controls;
- Tank trucks stand-by area;
- Truck choice decision process;
- Refueling process.

The process simulation has been made only on real data obtained by the reports written by the operators. The implemented model read the data from an external spreadsheet such as excel, access or any another compatible software, and reproduce the real system performance accordingly to these.

5.1. Aircraft arrival and stand-by

In this section (see Figure 4, Appendix A), it is represented the process of aircraft arrivals. We have represented in the simulation model what is of major interest for our purpose that is the arrivals of the refueling requests accordingly with the refueling report data written by the operators. The first part of this area is the one responsible for reading the above-mentioned data; in particular, each entity generated will read the specifications of each airplane that consists of:

- Flight identification number;
- Quantity of fuel requested (which will be communicated only upon arrival of the tank to the aircraft);
- Historically requested quantity of fuel;
- Landing time;
- Historical arrival time of the tank alongside the aircraft;
- Historical communication time of the quantity to be supplied;
- Expected departure time (checking that refueling does not cause delay);
- Scheduled refueling area.

After reading the data from the excel spreadsheet, it is simulated the phase of identification of the queues generate by the different arrival times. It is necessary to identify the part of flight plan that the operators analyze to operate accordingly to it. The reason behind this is to replicate how the operators estimate the time when a refueling request will arrive so to be in the best position possible and react to it as fast as possible.

5.2. Depot management

In this section of the model (see Figure 5, Appendix A), every action that takes place inside the depot is represented, so the following activities are simulated:

- Operators shift coordination, accordingly with the real work force existing;
- Tank trucks management, considering their stand-by and their load from the cisterns;
- Bridgers arrival coordination;
- Jet-fuel decantation.

As regards the management of the bridgers and the decantation of the fuel, a crucial activity is represented: it is that of the coordinator of the warehouse, responsible for deciding which tank to load and when, in order to ensure the possibility of having at least one of the tanks free (not in decantation) with enough product inside. Since the company lacks a written procedure for managing this task, it is entrusted to the depot supervisor experience the above-mentioned choice, and so does the model, approximating the real decisional process.

5.3. Customs controls

This section of the simulation model represents the process of customs control (see Figure 6, Appendix A) that occurs every time an operator goes into the apron coming from its outside. What is here important is the distinction of two recurring moments in the day, depending on the traffic that the operators find at the gates. It was in fact analyzed that in two specific time periods (on average from 8:00 AM to 9:00 AM, and from 1:00 PM to 2:00 PM) the congestion causes the average controls duration to rise from 2.5 minutes to 10 minutes.

5.4. Tank truck stand-by area

In this section (see Figure 7, Appendix B) it is represented the phase where the operators wait in standby the arrival of the communication of the permit of the refueling of an aircraft. It is due to the airport internal procedure that they have to wait in this area and that it is not allowed to wait near the ramp areas unless they wait only for a little amount of time, for example going from a previously refueled airplane to the next.

5.5. Truck choice decision process

This is the most crucial section of the simulation model, representing the decisional process undertook by the operators every time they finish an activity (see Figure 8, Appendix B). It is necessary for letting the simulated process be as flexible as the real one. It replicates the decision of the operators in choosing between approaching a ramp area in advance, going from the area of the last refueling activity to another one without passing for the stand-by area, or come back to the depot to load the tank trucks.

It is built accordingly to a survey made amongst the operators at the depot with which it was our intent to understand their behavior in approaching the process and in choosing to do an activity rather than another.

5.6. Refueling process

In this last section (see Figure 9, Appendix B) we represent the refueling activity in a ramp area. It is done when the flight captain has submitted the request, and accordingly to the quantity reported by the operators. For the truck’s pump output rate, it has been utilized the specification of the truck owned by the company to be close to reality as much as possible.

Once the refueling is done, the model reacts by writing a “report” (in excel format) of the flight refueled in order to:

1. Report if the flight has been refueled on time or if has been caused some delay;
2. Report data necessary to extrapolate the performance of the process and to validate the model.

