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EVALUATING CAPACITY AND EXPANSION OPPORTUNITIES AT TANK FARM: A DECISION SUPPORT SYSTEM USING DISCRETE EVENT SIMULATION

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ABSTRACT

This paper presents a discrete event simulation based Decision Support System to evaluate tank farm operations. The Decision Support System was developed in order to reduce capital expenditures and assist in decision making for assessing the impact of different improvement opportunities. The simulation based framework captures tank farm dynamics and can be easily scaled for additional products and different tank assignments/configurations. The model was successfully used to evaluate existing tank farm operations at a Freeport site of Dow Chemical company. In this paper, we discuss the general approach used for modeling tank farm operations and different output metrics generated by the Decision Support System.

1 INTRODUCTION

Chemical plant operations use tank farms for the storage of final product before shipping the products out to the end users or to other facilities. Large scale tank farm operations involve multiple feed lines, multiple product grades, multiple shipment modes and different type of storage tanks. The combination of these factors present some unique challenges such as: How to allocate different products to storage tanks while maintaining the operational and logistical constraints, How do new product additions affect existing operations and/or which storage tanks to allocate the new products, Will the existing tank farm capacity be able to meet the storage needs for anticipated production schedules?; What effects can result due to decommissioning out-of-service tanks? and how to allocate their storage to other storage units?.

These challenges present a unique opportunity for developing a decision support system (DSS) that can help in evaluating different options and identifying areas for improvement/ further investment. In this paper, we present a discrete event simulation based decision support system for evaluating opportunities that could reduce capital expenditures and assist in decision making for assessing the impact of additional production capacity, finishing line configurations, extending loading schedule and tank failures on tank farm operations. The simulation based DSS provides a general framework for modeling the tank farm operations and evaluating the effect of different decisions. The general framework presented here can be easily scaled for additional products and different tank configurations.

The problem discussed here is somewhat related to resource allocation and scheduling problems that are widely studied in literature. However, the intent of the DSS model is not to provide an "optimal" resource allocation or production schedule, but assist in evaluating whether the selected tank-product allocation can successfully meet storage needs given the anticipated production schedule. The selected tank-product allocation is provided by a team of subject matter experts by looking at different constraints relating to operational, product specific and logistic issues. Due to the large number of product types, multiple loading and shipment lines, multiple product unloading/loading modes, variability in shipment rates and unloading constraints, a mathematical programming based approach becomes more complicated and difficult to explain to end users. Keeping these considerations in mind, a Discrete Event Simulation (DES) based approach was selected.

DES has been used to evaluate multitude of problems in different areas for decades. Our choice for use of DES as a Decision Support System is motivated by the ability of DES to easily model complex and dynamic systems while considering variability due to various factors such as processing rates, shipments and individual product demands, and simultaneous loading/unloading of products from tanks. Law and Kelton (2000) and Banks et al. (2005) provide an excellent reference for understanding various aspects of DES. Current simulation software such as ARENA <www.rockwellautomation.com> allow the ability to model continuous operations (such as the addition and removal of material to and from tank) that are very common for chemical plant operations. DES has been applied to address different problems relating to chemical operations. Stewart and Trierwiler (2005) used a linear programming and Monte Carlo based simulation approach to study refining operations at Kuwait National Petroleum Company (KNPC). The model served as a basis for identifying bottlenecks, additional storage capacity and modifications required. Chen, Young, and Selikson (2002) used a DES based approach to study the logistics activities in a chemical plant and used DES to determine the required capacity of logistics operations to allow continuous operations at a chemical plant. In other related work, Ha et al. (2000) studied the intermediate storage tank operation strategies for production scheduling of multi-product batch processes. The authors used a MILP based approach to minimize makespan and studied the optimal number of storage tanks and their location in batch processes. Vecchietti (1998) used a Mixed integer non linear programming (MINLP) based approach for allocating intermediate storage for multi-product batch plant operations.

