A Decision Support Tool for Internal Tankers Logistics in Chemical Industry

Presented by:

Ernesto J. Aponte Rodríguez

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Approved by:

Héctor J. Carlo, Ph.D. President, Graduate Committee	Date
Viviana I. Cesaní Vázquez, Ph.D. Member, Graduate Committee	Date
Agustín Rullán Toro, Ph.D. Member, Graduate Committee	Date
Rodolfo Romanach, Ph.D. Graduate Studies Representative	Date
Agustín Rullán Toro, Ph.D. Chairperson of the Department	Date

ABSTRACT

This study presents a decision support tool (DST) developed in Visual Basic for Applications (VBA) for managing the logistics of a Yard in the Chemical Industry with the objective to minimize operational costs. It describes the current operational challenges in a typical Chemical Industry's Yard and the development of the DST focusing on the optimization problems related to decisions previously identified. The DST takes in consideration tankers, chemical tanks, truck scheduling, among others. The solution from the proposed DST reduced the costs associated with the Internal Truck movements by 34% and Yard operator duties reduced in 60% with the use of a Linear Assignment Problem, decision making heuristics and the Analytical Hierarchy Process as part of the methodology. The proposed DST can also be used to estimate the number of Dam parking spaces required in the facility. The simplicity of the software (*i.e.* only requires Excel to collect and administer information) and the quality of the results prompted interest from our collaborator's management to implement the proposed DST.

RESUMEN

Este estudio presenta una Herramienta para Toma de Decisiones (HTD) desarrollada en VBA para el manejo de la logística en la industria de químicos con el objetivo de minimizar costos operacionales. El estudio describe los retos operacionales de la actualidad en el patio de la industria y el desarrollo de la herramienta enfocado en problemas de optimización relacionados a la toma de decisiones. La solución obtenida de la HTD reduce los costos asociados a los movimientos del camión por un 34%, tareas del operario del patio en un 60%, y tiene la capacidad de reportar la localización exacta y el estatus de cada tanquero mediante el uso del Problema de Asignación Lineal, Proceso Analítico Jerárquico y heurísticos para el manejo y toma de decisiones. La HTD propuesta también puede ser utilizada para estimar en número de estacionamientos en el dique necesarios en una compañía. La simplicidad del uso de la herramienta y la calidad de los resultados inspiraron interés de nuestros colaboradores en la facilidad para implementar la HTD propuesta.

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This work would not be completed without the contribution of many colleagues and friends. Among those I thank Professor Hector J. Carlo for giving me the opportunity of working together in this project and the guidance throughout it to contribute in the industry and making me a better all around person.

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1 INTRODUCTION

Abbott Pharmaceuticals Ltd., located in Barceloneta, Puerto Rico was established in 1971; currently employing more than 2,300 people directly. Their facility has approximately 277 acres of land that are divided in five facilities: biotechnology, diagnostics, chemical, vascular and pharmacy. As part of its infrastructure, Abbott has a facility for waste water treatment and the largest industrial energy co-generation installation in Puerto Rico. Some of products at the moment produced in Barceloneta are: Claritromicina, Kaletra, Humira, Depakote, Hytriny and Meridia.

Abbott is an ISO 9000 certified manufacturing facility. The ISO 9000 family of standards represents an international consensus on good quality management practices. It consists of standards and guidelines relating to quality management systems, related supporting standards, fundamentals and vocabulary, performance improvements, documentation, training, and financial and economic aspects. This project, while improving aspects of the supply chain, contributes in ISO 9000 standardization and documentation.

This study focuses on the chemical facility where Clarithromycin is manufactured, Clarithromycin is an antibiotic used to treat some infections. The manufacturing process of Clarithromycin requires raw material (solvents) that is transported in tankers like the one presented in Figure 1.

Figure 1: Tanker

Figure 1 show the typical 20 feet tanker managed in the facility. This tanker can be delivered to the facility empty for waste fill up, full with fresh material and full with recovered material (described later in detail).

Upon arrival to the facility, the supplier is inspected at the guard house, and upon guard approval of basic documentation and appearance, the supplier takes the tanker to a sampling point located at the warehouses area. When facility identification and sampling of the tanker and solvent is completed, an internal truck is requested to move the tanker with solvent to a parking space. From there, the tanker waits until manufacturing area requires it, and when that occurs, the internal truck is requested again to move the tanker to a *Tank Farm* where all tanks connected to the manufacturing process are located. A more detailed description of the process will be described later in Chapter 2.

Efficient management of the tankers throughout the process benefits the company through the elimination of payments by delay, reduction in costs by movement of tankers, and an efficient handling in future changes of finished product demand. The goal of this study is to create a decision making tool to assist Abbott in their tankers management. These tankers may contain solvents, waste, and may be empty for supplier pick up or empty for waste filling. As part of this project, an automated tool for decision making ("Decision Support Tool") for the process management was created with Visual Basic for Applications (VBA). The proposed tool was validated by experts in the system and by comparing results against historical data.

The remainder of this document is organized as follows. Section 1.1 presents the motivation for this study. Section 1.2 provides an overview of the existing literature related to the problem studied. Chapter 2 includes the chemical management process in section 2.1 and the Analytical Hierarchy Process presented to determine priorities for decision making. Chapter 3 includes the methodology which is composed by the description of events and decision management. The description of events, section 3.1, provides comparison between the tool capabilities against the actual system. Section

3.2 details decision making methods. Chapter 4 includes the experimentation results. Section 4.1 presents the assumptions made for experimentation and section 4.2 shows the study results. Chapter 5 contains the conclusions of the study in section 5.1 and a description of the future work in section 5.2. The project references are listed in chapter 6 and an Appendix follows with screen shots of the support tool in action.

1.1 Motivation

Currently, Yard logistics operational decisions are made by individuals from different departments. Warehouse personnel identify and take a sample of the chemicals in arriving tankers. These samples are then taken to a company laboratory. The Sampling Area communicates with the manufacturing department to notify of the arrival of a fresh tanker. The manufacturing department manages the tankers sequencing for production consumption of fresh tankers and waste disposal in empty tankers; this department also keeps inventory of the tankers in the facility. A third department is responsible for the internal trucks management and supplier notification. A reasonable amount of time is expended just in communications between departments for basic instruction processing.

One concern regarding the current Yard management system is that if demand increases, the delay penalties and moving costs will increase exponentially as the problem will become unmanageable. Hence, a decision support tool based on optimization of resources is very desirable. However, the decision support tool must be easy to use (so data can be updated), must consider data from tankers, consumption of chemicals, laboratory schedule, as well as internal trucks. Also, the tool should have very low upkeep cost.

1.1.1 Project Objective

The main objective of this project is the creation of a decision support tool that would aid managing in operational (*i.e.* day to day) decision making for tankers management. With this tool the facility should be able to minimize moving, operational, spill risks and penalty costs while keeping track of the current inventory with fewer personnel. The same inventory information would be available to different departments since the information can be passed from the support tool to a global network.

1.2 Literature Review

To our better understanding, the problem to study has not been studied in its totality by a single previous publication. Several authors have worked similar problems in different fields that essentially seek an efficient allocation of resources fulfilling space restrictions, among others.

1.2.1 Related publications to allocation of doors in consolidation facilities

In a cross-dock (consolidation/deconsolidation facility), trailers arrive with a load directed to different destinies. In this facility, loads are consolidated into trailers loaded with material destined to the same city. Basically, at these facilities trucks arrive with a load, they are sent to a door to be unloaded and the material is moved in lift trucks to the trailers directed to the destiny of the load. Some publications related to the allocation of door to trailers in consolidation facilities (cross-docks) include; Gue (1999), Bartholdi and Gue (2000), Bozer and Carlo (2008) and Miao *et al.* (2009). At these facilities of consolidation, trailers that need to be directed to loading doors (empty trailers) or unloading doors (fully or partially full trailers) arrive. If these doors are not available at the arrival of a trailer, the trailer is sent to the Yard similar to what happens in the Yard management in Chemical Industries. The analogy is that an arriving tanker will be directed to the corresponding tank if the tank is available. Otherwise, the tanker is sent to the Yard. The problem concerning this work is different to a facility of consolidation in the following characteristics:

- In the consolidation facility, when there are no doors available, trailers are sent to Yard without additional restrictions. In this work, the tankers can be taken to two parking facilities: one prepared for tankers (Dam) where the possibility of blockage exists or the Yard that works is a similar way to the case of doors allocation. In this project it is priority to locate all the tankers in the Dam; this creates difficulty in the allocation of tankers. The problem in study also has to consider the time when the laboratory releases the sample result. Until this result is not submitted and confirmed to be within company's standards, manufacturing department cannot use this tanker. This is another complication that the consolidation facility does not have.

- In the Chemical Industry tankers typically have a grace period (given by the supplier) to keep the tankers in the facility. Exceeding this period involves costs related to delays and the movements that have to be made inside facility also have a cost per movement. In a cross-dock all (or most) of the trailers are served during the night.
- In the consolidation facility, the space available for temporary parking of the trailers is generally high or with enough space to handle the entire inventory. In the case in study, the parking space prepared for spills has limited spaces considering the actual inventory. A Yard is available for temporary parking, but the company wants to minimize its usage.
- In the case in study, tests of quality to the material being carried in full tankers are made before depositing it content in a holding tank. In the consolidation facility, as soon as there is a door available a trailer can be placed there without sampling or additional work to the load being carried.
- In the consolidation facility the trailers are selected to doors based on the location of the doors and the destination of the loads. In the Chemical Industry trailers are moved to minimize cost.

Among the studies of consolidation facilities, Yu (2008) simulates the arrival of inbound trailers in order to determine the best door-to-destination assignment for outbound loads. The author proposes an online algorithm to emulate the daily decision making done by the supervisor of a facility. This is analogous to assigning tankers (empty or full) to tanks (for solvent or waste) or to a parking. The author proposes the algorithm to make the following decisions:

I. Where to direct each trailer that arrives at the terminal

II. The selection of a trailer parked in the temporary parking to move to a door once it becomes available.

For the first decision, Yu classifies the different trailers that can be received in four classes. (1) Empty trailers to be loaded, (2) full trailers to be transported to another site (these go directly to the parking), (3) partially full to be filled and (4) of any other type to be completely emptied. Classes (1) and (3) are assigned according to the availability of the doors. If there are doors available, trailers are assigned to the doors; otherwise they go to the parking. For class (4) the time to unload the trailer is estimated for each unloading door that can be available and the trailer is assigned to the door where the calculated time is the minimum. If no unloading is available, the trailer is sent to the parking.

The second decision works directly with class (4). It is assigned to available unloading doors the trailers with smaller unloading time. It is assumed that trailers to be partially or fully loaded located in the parking are assigned to the loading doors as they become available. The next step is the preparation of the complete algorithm operating according to the occurrence of the events. The events are:

A. A trailer arrives at the terminal
B. An unloading door becomes available
C. A loading door becomes available

Yu (2008) constructed an online algorithm similar to what was made for the assignment of tankers in this project. Online heuristics were incorporated for various decisions and events to a tool automated for the decision making (“Decision Support Tool”). This tool was created to determine how, where and when to move the tankers in the facility.

1.2.2 Publications related to gate assignment in airports

Several authors like Bolat (2000), Yan *et al*. (2001), and Lim *et al*. (2005) have studied the problem of assigning flights to gates in airports. The problem of flights assignment to gates has the particularity that the flight schedules are known in advance; this includes (estimated) arrival and departures time of flights managed in one day. Therefore, a preliminary gate assignment is constructed. Unfortunately, the real time of arrival of the flights depends on the time of departure, of the traffic in the departure airport, of the flight conditions and the traffic in the arrival airport.

Airport gate assignment is similar to our problem as airplanes arrive and if the desired location is not available, planes must be parked temporarily until a gate is available. The main difference between the airport gate assignment problem and our problem is that planes could be assigned to a variety of gates as the chemical tanker assignment problem has a particular location in which it needs to unload. In general, planes are not expected to wait more than a few minutes. Also, the nature of the airport gate assignment problem is typically multi-objective since it aims to reduce the distance that passengers walk and the distance for luggage handling.

2 THEORETICAL BACKGROUND

2.1 Material Management at a Pharmaceutical Environment

For the manufacture of its products, the chemical facility in Abbott receives raw material in trailers and tankers. In addition, the company generates chemical wastes during the production. These wastes are also managed in tankers. The tankers used for waste drainage can be tankers that previously carried certain solvents (preferred case) and are parked empty inside the Yard. Another option is to use clean tankers that arrive empty for this purpose; these tankers inquire in additional rental costs.

This project focuses on the decisions pertinent to tankers management. Although there are decisions to be taken for trailers management, the priority at the moment is the handling of tankers since it represents 90% of the costs by delay or movement related the supply of raw material.

Tankers management can generate the following costs to the facility: (1) costs for delays and (2) costs per move. Costs details are described below:

1. Tankers are brought to the facility by different suppliers carrying raw materials or empty for waste drainage. When the supplier brings a tanker with raw material or solvent a grace period is given to the company to keep the tanker in the facility without informing the supplier for pick up. The company pays a fine that increases daily when the content of a tanker has not been unloaded in the grace period or in a case when it has been unloaded, but the supplier has not been notified for to pick up the empty tanker.
2. Each tanker carrying raw material requires at least three separate movements once they are inside the facility. These are: (a) from the sampling point to a parking space, (b) from the parking to the Tank Farm for unloading, and (c) from the Tank Farm to outside of the facility once they are emptied. Tankers that carry certain solvents can also be used for waste draining once they are empty. These tankers and the ones that arrived empty for waste draining require two

movements: (1) from the parking to a Waste Tank and (2) from the Waste Tank to a parking space. All these movements have to be made with an internal truck; a service provided by an external source that charges for each movement.

The facility has two available locations for tankers storage: a *Dam* and a *Yard*. It is preferable to have the tankers parked all the time at the Dam since it is prepared for spills. If a chemical spill takes place in the Yard, the facility is prepared with a water entrapment system in compliance with environmental health and safety standards that would eventually hold the spill, but the Dam is specially designed to hold tankers and better prepared for chemical spills. Spills are contained under the Dam and retrieved easily compared with possible spills that can occur in the Yard.

In Abbott, the current Dam has twenty two (22) available spaces. The same number of tankers could be fitted in the parking if all tankers are twenty feet in length; capacity varies since some suppliers also deliver raw material in forty feet tankers, thus less tankers can be fitted in the Dam due to its layout. Refer to Figure 2 for Dam layout.

Tankers Parking Grid

Back	1	2	3	4	5	6	7	8	9	10	11	12
Front		13	14	15	16	17	18	19	20	21	22	

Figure 2: Dam

Figure 2 shows the layout of the Dam. Back spaces run from space 1 to space 12 and Front spaces run from 13 to 22. All spaces are twenty feet deep. Hence, storing a forty feet tanker will use one back and the corresponding front positions (*e.g.* 2 and 13).