5.7. Validation

Once the model was run, it was possible to compare the output simulation data with the existing output data of the real case, in order to validate the model. With this validation in mind, given the available data it was thought to use two KPIs (Key Performance Indicators) of the system, which are capable to identify the performance in two aspects: the timing of the supplies, referring to the essential punctuality of this activity in the airport environment, and resource occupancy, specifically the fraction of time the operators use to carry out operations and activities aimed at the refueling itself (such as nearby parking, reporting, and fuel transfer to the aircraft) over the total available time at their disposal. As we will see later, the core business of the company is not centered on the performance identifiable by these two indices but, for the purposes of comparison, they are particularly interesting as they allow us to assess the validity of the simulation in terms of approximation of behavior and decisions implemented.

These two KPIs were identified:

- Average of the gaps (delta) between the expected departure of a flight and the moment the aircraft is released (end of refueling).
- Total utilization rate.

5.7.1. Average of the gap between the expected departure of a flight and the refueling finish time.

Denoting with δ_i the gap between the expected departure of a flight (P_i) and the end of refueling for that same flight (FR_i), in which the subscript i identifies the i-th flight:

$$\delta_i = P_i - FR_i \tag{1}$$

The KPI can now be defined as the average between the δ_i of all the n served flights:

$$\Delta = \frac{1}{n}\sum_{i=1}^{n} \delta_i \tag{2}$$

5.7.2. Total utilization rate.

It is defined as the ratio between the total time spent for refueling operations and the total available time. This does not indicate how much each operator has been operating during the day, even operationally uninteresting, but rather how much time is spent on "useful" operations to the final objective; the lower it is, the more it indicates a poor management of the dynamics inside the warehouse (such as the timing of loading of tankers). Denoting with AR_i the starting time of refueling flight i, keeping in mind that each operator's turn sees him present for t minutes a day, and that there are 5 operators per day divided into as many shifts for 7 days a week, the total utilization level GU is equal to:

$$GU = \frac{\sum_{i=1}^{n}(FR_i - AR_i)}{t*5*7} \tag{3}$$

5.7.3. Results.

After the introduction of the two indicators we can see in Figure 10 how the results obtained from the simulation are extremely like the ones obtained by the real report, indicating the simulation as a good approximation of the reality.

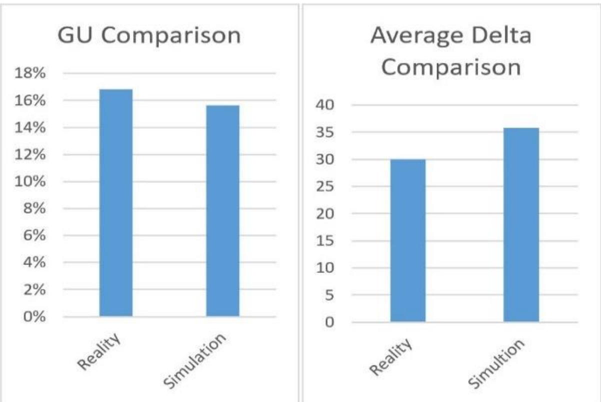

Figure 10: As-Is process simulation validation

6. TO-BE SCENARIOS ANALYSIS

The core scope of the proposed study is to generate a decision-making support tool capable of evaluating the impact of different changes in the system on the overall performance. For this reason, we have analyzed different possible changes in the operations and how they can change the performance; to evaluate this, we have simulated 4 different to-be scenarios and compared it with the indicators above-mentioned. These hypotheses include 2 changes in the structural factors such as:

- Doubling the flow rate of pumps for the loading of the cisterns;
- Possibility of loading two tank trucks at the same time.

The two other changes regard the demand and in particular:

- Customer resumption test;
- Capacity estimation based on the entire customer list.

As we can see from Figure 11, the overall performance is unchanged. It is because what we have changed is a non-critical factor in a way that an alteration of it does not affect the system capacity.