The DSS was developed to assist in evaluating multiple objectives. First, it was used to understand the existing tank farm capabilities and performance level by quantifying the proportion of unallocated orders of a given product-tank allocation. We assume that the upstream operations should not be allowed to wait due to tank farm assignment. Under this condition, any product that is produced from finishing lines and is not able to be assigned to a storage tank will be assumed as “unallocated” and referred to as “un-satisfied” quantity. Thus, a product-tank allocation is considered to be better than another if it results in minimal “un-satisfied” quantity. Second, the DSS will be used to evaluate the effect of additional products that will be added to different finishing lines. The production support team was interested in evaluating different product-tank allocations that will yield minimal “un-satisfied” quantity. Third, the DSS will be used to evaluate the effect of “product consolidation”, which means that some products will be re-assigned to other finishing lines. Finally, the DSS will be used to evaluate the effect of replacing out-of-service storage tanks, and evaluate new product-tank allocations. Some of the tanks may go out of service in the near future as they complete their life cycle and it is desired to determine if new tanks need to be put into service and if so, how many and when. In this paper, we discuss the general approach used for developing a DSS and preliminary results involving analysis of the existing tank farm operations. The results related to the other objectives listed here will be published in near future.

This paper is organized as follows. In section 2, we provide an overview of the tank farm process considered for developing the DSS. Section 3 presents the simulation approach used for developing the DSS and section 4 presents some preliminary results using the DSS. Finally, section 5 provides the summary and future work for this paper.

2 TANK FARM PROCESS

Figure 1 shows a general overview of chemical plant operations. There are X batch reactors that feed the reacted product into Y finishing trains. After the material is finished, the product is send through finishing lines into product designated storage tanks. From storage tanks, the product is loaded to a specified mode of transportation (MOT) which can be a railcar, tank truck or a direct transfer pipeline.

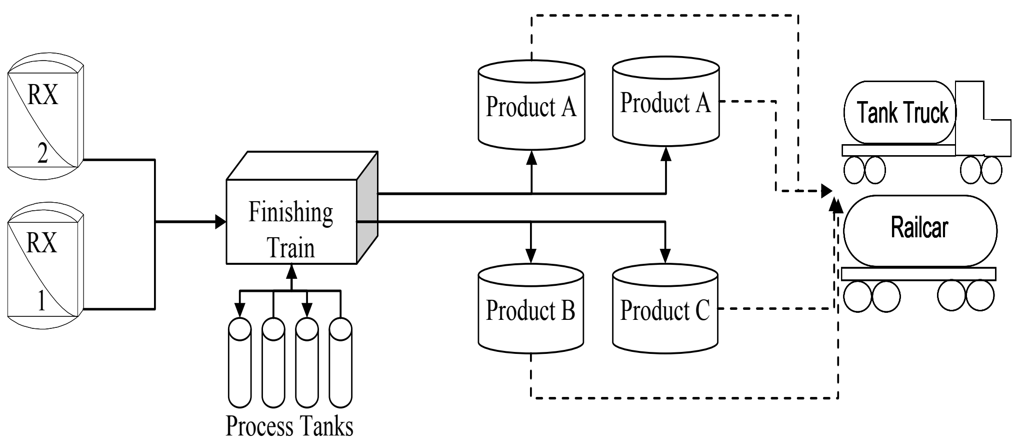

Figure 1: Material Flow Diagram

The model mainly looks at product addition and removal from storage tanks and will not include the reactors and in-process tanks. The model will focus on the production schedule and output rate of the finishing trains, product-tank assignment and shipment rates to different MOT. The resulting process diagram for the simulation model is presented in Figure 2.