Currently, delay fines are being paid by the company to the suppliers since it is not complying with the grace period of fourteen days to have the tankers inside the facility not ready for pick up. In the first eight months of the past year the company had paid more than $300,000 in surcharges to suppliers. It is also known that at times the company is paying the internal truck service for unnecessary moves that could be eliminated with proper sequence, scheduling and planning.

2.1.1 Process

A supplier truck arrives in the facility to deliver a tanker carrying raw material or empty for waste management. The supplier first stop is at the guardhouse for a basic driver and truck inspection of documentation and appearance; material carried manifest is also inspected in case of raw material delivery. After complying with the basic inspection, tankers with raw material are taken to a Sampling Area and empty tankers are taken to a parking space. After that, the supplier leaves the facility and does not return until informed that the tanker is ready for pick up.

The tanker carrying raw material at the Sampling Area is identified for inside the facility tracking purposes and a sample of the content is taken and sent to the laboratory personnel for testing. The Sampling Area personnel notifies manufacturing area of the tanker that has just arrived, shares the acquired information; the tanker is ready to be moved to a parking space. Manufacturing personnel contacts the traffic area to request a tanker movement to a given parking space in the Dam or in the Yard. A flowchart of the just described procedure is shown in Figure 3.

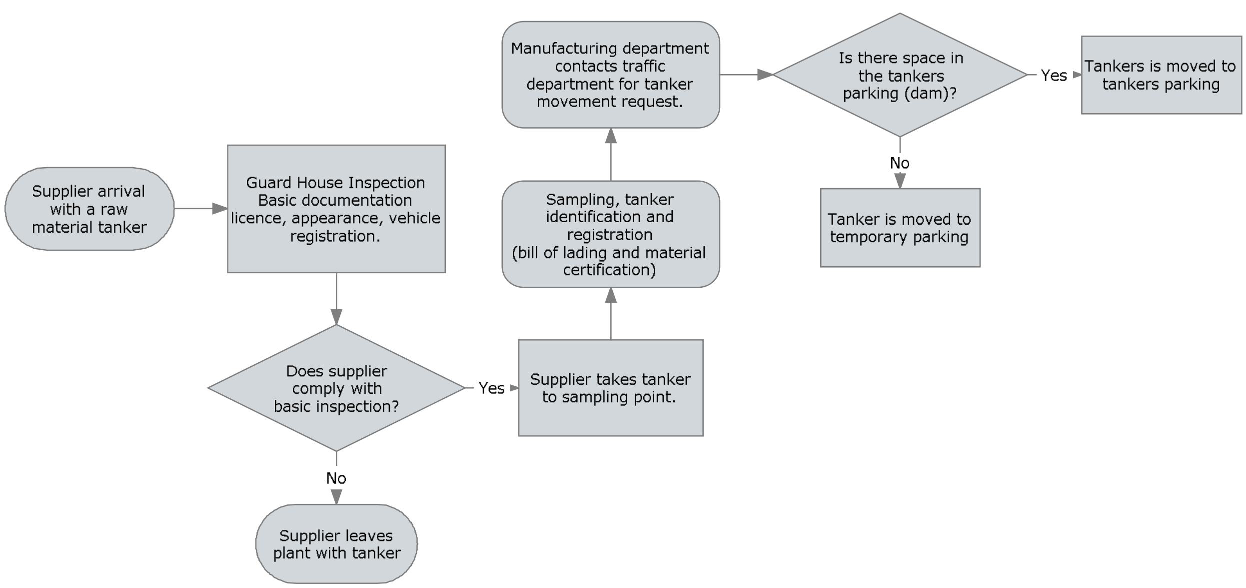

Figure 3: Tanker management from supply to parking space

Figure 3 presents a flowchart of a tanker carrying raw material that has just arrived to the facility, carried by a supplier until the tanker is sent to be parked in a parking space. The solvent carried in this tanker has been ordered by the planning department with anticipation. It is known that the laboratory testing can take up to three days to verify the quality of the solvent, thus the tanker is not expected to be used until at least three days. When suppliers do not meet basic inspection in the guardhouse, they are told to leave the facility. One example of this can be the case where a supplier comes to the facility without the shipment manifest.

The manufacturing area has storage tanks for the different solvents and when the level of one tank goes below 50% of its capacity or the content of one tanker can be deposited in the tank. At this point, the manufacturing area personnel search the facility to move a tanker with the required solvent to the specific tank.

When a tanker is selected, it is checked to see if its laboratory results are completed and with the proper quality. If that is the case, the manufacturing area personnel contacts traffic area to request the tanker movement. The internal truck moves the selected tanker from a parking space to the Tank Farm. A flowchart of the just described procedure is shown below in Figure 4.

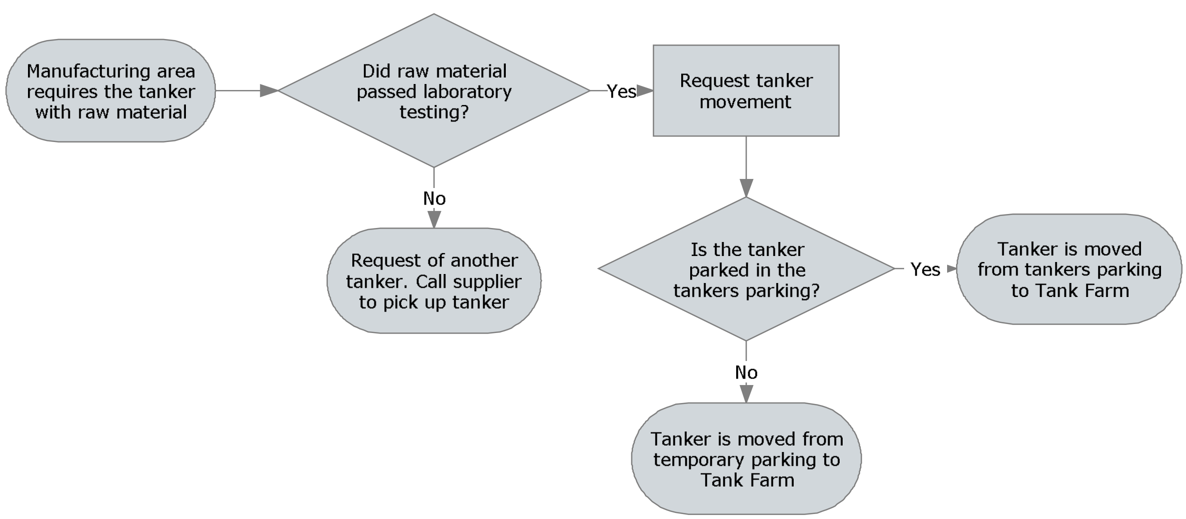

Figure 4: Tanker management from parking space to manufacturing area

Figure 4 illustrates the holding tank tanker requirement procedure in a flowchart. When the level of a holding tank in the Tank Farm reaches an established low where the content of one tanker can be deposited in the tank, the manufacturing facility searches its inventory for a tanker that contains the solvent required in this holding tank. At this stage, the recently arrived tanker is located in a parking space. When the manufacturing area determines that this tanker is required for fill up, the area personnel verifies if the raw material has passed the laboratory testing. After the laboratory approves the solvent, the internal truck is contacted for tanker movement. The internal truck then checks the location of the tanker and moves it from the parking space to the Tank Farm.

Before emptying the contents of the tanker in the Tank Farm storage tank, a routine test is made to the solvent in the tanker. If the results are accepted the tanker content is emptied in the holding tank at the Tank Farm. When this process is completed, it is required to move the empty tanker from the area to a parking space. The manufacturing area personnel contact the traffic area, the request is made and later the empty tanker is moved to a parking space. A flowchart of this process is presented below in Figure 5.

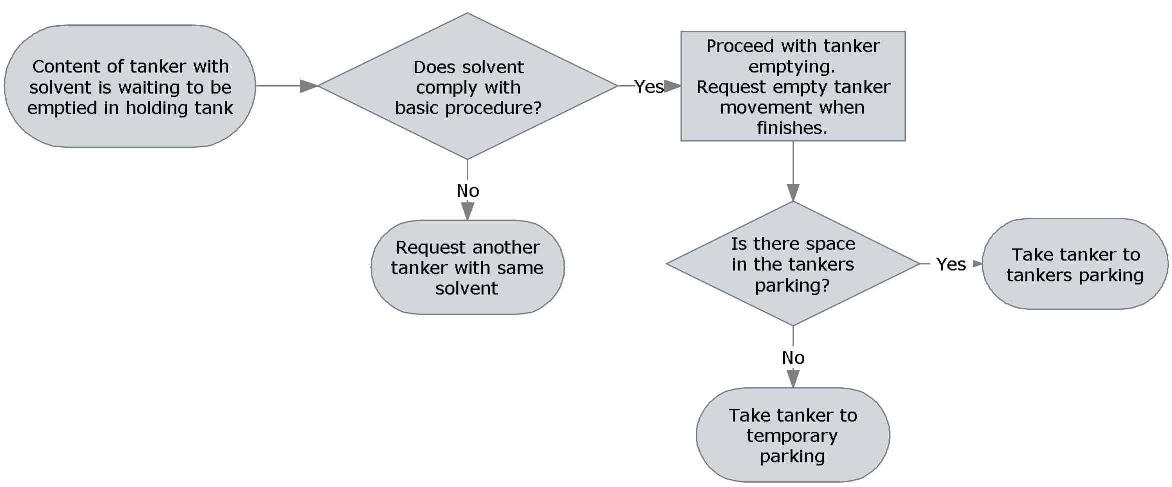

Figure 5: Tanker management from manufacturing area to parking space

Figure 5 shows the management of the tanker with solvent from a position where it is waiting at the Tank Farm area so that it content can be deposited in a holding tank to when it is deposited and the empty tanker is required to be moved to a parking space. If a solvent does not pass the routine test the solvent is rejected and another tanker carrying the same solvent is requested in the area. This rarely occurs but has to be considered.

The empty tanker is ready for supplier pick up when the tanker is not used for waste management. Tankers with certain solvents can be reused when empty to carry waste from Waste Tanks to a recycling facility outside the facility. The empty tanker with solvent residues is classified between ready for pick up or to be used for waste management. When it is classified for pick up, the supplier is notified and the period of stay is stopped, thus the company is not responsible for the days the tanker remains in the facility after notification.

Tankers that can be used for waste management are parked until they are requested for waste drainage. When this occurs, the empty tanker is moved from the parking space to a waste holding tank at the Waste Tanks area. Refer to flowchart in Figure 6 below to see process in detail.

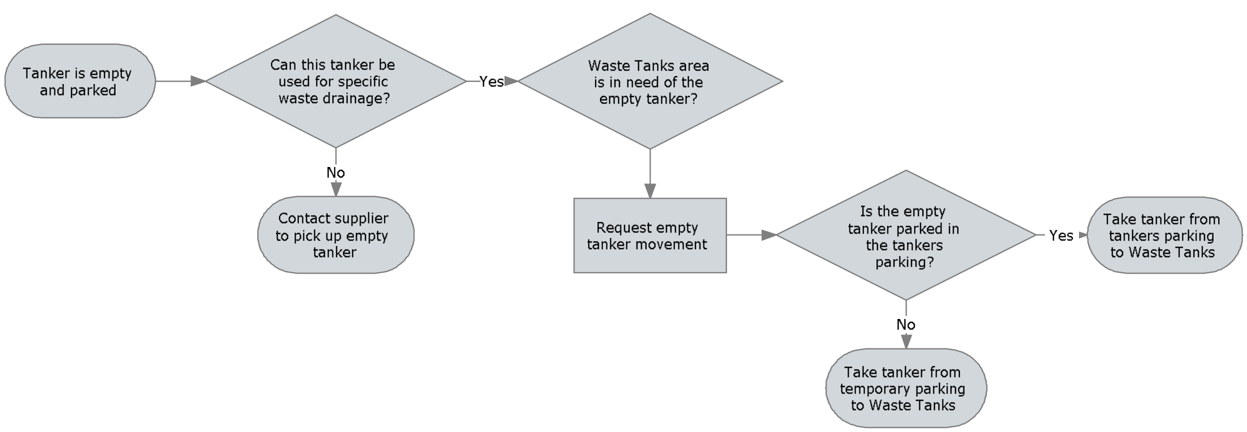

Figure 6: Empty tanker management from parking to Waste Tank

Figure 6 shows the procedure for empty tanker management. A tanker can be classified in ready for supplier pick up or to be used for waste drainage. When it is classified for waste drainage the tanker stays in the parking space until required in a Waste Tank, when this occurs the internal truck is notified to make the movement.

Once the tanker is placed next to the Waste Tank for drainage it waits until it is filled with waste; once filled it is ready to be shipped to the recycling facility. When the tanker is completely filled with waste, traffic area is contacted to request tanker movement to parking space. Refer to Figure 7 where this procedure is presented.

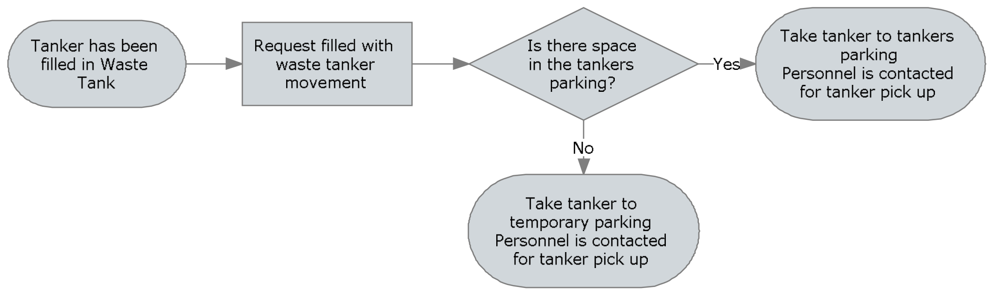

Figure 7: Filled with Waste Tanker management

Figure 7 shows that when the tanker has been filled with waste in Waste Tanks area, the tanker is requested to be moved to a parking space to later be picked up and taken to the recycling facility. This last procedure for recycling is not in the project scope.

2.1.2 Facility Layout

The Tank Farm, Waste Tanks, Sampling Area, Dam and Yard space are all located in Abbott´s south facility. Refer to Figure 8 below for a layout of the facility in study.