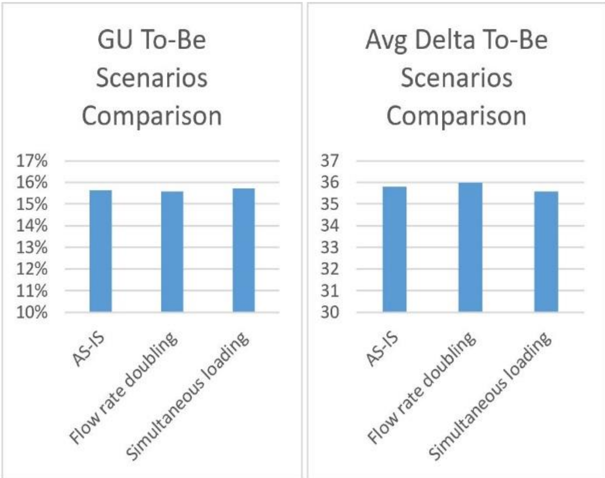

Figure 11: Structural To-Be scenarios analysis

Figure 12: New clients list scenario comparisons

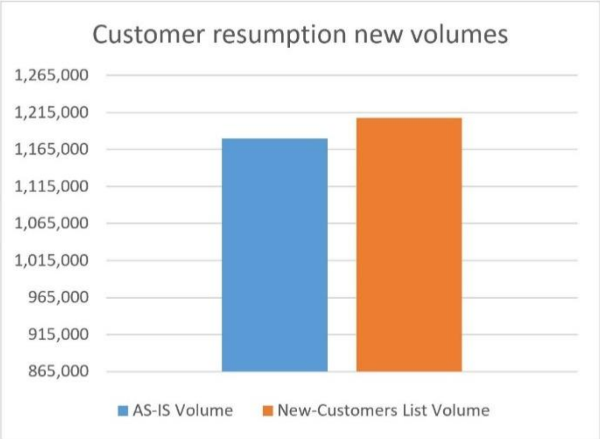

Figure 13: Customer resumption new volumes

As it is shown in Figure 12, also the customer resumption test leads to the same indicators. Despite this, what is more interesting is the fact that given the same indicators, the volume of the refueled product has increased without varying the resources (Figure 13).

7. CONCLUSIONS

The simulation model proposed is itself very complex, being constituted by a very large number of modules, representative of the activities of the process, and including the simulative representation of the behavioral rules used by the operators on field.

During its use, the structure of the model must be always kept in mind; in fact, it tries to approximate the real system with high flexibility miming all the behavior rules adopted by the operators. If it is not properly used, by narrowing operator’s behavior rules there is the risk of returning results and performance distant from reality. In the construction of the model, it was necessary to resort to the insertion of "rules" identified on the field by surveys, necessary to analyze the behavior of operators in extreme situations, non-frequent but possible. It was therefore natural to deepen their use in different scenarios, where it might be necessary to insert new behavioral rules or modify those already tested. By correctly implementing the rules acquired in the field, the simulation was particularly fast and efficient, allowing the analysis of various scenarios in a short time.

From the obtained results, we can conclude that the model can give excellent feedbacks and can be used as a decision-making support tool. By the last analysis we can highlight the possibility to increase the served demand carrying out an in-depth analysis on the own list of served airplane.

This last consideration focuses the attention on the two critical points of the model:

- the possibility of stiffening the process if not correctly approached;
- the lack of a database suitable for such an analysis.

Therefore, considering the results obtained, it is possible to follow two evolving paths:

1. The first concerns the continuous development and improvement of the proposed instrument, so as to enhance its characteristics as an excellent managerial tool that allows the rapid and efficient evaluation of strategic or tactical changes, providing the results that validate or refute the reasons of the proposed investments or changes in question.
2. The second one concerns the extension of this decision support tool towards an operational tool in which the model is no longer thought only as a strategic level tool, but rather as an operational verification tool and, in a more advanced phase, as a tool for optimization and preliminary allocation of resources.

Following this second path, we can evaluate the possibility of use it as an optimization tool. In fact, we can consider to use the simulation tool together with a scheduling model. In this scenario a scheduling model, analyzing the results previously obtained by the simulation, could be able to identify an optimal use of the available resources trying to improve what is be done.