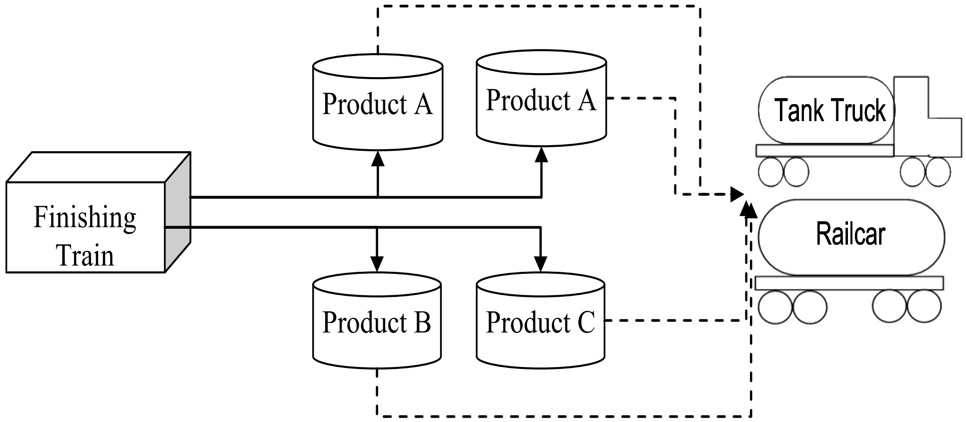

Figure 2: Material Flow Diagram used for simulation model

Lines are used to transfer the product from finishing train to storage tanks, and from storage tanks to MOT. For the finishing lines, there are 2 different types of connections (Figure 3): lines connected at the top of the tank and lines connected thru the recycle line. The type of connection is important because, in addition to product type considerations, this is a factor that determines if the product can be loaded and unloaded to and from a tank at the same tank (load and go – LnG) or can only be unloaded from the tank after the loading has finished and the entire lot is in the tank (Captive Lot - CL).

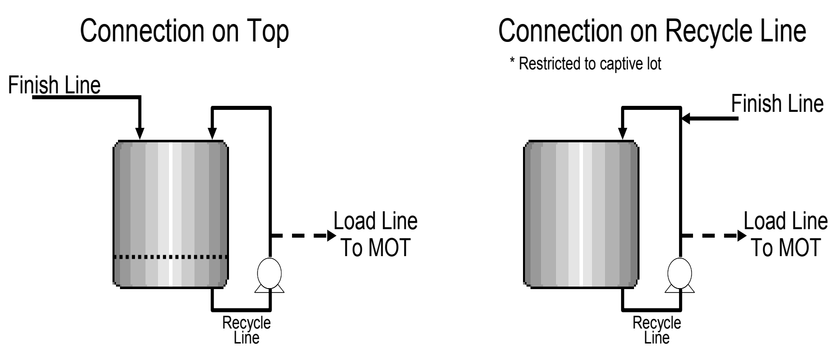

Figure 3: Types of line connections

For the CL product types, the entire campaign is first stored in a tank. After a batch number is assigned, the product can be send to the corresponding MOT. Transferring material from the finishing systems and loading to MOT at the same time is not allowed. The decision to determine a CL is based on the type of line connections in the tank and the type of product. The tanks with the finishing lines connections on the recycle line must be handle as captive lot.

For the LnG product types, the product is transferred from the finishing system into the tank, and as soon as the minimum level of the tank is reached, the loading to the corresponding MOT can start. The minimum tank level for starting unloading varies from one tank to another and is dependent upon the tank capacity.

The tank configuration is also dependent on the product type. For example, Tank A can be a LnG type for Product type X, however it can be CL for some other Product type (say Y). In addition, there are constraints regarding which products can be assigned to which tanks. This will be discussed in more detail in next section.

3 SIMULATION APPROACH

The DSS for evaluating tank farm operations was developed using ARENA <www.rockwellautomation.com> DES software. The first phase of the model development involved getting a clear understanding of tank farm operations and developing the entire process logic on paper. For a successful model development, it is imperative to get clear consensus on multiple aspects such as problem statement, model logic including rules for product assignment and shipment process. We use the Six Sigma "Define" process to make sure that problem definition, scope, boundaries and key deliverables are clearly documented and understood by different functions. Development of model logic on "paper" helps in making sure that the logic implemented can be easily understood by people who are not expert in DES. Different metrics that need to be computed during the simulation model and information requirements for the model are identified and responsibility to gather this information is assigned. During this phase, we included feedback from experts from different functions such as process planners, improvement engineers and logistic coordinators.