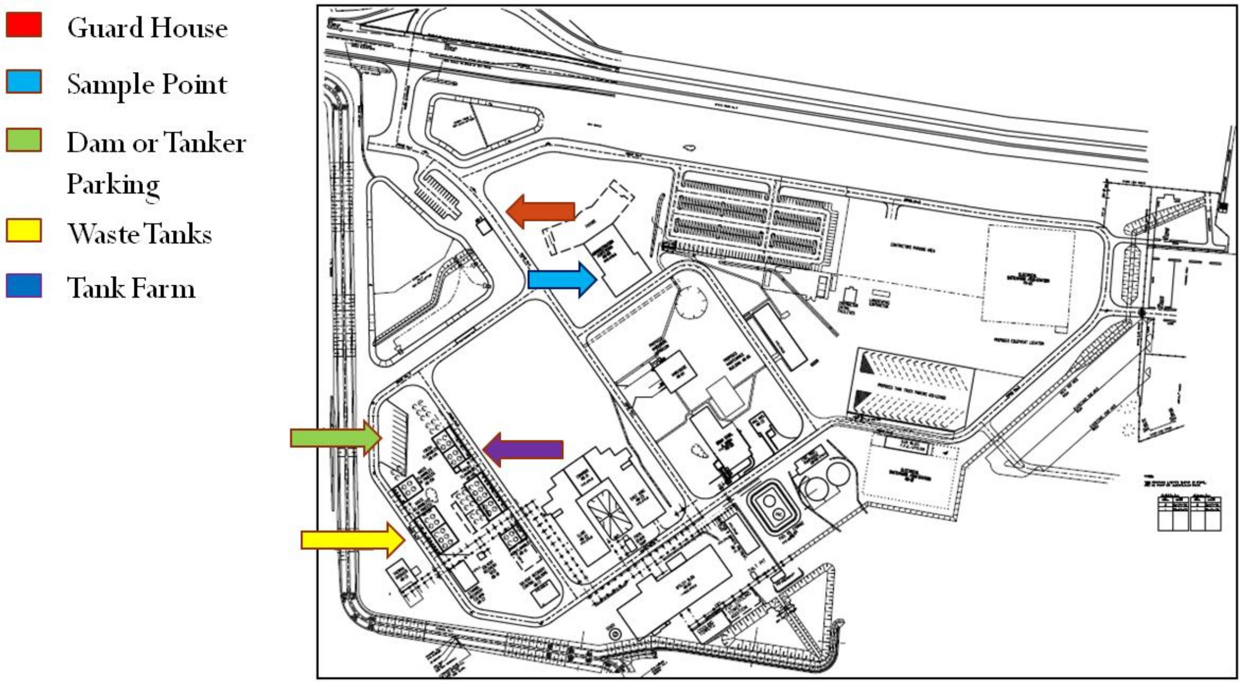

Figure 8: Facility Layout

Figure 8 is a site plan of the pharmaceutical environment of our industrial collaborators. The boxed red area represents the entrance to the site; this is where supplier enters and stops at the guardhouse. The blue circled marked area represents the sampling point where supplier takes tanker upon passing basic inspection. Green space is the retention lake where a spill that occurs outside the Dam would ultimately reach, and the remaining areas of interest are described in Figure 9.

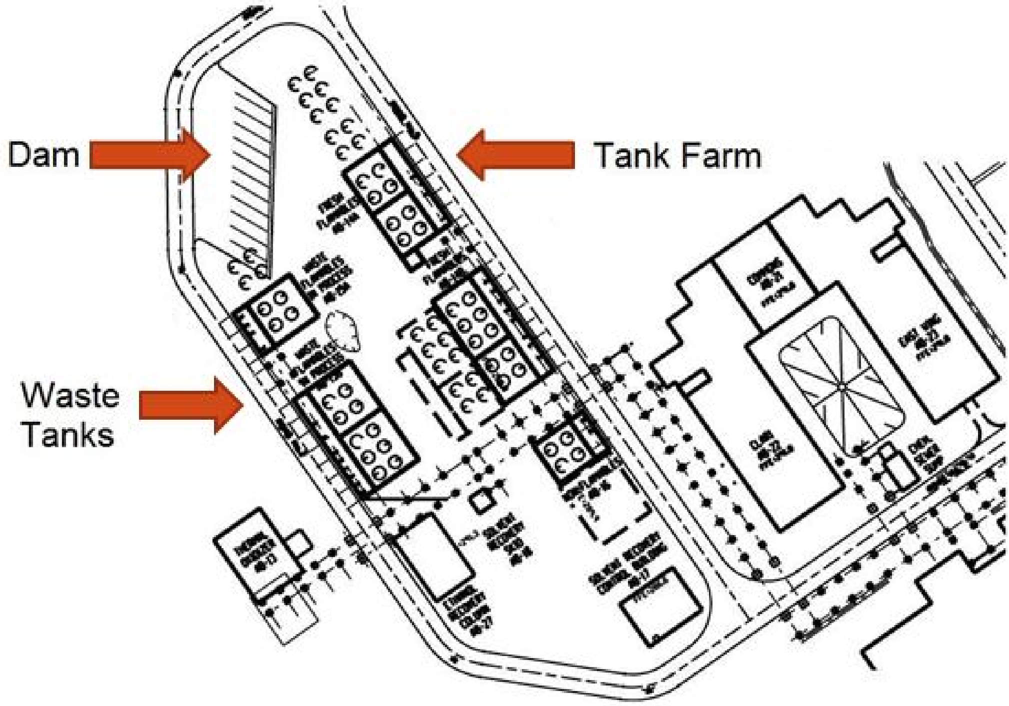

Figure 9: Area of Interest Close-Up

Figure 9 zooms on the Dam, Waste Tanks, holding tanks at Tank Farm and where manufacturing operations are located. A frontal view of the Dam is shown below in Figure 10.

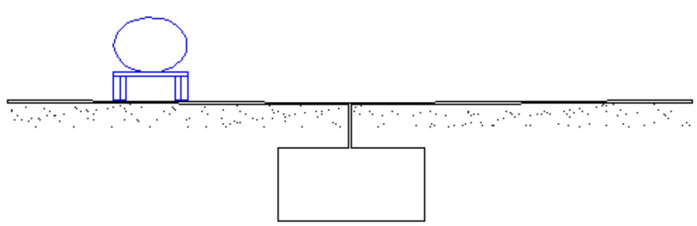

Figure 10: Dam Container

Figure 10 presents the container were chemicals would be contained in the case of a spill that occurs in the Dam.

3 DECISION AND EVENT MANAGEMENT WITH SUPPORT TOOL

3.1 Event Description and Management

This Chapter intends to describe the tankers management process from a decision making standpoint. This is made by classifying the tanker management process in mutually exclusive and exhaustive events for the proposed decision support tool.

The processes related to internal tankers logistics in our industrial collaborator's can be classified into the following ten (10) events.

(1) Arrival of a tanker with raw material (solvent). If the carrier and the truck pass the basic inspection, the carrier takes the tanker to a Sampling Area, otherwise it is returned to the supplier.

(2) Arrival of an empty tanker for waste pick up. If supplier passes basic paperwork inspection, the supplier takes the tanker to the Waste Tanks or to a parking space.

(3) Tanker with solvent at Sampling Area is ready to be moved to a parking space. Internal truck picks up this tanker and moves it to an assigned space.

(4) A tanker with a specific solvent is required at a holding tank in the Tank Farm since the tank's volume level has reached a point where the content of one tanker can be deposited in the holding tank.

(5) The volume of a holding tank has reached its critical level. A tanker with a specific solvent is required with urgency.

(6) An empty tanker is required at a Waste Tank in the Waste Tanks Area since its volume level has reached a point where one empty tanker can be filled with waste.

(7) The volume of a Waste Tank has reached its critical level. An empty tanker with is required with urgency.

(8) A tanker has been filled with waste at the Waste Tanks Area and needs to be moved to a parking space. This tanker is later picked up by an external truck to be moved to a recycling facility.

(9) The content of a tanker with solvent has been deposited in a holding tank at the Tank Farm. The now empty tanker needs to be moved to a parking space.

(10) A supplier or a contractor enters the facility to pick up an empty tanker or one full with waste.

Most of the events are combined with optimization procedures to determine parking spaces and tanker selection. These procedures are identified as decisions in the tool. They are classified in the following six (6) decisions:

- Decision 1: Selection of a parking space in the Dam or in the Yard where a tanker currently positioned in the Sampling Area is selected to be relocated. This decision is also called when a supplier enters the facility carrying an empty tanker and it has been sent to a parking space.
- Decision 2: Selection of a tanker with a specific solvent located in a parking space to then be moved to a Tank Farm holding tank.
- Decision 3: Selection of an empty tanker among dedicated empty tankers for waste management
- Decision 4: Selection of a parking space in the Dam or in the Yard where a tanker currently positioned in the Tank Farm needs to be relocated.
- Decision 5: Selection of a parking space in the Dam or in the Yard where a tanker currently positioned in the Waste Tanks area needs to be relocated
- Decision 6: Choosing from a list the next movement to be made with the internal truck.

Table 1 presents the relationship between the ten events and the six decisions in the decision support tool. There are events that require an optimization decision procedure; these decisions are presented in the second column and described in the third column.

Table 1: Events and Decision Match

Event	Decision	Decision Methodology
1		
2	1	Select Waste Tank or parking space
3	1, 6	Select parking location and schedule IT
4	2, 6	Select full tanker and schedule IT
5		
6	3, 6	Select empty tanker and schedule IT
7		
8	5, 6	Select full tanker and schedule IT
9	4, 6	Select empty tanker and schedule IT
10		

A detailed description of each listed event is presented below.

Event 1 (Arrival of a tanker with raw material (solvent). If the carrier and the truck pass the basic inspection, the carrier takes the tanker to a Sampling Area, otherwise it is returned to the supplier)

The support tool provides an interface with two (2) buttons to handle the management of incoming tankers with raw material (event 1) and empty tankers (event 2); one to handle each event.

When the supplier arrives at the gate with a tanker carrying solvent, the button assigned to event 1 is clicked in the interface and forces the guard to complete a basic inspection of the truck, the documentation of the content in the tanker and the supplier. The guard proceeds with the inspection and provides a feedback to the interface depending on the inspection result. If the basic inspection is satisfactory, the tool requests four things from the inspection: the identification of the solvent being carried, if the solvent is fresh or recovered (tankers that arrive with recovered solvent are rented thus do not pay penalty charges), the identification of the tanker, and the length of the tanker. After this data is registered in the tool, the interface shows a message indicating to send the carrier with the tanker to the Sampling Area.

If the carrier does not comply with the basic inspection, the proposed tool will indicate the guard to ask the supplier to leave the facility. It is company's policy for the supplier to comply with basic inspection.

The current system works in a similar way at this part of the process. The difference lies that in the current process, after basic inspection approval, the guard sends the supplier to the Sampling Area without acquiring data from the tanker. This is later performed by the Sampling Area in the current process. In addition, Sampling Area assigns a lot number for the solvent being carried in this specific tanker.

Observations regarding Event 1:

It is suggested to provide all the required identification and description of the arrived tanker at this part of the procedure to speed up the overall processing time. Waiting for the Sampling Area to gather this information requires extra effort to process the information. With the support tool having identified the tanker information as soon as it enters the guardhouse, it reduces processing time and eliminates current practice of tanker identification and tanker track keeping at the Sampling Area. Although is suggested that the Sampling Area confirms the solvent identified in the guardhouse; the area will be able to see the information in the network computer.

Event 2 (Arrival of an empty tanker for waste pick up. If supplier passes basic inspection, the supplier takes the tanker to the Waste Tanks or to a parking space)

When the supplier arrives at the gate with an empty tanker, the assigned button in the interface is clicked and requires completing a basic inspection of the truck, the documentation of the tanker and the carrier.

The tool inquires *"Did carrier passed basic inspection?"* If the answer is affirmative the tool shows a user form to enter the tanker Identification, the waste that can be managed in the arrived tanker, and the tanker length. After this information is processed, the tool checks if the Waste Tank where this tanker will be taken at some point requires an empty tanker. If that is the case and no tanker in inventory has been assigned for this purpose, the tool shows a message indicating the supplier to take the empty tanker to the Waste Tank location; otherwise, it calls Decision 1 to decide what parking space can be assigned to the recently arrived tanker. When the procedure in the optimization procedure assigns a parking space, a message indicates the operator to send the tanker to a specific parking space.

If the supplier does not comply with the basic inspection, the tool indicates the guard to ask the supplier to leave the facility.

The current system requires the guard to contact the traffic department for empty arrival notification, tanker identification and to provide the future position of the tanker. When the information is gathered by the guard, the supplier is sent to parking position as indicated by the traffic department. In common practice, the supplier checks the Dam for an open space that does not blocks another tanker. If this condition is met, the tanker is parked there; otherwise, the tanker is taken to the Yard.

Observations regarding of Event 2:

With this event, the support tool gathers a lot of information that is not managed in the current system. This eliminates the need of a second department to provide identification of the tanker, thus speeding the process. It also verifies the inventory in the facility and calling Decision 1 in the code, it selects a parking space for the tanker based on a heuristic process that will be presented in the following section that works with all the process for the ultimate goal of cost and penalty minimization. There is a possibility that the Waste Tank assigned for the arrived empty tanker is available when the supplier arrives. The tool checks the inventory for the applicable empty tankers and if there are no tankers available, the just arrived tanker can be sent directly to the Waste Tank. Given the complexity and current department separation, knowing the current system status and the Waste Tank level rarely occurs in the current management system.

Event 3 (Tanker with solvent at Sampling Area is ready to be moved to a parking space. Internal truck picks up this tanker and moves it to an assigned space.)

As soon as the Sampling Area personnel have finished the sample extraction of a tanker, they should call the traffic department, who has control of the support tool, so they can contact the internal truck for tanker movement. This is made after the traffic area operator clicks the Event 3 button in the interface so that the tool selects where to park the tanker.

The code works with the same Decision 1 mentioned in the previous event and assigns the proper parking space. The tool sends this movement request to a list that has been identified as Decision 6 and later described; when the just being processed movement request is selected to the first position by the tool, it shows a message to the operator and he/she contacts the internal truck operator to make this movement from the Sampling Area to a parking space.

The current system requires the Sampling Area to after sample extraction, identify the tanker, keep track of it in the department board and enter the information in a computer system to share the information with all departments. When this is concluded, they contact the manufacturing department who later contact the traffic department to move the tanker from the Sampling Area to a parking space.

Observations Regarding of Event 3:

This is the part of the process that currently consumes the most resources. In an effort to improve the process, the manufacturing and traffic departments have merged resources to keep track of the facility inventory. The source checks the inventory daily and updates the information as required. So far they have been successful with this process with the exception of the tanker assignment. Nevertheless, they have reduced the costs significantly by always assigning the tankers to the Yard when every back side space in the Dam is occupied. Blockage does not occur keeping the parking utilization low and risking the facility to spills outside the prepared Dam. The process has been handled this way due to the fact that time is not usually available to plan for each necessary movement and location implication for the case of the Dam. Abbott has also permanently rented several of tankers to avoid penalties but a cost associated with their rent is added to their operating costs.