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APPENDIX A)

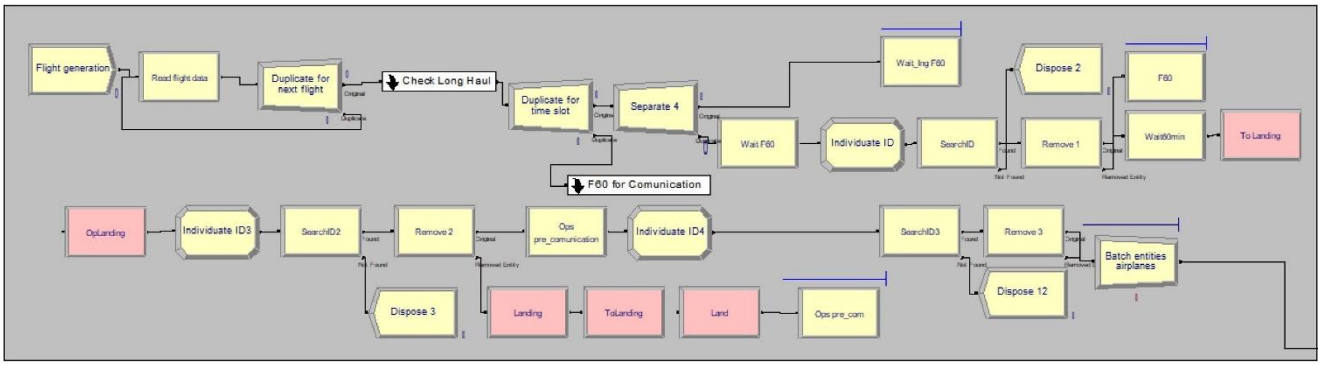

Figure 4: Airplanes arrival e stand-by

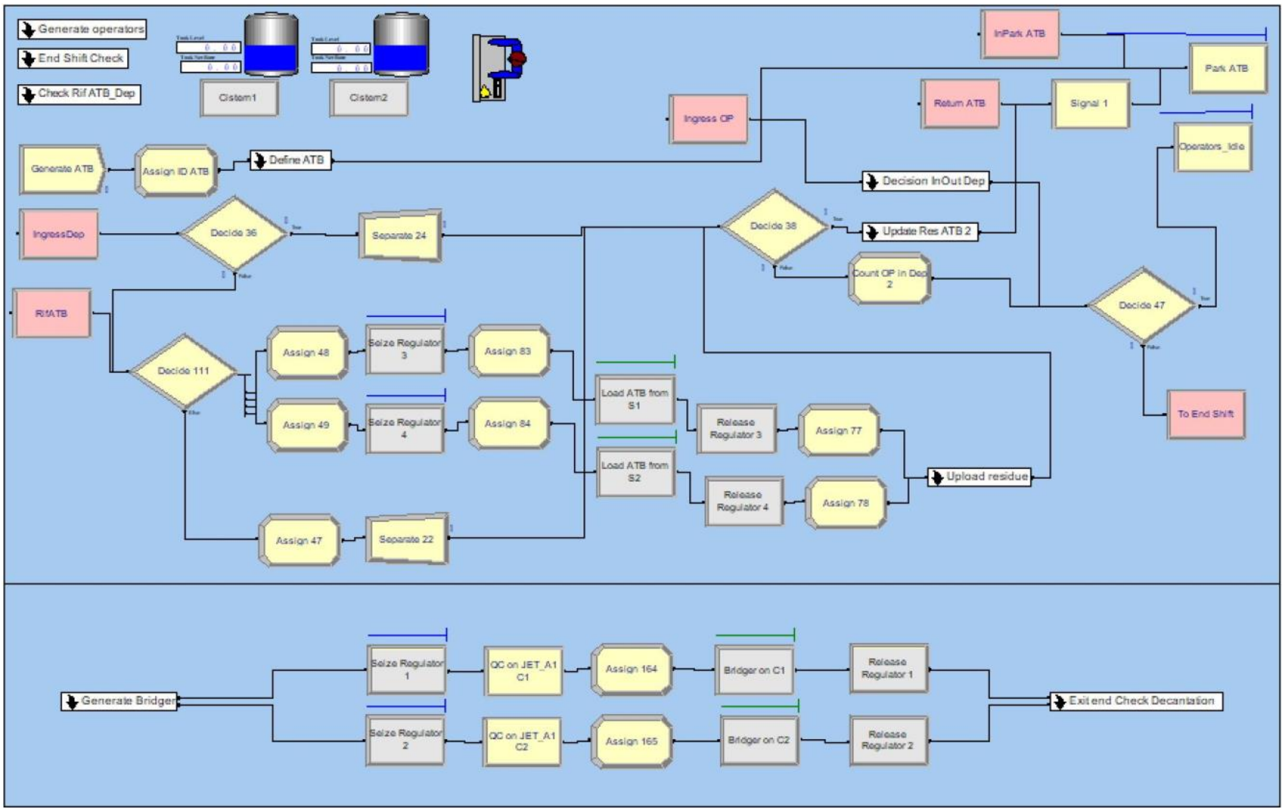

Figure 5: Depot management

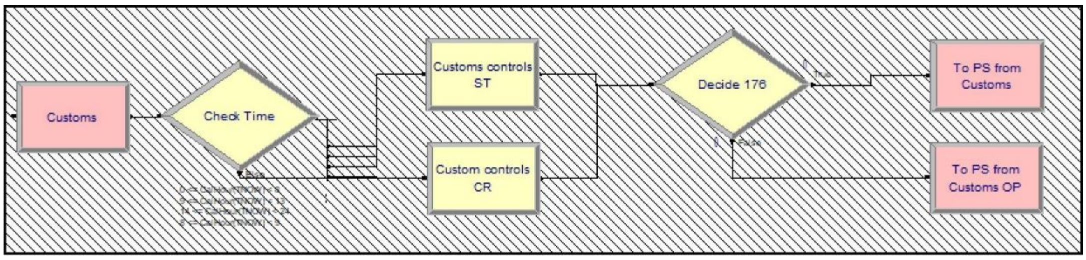

Figure 6: Customs controls

APPENDIX B)