The decision support tool keeps track of all the process, thus sending the tanker to the best available position which is not necessarily the Yard. Having everything in the Yard is not desirable since it represents more traffic, reduces facility space significantly and puts the facility in a position where if a spill occurs, containing it would require added costs to the process. Also, the Dam is significantly closer to the Tank Farms so it is desirable to use the Dam to minimize the internal trucks' travel distance. Although the facility is prepared for this type of spillage, it is easier and much inexpensive to handle it if takes place in the Dam which is prepared with a collection pan under it.

The decision support tool also removes the manufacturing department from the management loop. The information would be available for them electronically, but it is the tool that selects a space and notifies the traffic operator when to make the movement with the traffic operator assistant.

Event 4 (A tanker with a specific solvent is required at a holding tank in the Tank Farm since the tank's volume level has reached a point where the content of one tanker can be deposited in the holding tank.)

The decision support tool requires having the holding tanks inventory level information and changes available in real time. When the level of a holding tank reaches a level where filling is required, the tool recognizes the need, identifies the solvent required, and searches in the current inventory for a tanker. If there is only one tanker carrying this solvent, the event itself sends the request to the movements list of Decision 6. If there are no tankers with this solvent, a message is provided to the traffic operator, and if there is more than one tanker available to choose from, Decision 2 is called in the code which selects the tanker that represents the less management cost for all available tankers carrying this solvent at the time and sends the movement request to Decision 6. This procedure is presented in the following section. When the movement request is selected by Decision 6, it notifies the traffic operator and he/she contacts the internal truck operator to make the movement.

In the current system the manufacturing personnel constantly checks the holding tanks levels in a PLC interface to maintain the levels as required by the process. When the level reaches an established low, they contact the traffic department so that they contact the internal truck operator to require a tanker. The manufacturing department notifies the traffic department which tanker to move based on the required solvent and the time the tankers have been in the facility (in the case of more than one tanker available). Traffic confirms the selection and contacts the internal truck operator.

Observations regarding of Event 4:

The decision support tool selects the tanker that represents the minimum cost considering moving and penalty costs of all available tankers in the facility by solving an optimization problem (details regarding Decision 2 is presented in Section 3.2). Hence, the solution from the tool presents an advantage over the current system that does not have a tool or the time to consider various sequences and future implications. Also, as described above, the decision support tool eliminates the manufacturing area from the decision making loop, although they can still contact the traffic area in the case of a critical event that we intend to handle with the support tool in Event 5.

Event 5 (The volume of a holding tank has reached its critical level. A tanker with a specific solvent is required with urgency)

In the list of requests of movements in Decision 6 the requests are handled by prioritization with the Analytical Hierarchy Process (more details in Section 3.2, Decision 6). In this decision, the highest priority is given to a tanker that has been requested to be moved from a parking space to a holding tank in the Tank Farm. However, there might be cases where multiple requests have the same priority (requests from the same event 4, but for different solvents). For these cases, the tool has an event to handle critical levels in the Tank Farm. When the level of a holding tank reaches an established critical low, the tool recognizes the change and changes the priority of that request in the list for movements to the maximum, forcing Decision 6 to move this request in top of its list. This way a critical event is handled as soon as the internal truck becomes available.

The current system operates in a similar way when events like this take place. The manufacturing department contacts the traffic area for immediate attention and the internal truck handles the request.

Observations regarding Event 5:

Event 5 provides the facility with an automatic action that handles urgent holding tank refilling in the Tank Farm; a tool currently not available in the current management. This event guarantees that a holding tank can never reach an empty status without being noticed when the tanker containing the needed solvent is in the inventory.

Event 6 (An empty tanker is required at a Waste Tank in the Waste Tanks Area since its volume level has reached a point where one empty tanker can be filled with waste.)

When the level of a Waste Tank reaches a level where draining is possible, the tool detects the need and searches in the inventory for applicable empty tankers. If there is only one empty tanker in the facility, the event itself sends the request to the movements list of Decision 6. If there are no empty tankers available, a message is provided to the traffic operator, and if there is more than one empty tanker available to choose from, Decision 3 is called in the code which selects the empty tanker that represents the less management cost and sends the movement request to Decision 6. When the movement request is selected by Decision 6, it notifies the traffic operator and he/she contacts the internal truck operator to make the movement.

In the current system the manufacturing personnel sees the level of the Waste Tank in the PLC interface and when the level reaches the point where the volume can be drained in an empty tanker, they contact the traffic department so that they contact the internal truck operator. The manufacturing department indicates the traffic department which tanker to move based on the time the tankers have been in the facility (in the case of more than one tanker available). Traffic confirms the selection and contacts the internal truck operator. As this event is not always critical or with the most priority, in the case where there is no empty tanker for drainage, the operator checks for future availability from soon to be empty tankers or empty tankers that may arrive to the facility.

Observations regarding Event 6:

With the same purpose of event 4, the PLC shall be linked to the decision support tool for these events. The support tool selects the tanker that represents the minimum cost considering moving costs of all applicable empty tankers in the facility by using the Linear Assignment Problem; an advantage over the current system that does not have a tool or the time to consider various sequences and future implications.

Event 7 (The volume of a Waste Tank has reached its critical level. An empty tanker with is required with urgency)

This event works in the same principle of event 5 with the difference that the priority incremental in the list for movements in Decision 6 is less than the one assigned in event 5. Although the priority value incremental for this event is less than for event 5, it is higher than all other possible requests apart from the one of event 5.

Event 7 was programmed considering the suggestions made by the manufacturing area personnel since they operate with the same priority.

Observations regarding Event 7:

This event maintains the Waste Tanks from reaching a maximum level. The support tool handles the case without human intervention and maintaining a balance in the Waste Tanks as the manufacturing personnel aim to do.

Event 8 (A tanker has been filled with waste at the Waste Tanks Area and needs to be moved to a parking space. This tanker is later picked up by an external truck to be moved to a recycling facility.)

When a tanker has been filled completely with waste at the Waste Tanks area, the operator performing the drainage notifies the manufacturing area personnel. They later contact the traffic area decision support tool operator. The tool has a button in the interface at the traffic area that calls event 8 to look for a parking space for a just filled with Waste Tanker in the Waste Tanks area. The tool assigns a parking space calling Decision 5 in the code and lists the request for movement in Decision 6. When the movement request is selected by Decision 6, it notifies the traffic operator and he/she contacts the internal truck operator to make the movement.

In the current system these tankers are always sent to the Dam when it is available; the Dam is almost reserved for this type of tankers since they are quickly shipped from there to a destiny outside the facility.

Observations regarding Event 8:

It is a reality that the decision support tool operator could see when the level of a Waste Tank decreases - meaning that drainage to an empty tanker is being made - thus estimating an expected time and eliminating the manufacturing department from making the contact. This is something to consider in the future; adding lines to the code to consider this and send a message to the operator for the request. As it is currently programmed, it works like the manual process with the addition of the heuristic that searches for the best parking position considering minimizing costs; the manual system will be later studied against the results of the support tool in the following chapter.

Event 9 (The content of a tanker with solvent has been deposited in a holding tank at the Tank Farm. The now empty tanker needs to be moved to a parking space.)

When the contents of a tanker with solvent have been completely emptied in a holding tank of the Tank Farm, the operator performing the tank filling notifies the manufacturing area personnel. They later contact the traffic area support tool operator and he/she clicks the button in the interface that calls event 9 to look for a parking space for a just emptied tanker located in the Tank Farm. The tool assigns a parking space calling Decision 4 in the code, lists the request for movement in Decision 6 and when the movement request is selected by Decision 6, it notifies the traffic operator and he/she contacts the internal truck operator to make the movement.

In the current system these tankers are separated in two groups: the empty tankers that are shipped out of the facility and the tankers that are reused for waste management; this grouping is made by the traffic area personnel. In addition to the contacts, the traffic area team makes the grouping and notifies the supplier to pick up applicable empty tankers.

Observations regarding Event 9:

This event works almost as event 8. The main difference apart from the decision it calls is that the support tool makes the grouping that is currently being made manually (Decision 4) and tells the tool operator to contact the supplier when a tanker requires it; this reduces the processing time.

Event 10: (A supplier or a contractor enters the facility to pick up an empty tanker or one full with waste.)

When a supplier or contractor arrives at the gate to pick up an empty tanker or a tanker full with waste, the button assigned to event 10 is clicked in the interface. This indicates the guard to complete a basic inspection of the truck and the supplier.

The guard proceeds with the inspection and provides a feedback to the interface depending on the inspection result. If the basic inspection is satisfactory, the tool requests two (2) things in a user form: the selection of the tanker from a list and the selection of two possible options: empty or full with Waste Tanker pick up. After this data is registered in the tool, the interface locates the selected tanker and shows a message indicating to send the supplier to the exact location of the tanker. The tool also updates the tanker information; it enters the date the tanker leaved the facility and changes the location of the tanker to 'out of the facility'.

If the supplier does not comply with the basic inspection, the tool indicates the guard to ask the supplier to leave the facility.

In the current system, upon guard approval, the truck driver enters the facility and searches for the tanker to pick up. It is not recorded with tanker leave the facility. This information has to be inferred when the traffic employee makes the Yard inspection the next day and does not find the tanker.

Observations regarding Event 10:

The decision support tool provides the facility with a tool for management of suppliers and contractors for tanker pick up that they currently do not have. The current practice is unnecessary with this tool and the information helps the supplier or contractor to find their tankers in less time.

3.2 Decision Management and Support Tool

<u>**Decision 1:**</u> Selection of a parking space in the Dam or in the Yard where a tanker currently positioned in the Sampling Area is selected to be relocated. This decision is also called when a supplier enters the facility carrying an empty tanker and it has been sent to a parking space.

This decision takes place when sampling and identification of a tanker has been concluded in the Sampling Area or when a supplier enters the facility carrying an empty tanker and it has been sent to a parking space. It is always preferred to store tankers in the Dam, thus the procedure for this solution begins there. This decision manages two sub decisions, (1) where to park tanker in Dam given there is availability there and (2) where to park it in the Yard when Dam is unavailable. The procedure begins by checking the availability of the Dam. The solution intends the tanker storage with conditional blocking to facilitate cost oriented decisions.

Table 2: Arrived tanker estimated time of usage (ETU)

Tanker ID	Tankers with this solvent in inventory	Constant for this solvent (hours)	ETU (hours)
A-003	2	48	144

Table 2 shows an example of the ETU determination for an arriving tanker. As the tanker enters the facility, an ETU value is calculated for it as the consumption rate of each solvent was determined. The tool counts the available tankers in inventory with this arrived solvent and it multiplies the total tankers with the same solvent after current arrival to the constant value for that solvent to determine the ETU. The constant value for each solvent was determined by studying graphs of consumption for one month in the manufacturing facility. A flowchart of this process is presented in Figure 9 below.

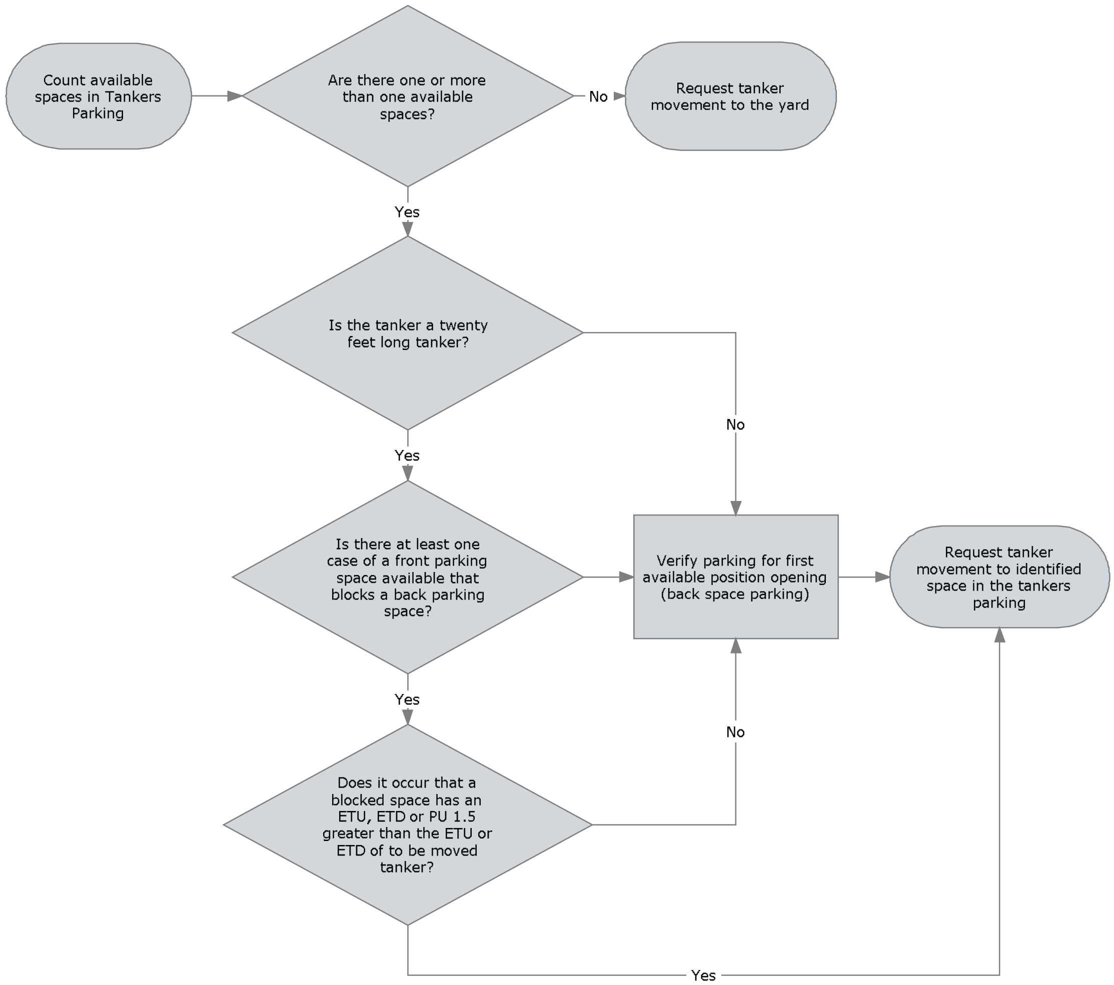

Figure 11: Decision 1 Flowchart

Figure 11 shows a flowchart of Decision 1. The first action in this decision is checking how many spaces are available in the Dam. If there are no spaces available, the tanker is requested to be moved to the Yard; otherwise, the parking is checked to see if there are positions where the front side of a position in the parking is unoccupied but the back side space is occupied (partially occupied positions). If there are no partially occupied positions available or the tanker being managed is twenty feet long, the tanker is requested to be moved to the first available back side position. If partially blocked positions are available and the tanker is twenty feet long, the tanker parked in the back side space is verified to see if they have an ETU, ETD or PU 1.5 times greater than the ETU or ETD of the tanker in need to be moved. This value of 1.5 is an arbitrary value consulted and accepted by the company to promote the selection of previously arrived tankers. As this value is made equal or closer to one (1), the probability of double moves in the Dam increases. This value could be further studied and easily changed in the VBA code as necessary, during DST simulation it was changed from 2 to 1.5 and the results were acceptable without making double moves with the internal truck while reducing current movement costs.

If previous condition does not take place, the fully empty positions are checked for availability. If a position in the parking complies with heuristic methodology, the position in the parking is identified and a request is made to move the tanker to the Dam, otherwise, the tanker is sent to the Yard.

Decision 2: Selection of a tanker with a specific solvent located in a parking space to then be moved to a Tank Farm holding tank.

The manufacturing process at this facility requires through different chemical processes a set of raw materials which we refer to solvents in this report. These solvents are stored in a Tank Farm in the facility connected to the manufacturing area and consumed at different rates daily as required per production lots. When these tanks reach an established minimum level where the contents of one tanker can be deposited in the tank, refilling of the tank is requested.

The solvents for refilling are carried in tankers parked in the Dam or the Yard inside the facility. As more than one tanker may be available in the facility for refilling, this optimization decision manages which tanker is selected to be moved to the Tank Farm. The solution intends to make the selection of the tanker that represents the lowest cost for all tankers in inventory with a Linear Assignment Problem (LAP). The LAP selects between m number of tankers assigned to a m number of sequences. The Hungarian Method is programmed in VBA to select the tanker that represents the least cost in the next sequence. Although the Hungarian Method is not the most efficient algorithm to solve the LAP, it works nicely for small values of m such as the one observed in reality.

There are two costs considered in this study, moving costs (internal truck charge per move) and penalty costs (which are amounts to be paid if a tanker exceeds the grace period given by the suppliers). This solution seeks to simultaneously minimize both costs.

For this solution the grace period is considered and named: Days Until Penalty (DUP) for programming purposes. Entering the facility the tankers will have a DUP value equivalent to the grace period given by the supplier for fresh tankers and a value of 1000 for recovered tankers that will decrease as days pass and the tanker remains in the facility. Recovered solvent is a recycled material carried in tankers that do not pay penalty. These tankers are rented tankers and the cost of rent is not considered in this project as the company will continue using them regardless of their decision to implement or not the proposed decision support tool. With all this mentioned, this is what the support tool considers:

Table 3: Solvent Inventory in Tank Farm

Solvent	A tanker is expected in: (hours)	Constant value of solvent requirement (hours)
1		120
2		72
3		72
4		336
5		72
6		288
7		48
8		72

Table 3 is an example of how the support tool tabulates expected hours until the next tanker for a given solvent will be required at the Tank Farm. The expected time of a tanker requirement is used in the code in a linear assignment problem to consider different scenarios of costs (Table 5). Table 3 keeps track for the next required tanker and a second column of constant requirement dependant of the weekly production for all solvents. As the consumption graphs of all solvents were studied for one month, an expected value was assigned to each solvent. The linear assignment problem, described later, works with this information and the one presented below.

Table 4: Movement cost for each tanker (example)

Tanker ID	Solvent	DUP	Current pick up Cost ($)
ABC-111	1	2	40
ABC-112	1	12	120
ABC-113	1	9	120
ABC-114	1	1	40

Table 4 shows a case for the tracking of each tanker carrying a required solvent, the days until penalty remaining, and its associated cost of pick up with the internal truck. This last piece of information depends on where the tanker is parked and positioned. If the tanker is at the Yard or in the front side of the Dam, where only one movement will be required, the cost for this movement is for example 40 dollars. The same cost applies to a tanker in the back position not being blocked. If the tanker is at the back of the Dam and blocked by another tanker the cost of this movement is three times the first movement (temporarily relocate the blocking tanker, retrieve the tanker desired, accommodate the blocking trailer back in position). Nevertheless this value is notably larger than the first; scenarios might suggest selecting a tanker in this position if the combined cost of penalty and movement results in a minimum cost when all cases are studied with the LAP. The selected tanker is not always the one that has the longest period of time in the facility. Although it makes sense to think that this tanker would have the greater cost in the future, there are situations that suggest the selection of a tanker with fewer days in the facility. For example, say two tankers with the same content are located in the Dam. The tanker with longer period in the facility is blocked by another tanker and the one with fewer days in the facility is not. This implicates that the one with older period will be charged 120 by the internal truck and the other would cost 40; this is just considering pickup cost. If both tankers, considering the expected times of usage known from production, would not have demurrage costs, since DUP for both tankers is greater than expected times of usage, the tanker selected by the DST would be the not blocked with fewer days in the facility tanker. This methodology is not used by current management due to lack of information.

Table 5: Linear Assignment Problem example

Solvent 1 Tank cost assignment					
		Tanker requirement sequence			
Tanker		1	2	3	4
1	ABC-111	*40	120	170	230
2	ABC-112	120	120	40	*40
3	ABC-113	120	120	*40	90
4	ABC-114	40	*40	90	140
Best sequence: 1-4-3-2			Total Cost: 160		

As mentioned above, Table 5 requires the information of Tables 3 and 4 to consider all applicable costs to the sequences. This assignment guarantees the selection of a tanker with minimum cost studying all possible sequences. This problem is solved in detail in Appendix B.

Let:

i be an index for the tankers (i=1,..,m)

j be an index for the positions (i.e. orders) (j=1,..,n)

C_{ij} be the cost associated with assigning tanker i to position j;

X_{ij} be an indicator variable to denote that tanker i is assigned to position j;

Linear Assignment Problem [10]

Min $\quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}$ (Minimize the total cost of all assignments)

$$\sum_{j=1}^{n} X_{ij} = 1 \quad , \quad (i = 1, 2, ..., m)$$

$$\sum_{i=1}^{m} X_{ij} = 1 \quad , \quad (j = 1, 2, ..., n)$$

$$X_{ij} \in \{0 , 1\}$$

The LAP provides the order in which the selected tankers containing the required solvent or the empty tankers for a required waste must be sequenced to minimize the applicable costs. The m tankers are assigned for the n positions (*i.e.* order) and the tanker selected for the first period in the final solution is the one picked for movement. The first constraint forces each tanker to be assigned to exactly one order. The second constraint forces exactly one tanker to be assigned to each order. Figure 12 shows a flowchart of Decision 2

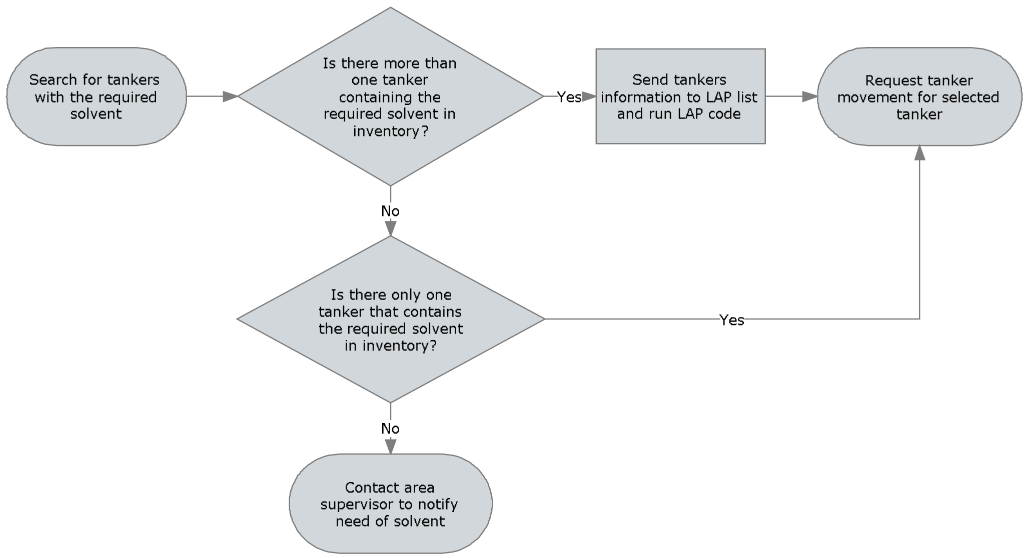

Figure 12: Decision 2 Flowchart

The first action in this decision is checking the available inventory in the facility for tankers with the required solvent in the Tank Farm. If there is more than one tanker carrying the required solvent in inventory, the required tankers information is copied to the pre-coded *Linear Assignment Problem* (LAP) list. The LAP is started and the selected tanker by the code is requested for movement. If there is only one tanker carrying the required solvent, the movement is required for this tanker. If there are no tankers in inventory containing the required solvent, a message is shown in the support tool to notify the need of the solvent.

Decision 3: Selection of an empty tanker among dedicated empty tankers for waste management

Chemical wastes are generated during the manufacturing process. These wastes are stored in five (5) Waste Tanks connected to the manufacturing process. When one of these tanks reach an established level where the volume of one tanker can be completely filled; draining of the Waste Tank is required.

The wastes are drained in empty tankers parked in the Dam or in the Yard. As more than one tanker may be available in the facility for this process, this optimization decision manages which tanker is selected to be moved to the Waste Tanks. The tanker selected will be the first in the sequence resulting from the LAP.

There is only one cost considered in this decision, the moving cost (internal truck charge per move). Penalty costs are not considered in this decision since tankers for waste management are rented thus with unlimited time for usage. This solution intends to minimize the moving costs in tanker selection.

The next set of tables and information is what the support tool considers:

Table 6: Waste Tanks tanker requirements

Waste Tank	A tanker is expected in: (hours)	Waste Tank requirement per Tank (hours)
1		48
2		48
3		48
4		168
5		144

Table 6 of the support tool tabulates expected hours until the next empty tanker for a given waste will be required at the Waste Tank. The expected time of a tanker requirement is used in the code in a LAP to consider different scenarios of costs (Table 8). Table 6 keeps track for the next required tanker and a second column of constant requirement dependant of the weekly production. As the waste generation graphs for all Waste Tanks were studied for one month, an expected value was assigned to each Waste Tank. The LAP, described later, works with this information and the one presented below.

Table 7: Movement cost for each tanker

Tanker ID	Waste	Current pick up Cost ($)
W2-111	2	40
W2-112	2	120
W2-113	2	120
W2-114	2	40

Table 7 shows the tracking example of each empty tanker dedicated for waste 2 (W2) with its current associated cost of pick up with the internal truck. This last piece of information depends on where the tanker is parked and positioned. If the tanker is at the Yard or in the front side of the Dam, where only one movement will be required, the cost for this movement is 40 dollars and if the tanker is at the back of the Dam the cost of this movement is three times the first movement. Nevertheless this value is notably larger than the first; scenarios might suggest selecting a tanker in this position if the cost is smaller than one with high penalty cost implications. Refer to the LAP in Table 8 which provide the final solution to this decision.

Table 8: Linear Assignment Problem example

<table>
<tr><td colspan="6">Waste Tank 1 cost assignment</td></tr>
<tr><td colspan="2"></td><td colspan="4">Tanker requirement sequence</td></tr>
<tr><td colspan="2">Tanker</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>1</td><td>W2-111</td><td>*40</td><td>40</td><td>40</td><td>40</td></tr>
<tr><td>2</td><td>W2-112</td><td>120</td><td>120</td><td>*40</td><td>40</td></tr>
<tr><td>3</td><td>W2-113</td><td>120</td><td>120</td><td>40</td><td>*40</td></tr>
<tr><td>4</td><td>W2-114</td><td>40</td><td>*40</td><td>40</td><td>40</td></tr>
<tr><td colspan="3">Best sequence: 1-2-3-4</td><td colspan="3">Total Cost: 160</td></tr>
</table>

As mentioned above, Table 8 requires the information of Tables 6 and 7 to consider all applicable costs to the sequences. This table guarantees the selection of a tanker with minimum cost considering future possibilities.

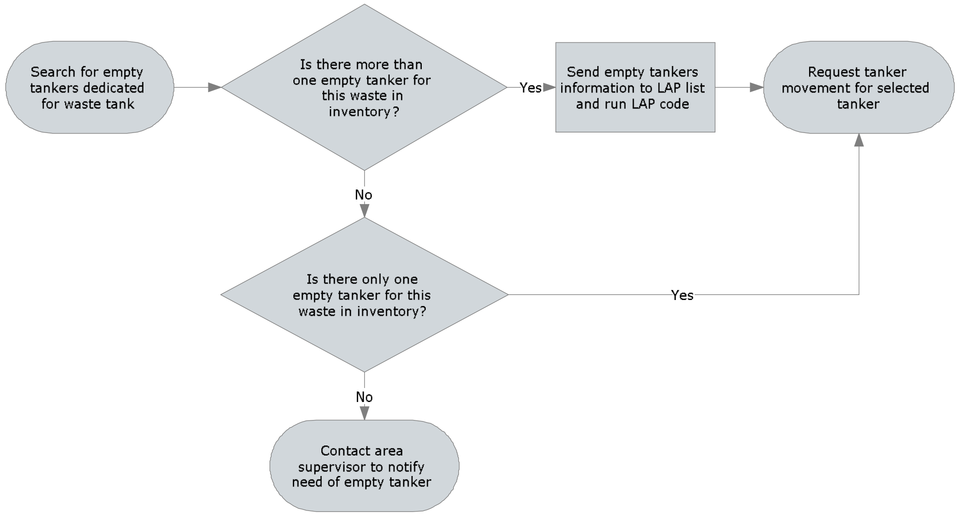

Figure 13: Decision 3 Flowchart

Figure 13 shows a flowchart of Decision 3. The first action in this decision is checking the available inventory in the facility for empty tankers that can be used for the Waste Tank in need for drainage. If there is more than one empty tanker available for this Waste Tank in inventory, the required tankers information is copied to the pre-coded LAP list. The LAP is started and the selected empty tanker by the code is requested for movement. If there is only one tanker available for this Waste Tank, the movement is required for this tanker. If there are no empty tankers in inventory available for this Waste Tank, a message is shown in the support tool to notify the need of the empty tanker.

Decision 4: Selection of a parking space in the Dam or in the Yard where a tanker currently positioned in the Tank Farm needs to be relocated.

This decision takes place when the content of a tanker with solvent has been completely deposited in its respective tank (Tank Farm). The solution for this decision intends to locate the empty tanker in the Dam without blocking tankers that are expected to be moved earlier than the tanker being managed. In the cases where this is not possible, the tanker is requested to be moved to the Yard. The solution intends the tanker storage with conditional blocking to facilitate cost oriented decisions.

As soon as the tanker is considered empty (when deposit in tank is completed), an estimation of expected time for drainage (ETD) or an estimation of expected time of pickup (PU), depending on the case, is assigned to the tanker.

An ETD is assigned to empty tankers that can be used for drainage of waste; tankers with certain solvents apply for this. It is known which are these solvents and it is considered in the program code; it is not included in this report since it was previously agreed not to divulge this information. The ETD is calculated based on estimation by observing the waste fill rate graphs for each tank. Refer to Table 9 where an example is shown of ETD determination with Decision 4.