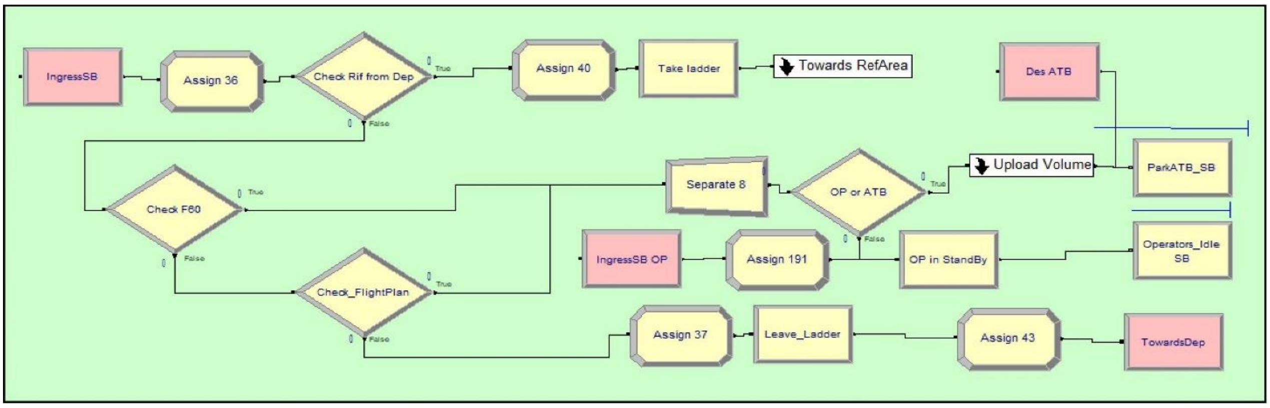

Figure 7: Tank truck stand-by area

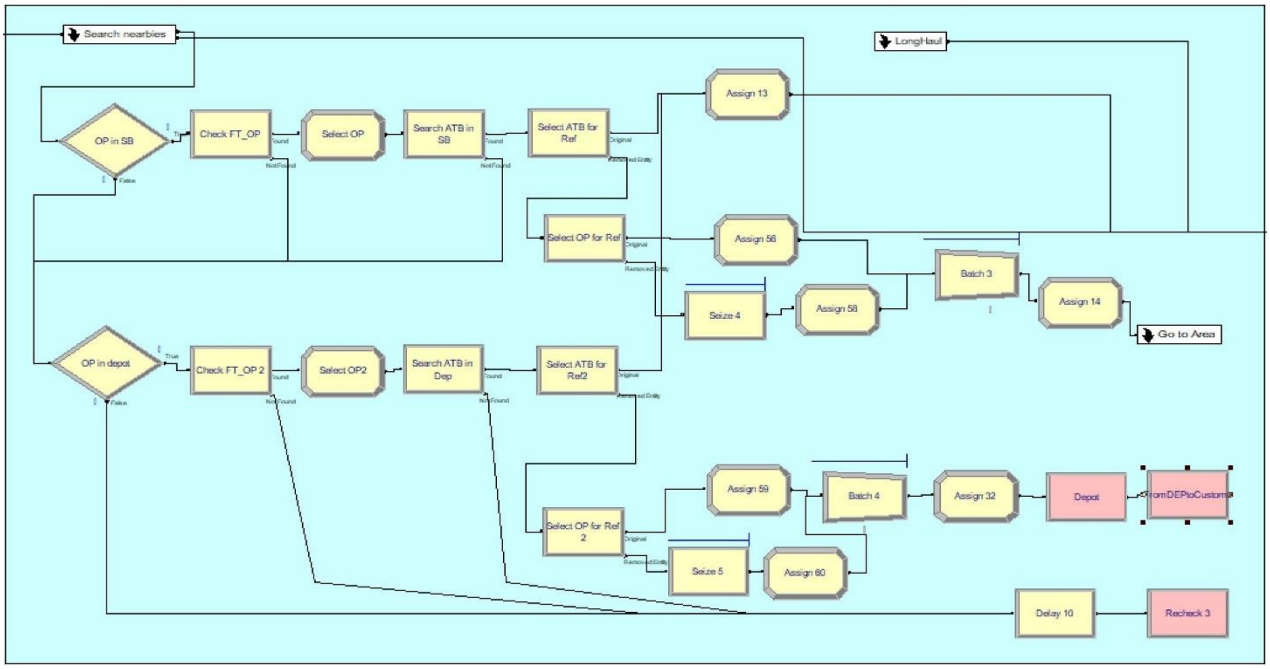

Figure 8: Truck choice decision process