For the remaining empty tanks, a pick up time (PU) is assigned. Suppliers usually take from 24 to 48 hours to pick up a tanker after they have been notified by the traffic department. The PU for tankers is given a value of 48 hours in the support tool; the maximum time it generally takes a supplier to pick up a tanker. As soon as this value is assigned, the supplier is contacted and penalties are no longer applicable for these tankers.

Table 9: Emptied tanker estimated time of drainage (ETD) example

Tanker ID	Tankers for this waste available in inventory	Constant for this Waste Tank (hours)	ETD (hours)
A-001	1	48	96

After a tanker is emptied in a holding tank, it is classified as ‘for waste management’ or as ‘for pick up’. When a tanker is classified as ‘for waste management’, an estimation of expected time of drainage is determined for it. The tool counts the available tankers in inventory for the waste purpose, and it multiplies the total tankers for the same waste management to the constant value for that Waste Tank to determine the ETD.

The flowchart of Decision 4 is not shown to avoid redundancy since is almost identical to Decision 1 flowchart. The only detail of difference is that the tanker to be moved to a parking space has an assigned ETD or PU value instead or an ETU or ETD value. The heuristic for management is the same.

Decision 5: Selection of a parking space in the Dam or in the Yard where a tanker currently positioned in the Waste Tanks area needs to be relocated.

This decision takes place when an empty tanker has been completely filled with waste in the Waste Tanks area. The solution for this decision intends to locate the tanker (filled with waste and ready for pick up) in the Dam without blocking tankers that are expected to be moved earlier than the tanker being managed. In the cases where this is not possible, the tanker is requested to be moved to the Yard. The solution intends tanker storage with conditional blocking to facilitate cost oriented decisions

As soon as the tanker has been completely filled with waste, an estimation of expected time of pickup (PU) of 48 hours is assigned to the tanker. After this value has been assigned, the supplier is contacted and penalties are no longer applicable for these tankers.

The flowchart of Decision 5 is not shown to avoid redundancy since is almost identical to Decision 1 flowchart. The only detail of difference is that the tanker to be moved to a parking space has an assigned PU value instead of an ETU or ETD value. The process for management is the same.

<u>Decision 6:</u> Choosing from a list the next movement to be made with the internal truck. Given the case of study, several movements are requested by the series of events. These requests for movements arrive in a list dynamically and this decision picks the next request to be managed as long as there are requests for management. The Solution is a dynamic list with priority management.

Decision 6 is linked with decisions 1 to 5 previously described. Although it does not minimize costs by itself, it is the final piece of management required to complete all described decisions that do directly. Moving tankers from destination to destination is necessary and in an organized way, it requires planning and organization to schedule the movements since several movements (*i.e.,* moving a tanker with fresh material to a holding tank in need of material for production) have higher priority than others in order to maintain proper production levels and tanker distribution working together with all decisions. Due to this it is important to schedule movements for internal truck with Decision 6.

The following table was copied from the support tool to illustrate this proposed solution.

Table 10: Decision 6 Request List

Internal truck Position: Idle (home)

	From	To	Priority value	Distance (feet)	*Processing Time (minutes)
1	Dam	Tank Farm (critical)	1	270+180 = 450	$\left[\frac{\frac{(dist)\,feet}{(5280)\frac{feet}{mile}}}{10\frac{miles}{hour}}\right]*60\,\frac{\text{min}}{hour}$
2	Yard	Tank Farm (critical)	1	195+360 = 555	
3	Dam	Waste Tank (critical)	2	270+105 = 375	
4	Yard	Waste Tank (critical)	2	195+435 = 630	
5	Dam	Tank Farm	3	270+180 = 450	
6	Yard	Tank Farm	3	195+360 = 555	
7	Dam	Waste Tank	4	270+105 = 375	
8	Yard	Waste Tank	4	195+435 = 630	
9	Tank Farm	Dam	5	270+180 = 450	
10	Tank Farm	Yard	5	270+360 = 630	
11	Waste Tank	Dam	6	350+105 = 455	
12	Waste Tank	Yard	6	350+405 = 755	
13	Sample point	Dam	7	150+285 = 435	
14	Sample point	Yard	7	150+45 =195	

*tanker hook up and release times are not considered in this column.

The first line just outside of Table 10 tells us the exact location of the internal truck. The internal truck can be positioned at: Tank Farm, Waste Tanks, Dam, Yard or home. The program sees this location and adds the distance value from Table 23 to each distance of movement listed in the table decision (refer to Distance column in Table 10). The distances have been previously measured and entered in the tool's spreadsheet and are presented in Table 23 below.

Table 10 shows a list of all possible movements with a priority value assigned to each movement. These priority values were assigned using the Analytical Hierarchy Process (AHP) with the exception of the first four listed movements which require immediate attention as they occur (Events 5 and 7 further described in the previous sub-section); refer to sub section 3.2.1 for further details about the AHP for this solution. Table 10 also shows the distance from the position where the internal truck is located to the distance where the tanker will be picked up plus the distance that the movement requires. The Processing Time column shows the time that takes to process each job and considers the information shown bellow. The distance values and processing times for movements are used to break ties in the movement selection.

$$\left[\frac{\dfrac{(dist)\,feet}{(5280)\dfrac{feet}{mile}}}{10\dfrac{miles}{hour}}\right]*60\frac{\min}{hour}$$

-**dist (feet)** represents the distance shown in column 5

-**5,280 feet per mile** is a unit convertor to change the feet to miles

-**10 miles per hour** is the maximum speed limit inside the facility and it is used as constant to determine the processing times of movements

-**60 minutes per hour** is a unit convertor to change units from hours to minutes

The Analytical Hierarchy Process

Optimization Decision 6 defined in the tool selects the next movement to be made by the internal truck from a list of movements. The decision support tool selects the movement with highest priority value previously determined with the Analytic Hierarchy Process (AHP). The AHP is a methodology useful for ranking alternative solutions. It was developed by Thomas L. Saaty in 1970s [10]. The simplicity and power of the AHP has led to its widespread use in different applications such as: business, social studies, research and development and defense among others to make decisions where prioritization is needed. It helps structure the decision maker's thoughts and can help in organizing problems in a manner that is simple to follow and analyze. The AHP provides means of decomposing the problems into a hierarchy of sub problems which can more easily be understood and subjectively evaluated. The subjective evaluations are converted in numerical values and process to rank each alternative on a numerical scale.

AHP works by making a pairwise comparison of all possible moves that could be made by the internal truck (alternatives). This pairwise comparison has to be made by each identified attribute: traffic department, manufacturing department and the programmer (Tables 12 – 14). Then we synthesize judgments by calculating the priority of each move for each identified attribute (Tables 15 – 21). We finally summarize (Table 22).

The personnel in the facility that currently make all the decisions related to multiple movement selection and ordering priority was interviewed to obtain their input on movement selection among a list of all possible scenarios. Figure 14 shows the hierarchy used for the priority determination.

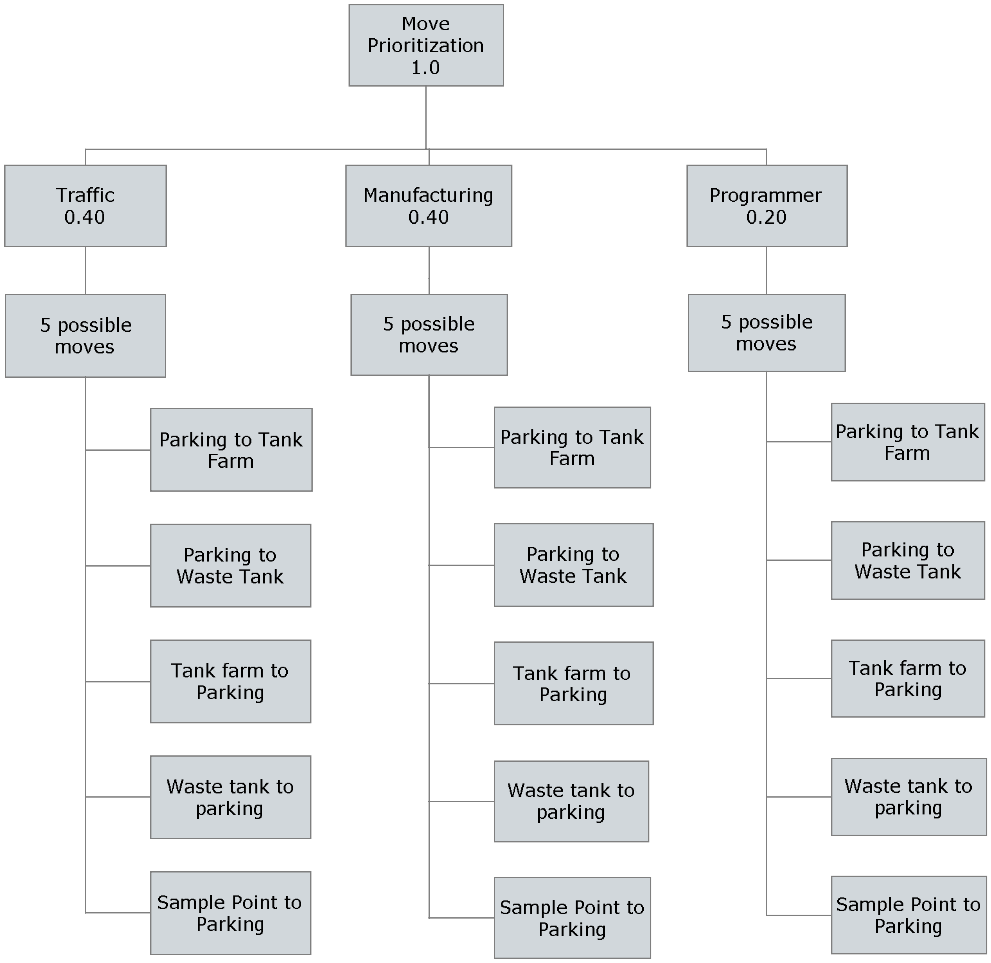

Figure 14: AHP hierarchy for the move prioritization

The would-be decisions of two departments and the programmer's were taken in consideration for the process. A weight of 0.40 was given to the departments since they are the day to day decision makers. The five possible moves to be made with the internal truck are described below.

Table 11: Scale for Pairwise Comparison

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

Table 11 was used by decision makers to compare between moves and determine the intensity of importance on their selection. This information is tabulated in the fourth column of Table 12 through Table 14.

Table 12: Traffic Department Judgment Results

Criteria		More Important	Intensity
A	B		
Parking to Tank Farm	Parking to Waste Tank	A	1
	Tank Farm to Parking	A	7
	Waste Tanks to Parking	A	5
	Sample Point to Parking	A	3
Parking to Waste Tank	Tank Farm to Parking	A	3
	Waste Tanks to Parking	B	3
	Sample Point to Parking	B	3
Tank Farm to Parking	Waste Tanks to Parking	B	3
	Sample Point to Parking	B	3
Waste Tanks to Parking	Sample Point to Parking	B	1

Table 12 present the judgments made by the Traffic Department personnel for each identified move.

Table 13: Manufacturing Department Judgment Results

Criteria A	Criteria B	More Important	Intensity
Parking to Tank Farm	Parking to Waste Tank	A	5
	Tank Farm to Parking	A	7
	Waste Tanks to Parking	A	7
	Sample Point to Parking	A	9
Parking to Waste Tank	Tank Farm to Parking	A	3
	Waste Tanks to Parking	A	3
	Sample Point to Parking	A	3
Tank Farm to Parking	Waste Tanks to Parking	A	1
	Sample Point to Parking	A	1
Waste Tanks to Parking	Sample Point to Parking	B	1

Table 13 present the judgments made by the Manufacturing Department personnel for each identified move.

Table 14: Programmer Judgment Results

Criteria A	Criteria B	More Important	Intensity
Parking to Tank Farm	Parking to Waste Tank	A	3
	Tank Farm to Parking	A	5
	Waste Tanks to Parking	A	5
	Sample Point to Parking	A	7
Parking to Waste Tank	Tank Farm to Parking	A	5
	Waste Tanks to Parking	A	5
	Sample Point to Parking	A	5
Tank Farm to Parking	Waste Tanks to Parking	B	3
	Sample Point to Parking	B	3
Waste Tanks to Parking	Sample Point to Parking	B	3

Table 14 present the judgments made by the Programmer for each identified move.

Table 15: Traffic Department Intensity Matrix

Traffic Department

	1	2	3	4	5
1	1	1	7	5	3
2	1	1	3	1/3	1/3
3	1/7	1/3	1	1/3	1/3
4	1/5	3	3	1	1
5	1/3	3	3	1	1

Normalized Columns

	1	2	3	4	5
1	0.3737	0.1200	0.4118	0.6522	0.5294
2	0.3737	0.1200	0.1765	0.0435	0.0588
3	0.0534	0.0400	0.0588	0.0435	0.0588
4	0.0747	0.3600	0.1765	0.1304	0.1765
5	0.1246	0.3600	0.1765	0.1304	0.1765

Table 15 uses judgment data of Traffic Department and changes it into matrix format. The matrix results are normalized to convert judgments into priority values.

Table 16: Traffic Department Priority Results

Sum Rows	Divided by # of moves
2.0870	0.4174
0.7724	0.1545
0.2545	0.0509
0.9181	0.1836
0.9679	0.1936

Table 16 adds the results of Table 15 in each row and divides these values by 5 (number of moves).

Table 17: Manufacturing Department Intensity Matrix

Manufacturing Department

	1	2	3	4	5
1	1	5	7	7	9
2	1/5	1	3	3	3
3	1/7	1/3	1	1	1
4	1/7	1/3	1	1	1
5	1/9	1/3	1	1	1

Normalized Columns

	1	2	3	4	5
1	0.6262	0.7143	0.5385	0.5385	0.6000
2	0.1252	0.1429	0.2308	0.2308	0.2000
3	0.0895	0.0476	0.0769	0.0769	0.0667
4	0.0895	0.0476	0.0769	0.0769	0.0667
5	0.0696	0.0476	0.0769	0.0769	0.0667

Table 17 uses judgment data of Manufacturing Department and changes it into matrix format. The matrix results are normalized to convert judgments into priority values.

Table 18: Manufacturing Department Priority Results

Sum Rows	Divided by # of moves
3.0175	0.6035
0.9296	0.1859
0.3576	0.0715
0.3576	0.0715
0.3377	0.0675

Table 18 adds the results of Table 17 in each row and divides these values by the number of moves.

Table 19: Programmer's Intensity Matrix

Programmer

	1	2	3	4	5
1	1	3	5	5	7
2	1/3	1	5	5	5
3	1/5	1/5	1	1/3	1/3
4	1/5	1/5	3	1	1/3
5	1/7	1/5	3	3	1

Normalized Columns

	1	2	3	4	5
1	0.5330	0.6522	0.2941	0.3488	0.5122
2	0.1777	0.2174	0.2941	0.3488	0.3659
3	0.1066	0.0435	0.0588	0.0233	0.0244
4	0.1066	0.0435	0.1765	0.0698	0.0244
5	0.0761	0.0435	0.1765	0.2093	0.0732

Table 19 uses Programmer's judgment data and changes it into matrix format. The matrix results are normalized to convert judgments into priority values.

Table 20: Programmer's priority results

Sum Rows	Divided by # of moves
2.3403	0.4681
1.4039	0.2808
0.2565	0.0513
0.4207	0.0841
0.5786	0.1157

Table 20 adds the results of Table 19 in each row and divides these values by the number of moves.

Table 21: Individual decision maker priority results

TD*0.4

1	0.1670
2	0.0618
3	0.0204
4	0.0734
5	0.0774

MFG*0.4

1	0.2414
2	0.0744
3	0.0286
4	0.0286
5	0.0270

P*0.2

1	0.0936
2	0.0562
3	0.0103
4	0.0168
5	0.0231

Table 21 multiplies the obtained results in Tables 16, 18 and 20 and multiplies these values to the weight given to each decision maker.

Table 22: AHP Hierarchy for the move prioritization

Moves	Traffic	Manufacturing	Programmer	Total
1. Parking to Tank Farm	0.1670	0.2414	0.0936	0.5020
2. Parking to Waste Tank	0.0618	0.0744	0.0562	0.1923
3. Tank Farm to Parking	0.0204	0.0286	0.0103	0.0592
4. Waste Tanks to Parking	0.0734	0.0286	0.0168	0.1189
5. Sample Point to Parking	0.0774	0.0270	0.0231	0.1276
	0.40	0.40	0.20	1.00

Table 22 summarizes the final priority values obtained from the AHP. This is how the priority values column in Table 10 were determined.

The methodology of Decision 6 suggests the selection for the next movement to be the one with higher priority value in the list. A time cycle is considered in this method; each time a movement is made, the priority values of the movements remaining in the table increase by 0.05. Movements are added to the list as they take place in other events; the priority values of these movements increase after their first cycle in the list. The idea of the addition helps in the selection for movement of the initial movements that arrived to the list.

The VBA code created scans this list for each movement from the beginning searching for the higher value in the Priority Value column. Ties are broken with the Shortest Processing Time policy by choosing the movement that takes less time to make by the internal truck. If a tie remains, any movement among the ones tied can be selected arbitrarily.

A pseudo code for this decision is presented below:

```
If, there is only one request in the list
        Make movement
Else, continue
Do
        Copy location of the internal truck
```

Fill distances column in list table

Calculate processing time of jobs column

Sequence jobs by higher priority value

If, priority value (P) for job in first position is higher than for job in second position ($P_1 > P_2$)

Select first job in sequence

If, ($P_1 = P_2 \ldots = P_n$) all tied jobs in first position

Sequence applicable jobs by shortest processing time

Select job with shortest processing time

End If

End If

Loop until list has less than two requests

End If

Table 23: Distance Matrix

	Idle (home)	**Tank Farm**	**Waste Tanks**	**Dam**	**Yard**	**Sample Point**
Idle (home)		270	350	270	195	150
Tank Farm	270		120	180	360	315
Waste Tanks	350	120		105	435	390
Dam	270	180	105		330	285
Yard	195	360	435	330		45
Sample Point	150	320	390	285	45	

Table 23 summarizes the distances of every possible trip to be made by the internal truck. This information is used in the support tool to update the list for each cycle after the exact location of the truck is given (refer to Table 16). With this information the Distance and Processing Time columns of the list in Table 10 are filled for each cycle.

Table 24: Current Truck Location

	Idle (home)
	Tank Farm
	Waste Tanks
●	Dam
	Yard
	Sampling Point

Table 24 tells us the exact location of the internal truck. As events take place in the tool and requests are managed with Decision 6, the inside support tool operator contacts the internal truck operator to update its location before activating Decision 6 in the support tool. This information is used in the program with the one showed in Table 23 to complete the necessary information in the list (Table 10).

The list changes in time as requests are managed or as new requests are generated in other events. These events are the following:

1. Sampling and identification of fresh tanker has been concluded in the Sampling Area, thus a request is generated and documented in the list to move the tanker from warehouse area to a parking space.
2. The level of a tank in the Tank Farm drops below 30% of its level, thus a request is generated and documented in the list to move a tanker from a parking space to the Tank Farm tank.
3. The level of a tank in the Waste Tanks area increases above 30% of its level, thus a request is generated and documented in the list to move an empty tank from a parking space to the Waste Tanks area.
4. A tanker has been completely emptied in the Tank Farm. This generates a request to the list to move the empty tanker to a parking space.
5. A tanker has been completely filled in the Waste Tanks area. This generates a request to the list to move the full tanker with waste to a parking space.

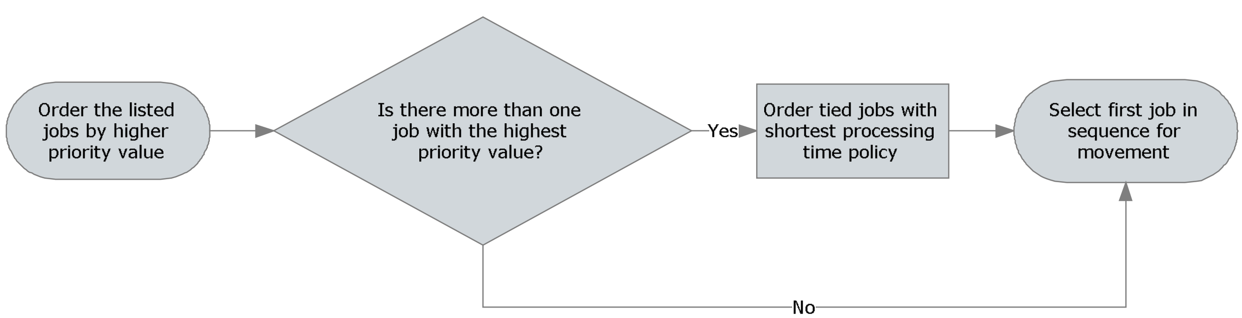

Figure 15: Decision 6 Flowchart

Figure 15 shows a flowchart of Decision 6. After jobs are sequenced by higher priority for each movement, if no more than one job has the higher value, the first job sequenced is selected for movement. If there is more than one job with higher priority the tied jobs are sequenced by shortest processing time. The job with shortest processing time is selected for movement. If there is more than one job with equal processing time in first position, any job can be selected arbitrarily.

4 EXPERIMENTAL RESULTS

The tanker inventory of one month and its management during that time was acquired from the facility to simulate the management of tankers in the programmed decision tool. The data included the following information:

- Tanker arrival date and identification
- Solvent carried if full
- Intended usage if empty
- Tanker location
- Days the tanker had in the facility
- Date the traffic department was notified that the tanker was ready to be shipped (when applicable)
- Date the carrier was notified that the tanker was ready to be shipped (when applicable)
- Tanker departure date (when applicable)

This information is currently being gathered by a traffic department operator who visits the Yard and the parking spaces daily to observe for tankers that have arrived and leave the facility. He collects inventory information and coordinates changes (tanker arrivals and exits) with the production and sample point personnel. Operators at the sampling point document information as tankers arrive in one spreadsheet; the production department documents the tankers managed for solvent fill up or waste drainage in a second spreadsheet. The traffic operator consolidates both spreadsheets with his own that contain the actual inventory from Yard inspection. This operator contacts the internal truck operator to make all necessary movements and also notifies the carriers for tanker pick up when ready. With this information, the costs associated to moves and penalties are determined each month. At the end of the experimentation the current costs will be compared to the costs of managing the same inventory with the decision support tool.

This inventory was managed by the facility with their personal decision support tool. The same inventory was managed with the decision support tool and the results are compared in the following sub sections.

4.1 Assumptions

- The initial inventory, which represents the tankers that remained in the facility at the end of the previous month, will be managed with the tool as if they arrived the first day of the month, *i.e.*, these tankers will be the first to occupy the Dam.
- During the first two weeks of the study the Dam utilization was not compared in order to flush the previous period inventory. After the two weeks the management is considered mostly made by the tool and utilization of the Dam is presented for study.
- When a supplier arrives with an empty tanker, the tool assigns the next move and the supplier takes the tanker to the exact indicated location.
- Internal truck operator contacts the tool operator after each move to confirm assigned position.
- Decision tool operator contacts the internal truck operator to ask for current truck location before making a movement decision.

4.2 Description of Results

The inventory information of one month (September 2009) was managed with the tool daily as events took place. The estimation of expected time of usage for full tankers as they arrived to the facility, expected time of drainage when empty tankers arrive (or were assigned for drainage after holding tank fill up), and pick up times project methodology performed as expected since the Dam utilization was kept high during experimentation without having to make double moves due to tanker blockage. Efficient tanker blocking in the Dam increases its utilization. In the current system, tanker blockage almost never takes place to decrease the possibility of a double move, and when it occurs, double moves have to be made almost every time. Table 25 summarizes the parking utilization for the last two weeks of the study. The days that represent weekend days are highlighted since no tanker management occurs at this time.

Table 25: Dam utilization with Decision Support Tool

Date	Tankers in Facility	Dam Availability	In Dam	In Yard	% tankers in Dam
21/09/2009	15	19	13	2	86.67
22/09/2009	18	19	16	2	88.89
23/09/2009	17	18	14	3	82.35
24/09/2009	19	18	15	4	78.95
25/09/2009	19	18	15	4	78.95
26/09/2009	19	18	15	4	78.95
27/09/2009	19	18	15	4	78.95
28/09/2009	20	18	16	4	80.00
29/09/2009	19	20	15	4	78.95
30/09/2009	22	20	17	5	77.27

Table 25 details the tankers location during the last two weeks of simulation with the decision support tool. The ‘Tankers in Facility’ column indicates the amount of tankers currently in the facility. The full tanker availability of the Dam is twenty two (22) spaces when empty for twenty feet (20’) tankers. The amount of available spaces varies if forty feet (40’) tankers are managed in the inventory; this is the case for most of the study period. The Dam Availability column shows the amount of available spaces for storage considering the tankers parked in the Dam. The In Dam column indicates how many of the total tankers were parked in the Dam at the end of the day and the next column indicates how many were placed in the Yard. As a result of where the tankers are parked, the last column shows the percent of tankers that are located in the Dam.

It was observed that the tankers that were assigned to be parked in the Yard were forty feet (40’) tankers though all these weeks with the exception of the last day when one of the tankers was a twenty feet tanker. Table 26 below summarizes the results of the facility’s current decision support tool.

Table 26: Dam utilization in facility's current system

Date	Tankers in Facility	Dam Availability	In Dam	In Yard	% tankers in Dam
21/09/2009	15	19	12	3	80.00
22/09/2009	18	19	12	6	66.67
23/09/2009	17	18	12	5	70.59
24/09/2009	19	18	12	7	63.16
25/09/2009	19	18	12	7	63.16
26/09/2009	19	18	12	7	63.16
27/09/2009	19	18	12	7	63.16
28/09/2009	20	18	12	8	60.00
29/09/2009	19	20	12	7	63.16
30/09/2009	22	20	12	10	54.55

Table 26 shows the results of parking utilization during the last two weeks of the studied month. The percent of tankers in the Dam was increased on average by more than 15%, and it is possible to increase it further if only twenty feet tankers are managed in the facility.

4.3 Decision Support Tool Summary of Benefits

- Internal Truck movements and operational costs were reduced in 34%.
- Yard logistics operator duties were reduced in 60%.
- Inventory information reporting. (Currently performed manually at the end of each month.)
- Exact tanker location and its current status. (full, empty and its content)

Internal truck movements were reduced in 34% by reducing the amount of movements made by the internal truck during the month of simulated study. The DST gives management the option of checking the Waste Tank levels as soon as a carrier enters the facility, an option not available in the current practice. This option eliminates movements current being made since in the present practice, upon carrier entrance with an empty tanker for waste management, the tanker is always taken to a parking space. After requirement of this tanker the internal truck is requested to make a move. With the DST, if upon carrier entrance to the facility a Waste Tank is available for drainage, the instruction to the carrier is to take the tanker to that Waste Tank, thus eliminating one movement.

Yard logistics are reduced in an estimated 60% since the Yard operator is not required to perform routine tanker location and content checking in the Yard and reporting information takes much less time with the tool than the way it is presently performed. DST maintains inventory information as soon as tankers enter the facility and actualizes its information of location and status after each applicable movement. It also tracks tankers that have left the facility at the studied month. Monthly reporting with the DST is as simple as printing the actual inventory tab at any given time.

No penalty costs were inquired during the month of study neither with the current management system nor with the decision support tool for maintaining applicable tankers inside the facility exceeding the grace period. The managed inventory during the month of September was low compared to previous months. It is known that the grace period is often exceeded due to retaining tankers inside the facility during high inventory periods. Nevertheless this did not took place during the studied time, the decision support tool is prepared to handle high inventory and optimization decision making for tanker selection, an exercise the current system is not able to manage to minimize penalty costs.

The facility did pay demurrage costs for exceeding grace periods in many tankers counting the period since tankers arrive at the dock; a part of the process that was not considered in this project scope. This since Abbott purchases different solvents from a supplier in the US for its manufacturing process. These tankers are shipped to Puerto Rico and stationed in a dock facility outside of Abbott until the traffic department coordinates the shipment delivery locally. At the moment that these tankers arrive at the dock at Cataño, PR, a fee is charged to Abbott. Suppliers' clock of grace also starts counting from this moment. These costs that take place due to parts of the process outside of the Abbott facility were not considered in this project scope since we are not able to control shipments at this stage of the project.

For other solvents, tankers are purchased locally and managed directly from supplier to Abbott facility without the dock as intermediary.

4.4 DST Steps to Implementation

In order to implement the Decision Support Tool at the Chemical facility the following steps are recommended.

1. Parking and Yard identification – These areas shall be identified by sequential numbering.
2. Holding tanks levels and information connection between DST and tanks PLC – This information is vital for the DST, with this available events 4 and 6 take place automatically as required.
3. Yard operator relocation or guard training – Yard operator shall be relocated to the guardhouse to manage the DST and entering tankers or the guard could be trained to handle this part of the procedure where tankers enter the facility in a customized tool that handles events 1 through 3 and 10.
4. Yard operator training – Yard operator has to be trained to operate the DST to manage tankers, internal truck scheduling and to prepare reports as required.
5. Parking card or equivalent system to corroborate movements – a system must be in place to assure the directions given to carriers and the internal truck. If one is told to move a tanker to parking space 8, a card could be in place at the parking space that the carrier or truck operator picks up to deliver the Yard operator in order to corroborate the made movements.
6. Standard Operating Procedure documentation and training – A procedure for the facility must be written to train all affected personnel and future involved employees. This is also required for Good Manufacturing Practices.
7. DST Validation – With all previous steps in place the tool can be validated to perform daily material management in the facility.