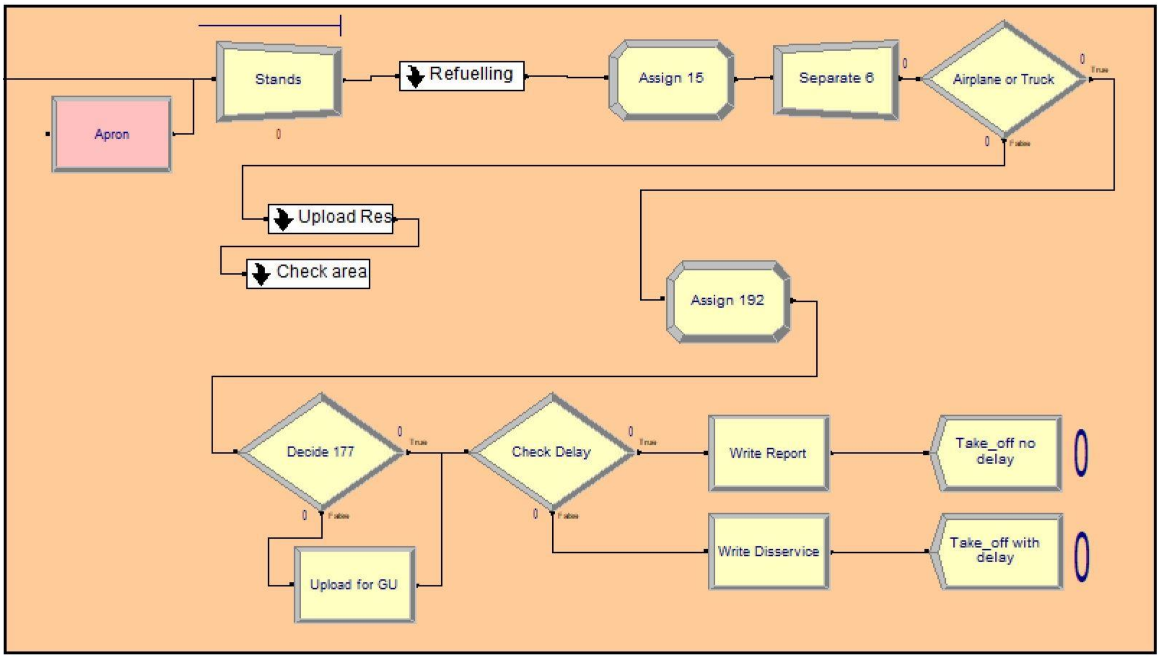

Figure 9: Refueling process

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