4.5 DST in Supply Chain

Optimal Dam determination

A cost in which the facility should never be involved is the cost of handling a spill in the Yard. While the Decision Support Tool pushes so that all tankers are kept in the Dam, it was known from the beginning of the project that this was not possible due to the space limitation in the available Dam. The tool during study increased the Dam utilization significantly, and recommendations like using only twenty feet tankers to improve further more utilization were given, but knowing about the spill possibility is optimal to maintain tankers at a spill prepared Dam at all times.

The DST should be helpful in achieving the goal of optimal Dam space determination. The proposed methodology is to acquire a longer period of historic data (*e.g.,* one year of historical data) and simulate the management with the tool while increasing the amount of available spaces in the Dam. This can be made possible with minor programming modifications to the VBA code and testing of historic data until it can be validated that all managed tankers (or an acceptable percent) are maintained in the proposed Dam. By doing this the DST would not only manage tankers to minimize operational costs, it would also eliminate the possibility of inquiring in undesirable spill costs which not only are costly for the company, but to the environment and surrounding communities as well.

Planning for Purchasing

A major issue in the facility supply chain is the handling of inventory. Having to purchase raw material from a different country (United States), the facility is required to have good planning in order to maintain the necessary levels of inventory in the facility while not inquiring in supplier penalty charges for having tankers in the facility exceeding their given time for usage.

The DST can be helpful for the planning since different scenarios can be simulated in order to maintain the necessary inventory in the facility given product demands. At the time of study it was known that the demand for finish product has a low variability. It varied from five lots to seven lots of finished product. In order to perform this simulation, the historical data for about a year is recommended (in order to handle all demand fluctuations by season) and additional data would be necessary of the suppliers' delivery times. This planning exercise would have to focus on different aspects of the supply chain, but the DST already in place helps in the inventory management while reducing costs for movements and demurrages.

5 CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

The company inventory of tankers for one month was simulated with the decision support tool adequately providing results that suggest the implementation of the tool in the current system for management. The affected departments were impressed with the achieved results and at the time the responsible personnel is discussing the possibility of inserting the tool to their system. The implementation cannot be made at the time unless it is approved subject to a traffic proposal that has to be submitted. This proposal has to show the plan for reorganization and training of the personnel affected by the implementation. In addition, it must provide details of suggested layout modifications that include Yard parking identification and facility signboards for tanker carriers' guidance.

The total management at the south facility was completely programmed in detail and proves to offer realistic results with additional information that is currently obtained with added effort and resource utilization. Information includes in-time inventory status and tanker exact location, tanker time of arrival and supplier notification for pickup among other information included in Section 4.2.

The parking utilization was increased in fifteen percent (15%) during the experimentation period. This reduces the number of tankers parked in the Yard, which is a goal that the facility has to improve safety and flow of material throughout the facility. It was observed that the management of forty feet (40') tankers accounts for considerable parking reduction. It is recommended to use only twenty feet (20') tankers since they represent the majority of tankers in the facility and it is known that forty feet (40') tankers are old tankers that most suppliers do not carry.

It is also recommended to consider the usage of a hand held material analyzer for incoming solvents to the facility. These analyzers made for this type of industry are capable of detecting the exact material being carried in a container tank in seconds and it can also provide additional information currently obtained during laboratory testing. If tanker contents can be verified at the entrance, thus eliminating laboratory testing, the raw material tankers can be taken directly to holding tanks if they are available at the time of tanker entrance to the facility. By doing this, the internal truck movements reduce furthermore, thus minimizing operational costs.

The decision support tool provides inventory information reporting which is currently being made manually at the end of each month. This includes the tankers that were managed during the month, date of arrival, date the carrier was notified to pick up the tanker (as applicable) and the exact tanker location of those tankers that have not left the facility; the current status of these tankers is also known in the tool (empty, full and its content).

During the time of simulated study with data management in the DST, the internal truck movements and its associated costs were reduced in 34%. The Yard logistics operator costs were reduced in 60% since the tool provides the inventory information and reporting currently being made by the operator manually.

5.2 Future Work

As it was planned by the traffic department manager, the management tool is proven to work as required for tankers management. Implementation is the next step of the future work, but the real challenge from this point is working with material purchasing and planning. This department was not handled during this project since management required a tool for management first to determine based on management results if planning was purchasing properly. It was concluded based on knowledge of day to day purchasing that local suppliers are being contacted without a plan in practice, this not inquiring a cost on penalties, but putting the facility on risk of shortage of material. Based on the final inventory it was observed that the most used solvent, not locally purchased, was about to enter in penalty, costs that will be paid for in the month of October.

It is also known that the facility is paying for penalty costs for tankers already in the country parked at the dock waiting to be required in the facility. This is due to the common practice of purchasing too much in advance lacking a plan that considers the actual consumption and fluctuations in production.

At the time when planning is determined to be reliable by observing the material flow in the support tool, and having penalty costs eliminated, the program can be modified to work with expected arrivals considering the inventory in the dock outside of the facility. The combination of the just created tool with efficient planning completes the facility goal of zero cost due to penalties and unnecessary moves.

Now that the decision support tool has been experimented, the amount of parking spaces required in a Dam to manage the actual inventory and possible changes in the future demand can be determined as part of a simulation with the DST. This could lead to suggest the construction of a new Dam or modification of the existing one. The costs associated with construction and/or modification could be studied in an economic analysis to support the investment. In addition, the planning requirements can be adjusted to optimize the facility inventory with the help of the tool.

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Appendices

Appendix A: Support Tool Snapshots

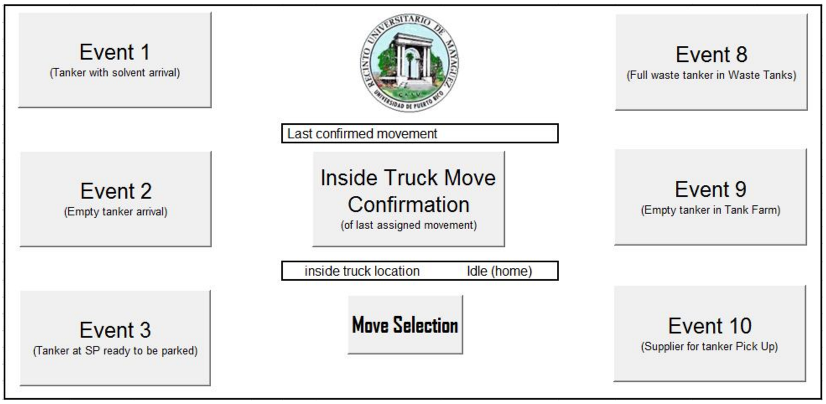


Figure I: Support Tool User Interface

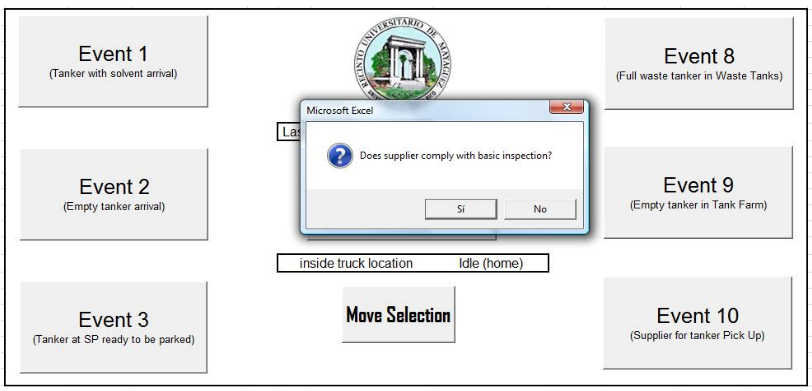


Figure II: Basic Inspection Confirmation upon Tanker Entrance

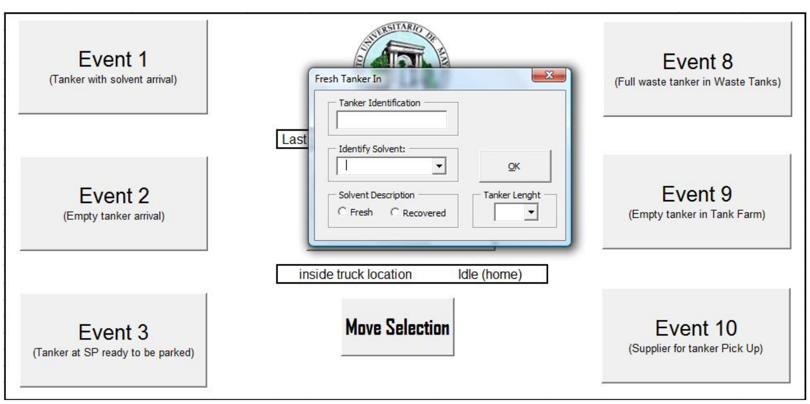


Figure III: Event 1 Information Request After Inspection Approval

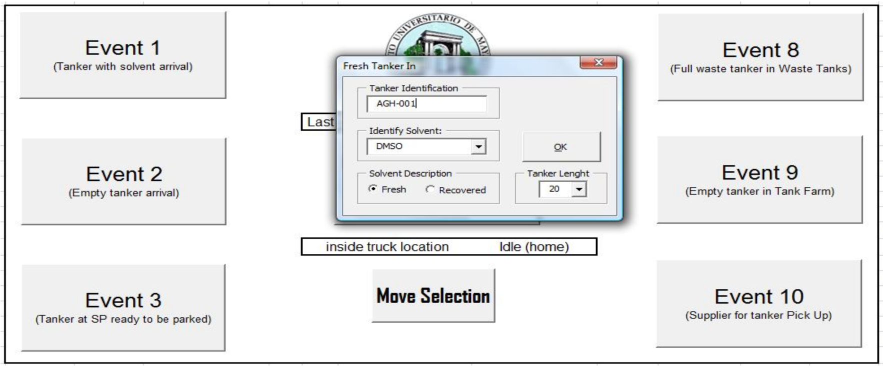
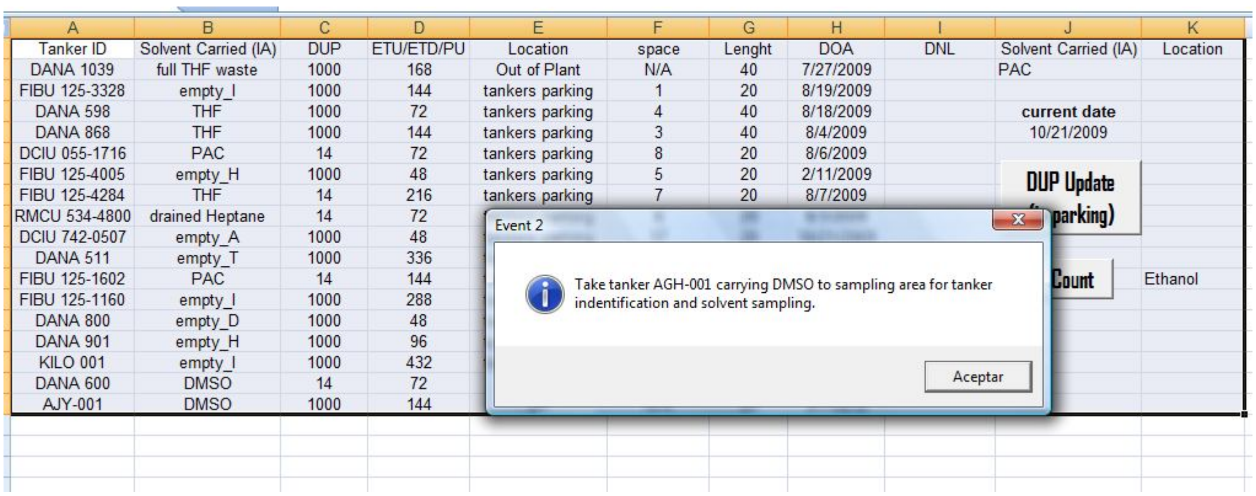


Figure IV: Event 1 Information Being Entered



Tanker ID	Solvent Carried (IA)	DUP	ETU/ETD/PU	Location	space	Lenght	DOA	DNL	Solvent Carried (IA)	Location
DANA 1039	full THF waste	1000	168	Out of Plant	N/A	40	7/27/2009		PAC	
FIBU 125-3328	empty_I	1000	144	tankers parking	1	20	8/19/2009			
DANA 598	THF	1000	72	tankers parking	4	40	8/18/2009		current date	
DANA 868	THF	1000	144	tankers parking	3	40	8/4/2009		10/21/2009	
DCIU 055-1716	PAC	14	72	tankers parking	8	20	8/6/2009			
FIBU 125-4005	empty_H	1000	48	tankers parking	5	20	2/11/2009			
FIBU 125-4284	THF	14	216	tankers parking	7	20	8/7/2009			
RMCU 534-4800	drained Heptane	14	72							
DCIU 742-0507	empty_A	1000	48							
DANA 511	empty_T	1000	336							
FIBU 125-1602	PAC	14	144							Ethanol
FIBU 125-1160	empty_I	1000	288							
DANA 800	empty_D	1000	48							
DANA 901	empty_H	1000	96							
KILO 001	empty_I	1000	432							
DANA 600	DMSO	14	72							
AJY-001	DMSO	1000	144							

Figure V: Event Information Processed

Appendix B: LAP solved problem

Hungarian Method

Solvent 1 Tank cost assignment					
		Tanker requirement sequence			
Tanker		1	2	3	4
1	ABC-111	40	120	170	230
2	ABC-112	120	120	40	40
3	ABC-113	120	120	40	90
4	ABC-114	40	40	90	140

Values in each sequence for each tanker represent the current cost of internal truck pickup plus the demurrage cost (if applicable at the moment).

Step 1: Find the minimum element in each row of the *m* x *m* matrix.

						Min. value in each row
1	ABC-111	40	120	170	230	40
2	ABC-112	120	120	40	40	40
3	ABC-113	120	120	40	90	40
4	ABC-114	40	40	90	140	40

Subtracting the obtained minimum value in same row columns

1	ABC-111	0	80	130	190
2	ABC-112	80	80	0	0
3	ABC-113	80	80	0	50
4	ABC-114	0	0	50	100

Step 2: Draw the minimum number of lines (horizontal, vertical or both) that are needed to cover all zeros in the reduced cost matrix. If *m* lines are required, then an optimal solution has been reached.

1	ABC-111	0	80	130	190
2	ABC-112	80	80	0	0
3	ABC-113	80	80	0	50
4	ABC-114	0	0	50	100

Since crossing lines is equal to *m*, optimal solution has been reached. Thus, sequence is 1-4-3-2. Tanker ABC-111 is selected for movement.