Figure 4 shows the logic diagram for the product assignment and shipment process. Once the finishing process is started, a tank is selected based on availability and priority index. The priority index is a number assigned to allocate a tank in case multiple tanks are available. Higher priority is given to a tank with lower priority index. If all the tanks are searched and there is still some additional amount left to be allocated, then the quantity is recorded as unsatisfied. If a tank is selected, then the loading process from the finishing lines starts. The product keeps on loading into a tank unless terminal conditions are met. The tank loading stops when either the order is filled or maximum tank level is reached. If the maximum tank level is reached and there is additional quantity required to be filled in a tank, then the tank with next priority index is searched and assigned for loading. For a CL type tank, the unloading process (or shipment process) starts when the loading process is finished. For a LnG type tank, the unloading process starts only when the tank reaches a minimum level. It is important to point here again that for an LnG type tank, both loading and unloading process can be carried out at the same time. However, for a CL type tank, the unloading process can only begin if the loading process is finished and vice versa. It is also important to point here that the shipment process is carried out only for a specific period of the day.

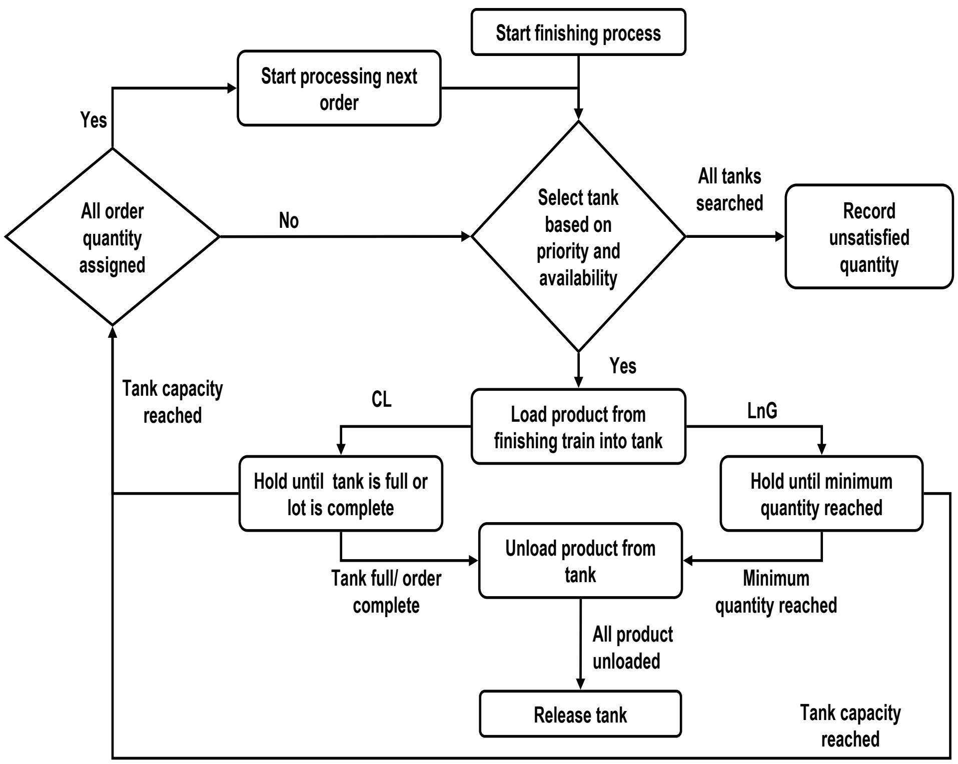

Figure 4: Flow logic for order processing and shipping

The key input parameters for the simulation model were production schedule for different finishing lines (including production order quantity, product type, product family), production rate from different finishing trains, product-tank allocation with priority index (1, 2, 3, ..), tank capacities and configuration type (CL or LnG), and shipment rates from different tanks. The priority index is used to assign a priority if a product can be assigned to multiple tanks with 1 being the highest priority and so on. In order to facilitate easy data input, some of the input parameters were read directly from an Excel® file.

Table 1 shows a product- tank configuration (LnG or CL) table created in Excel®. The shaded cells represent which product-tank assignments are feasible. For example, product 1 on train 1 can be assigned to tank A, however it cannot be assigned to tank C. In addition, the same tank can have multiple configurations (LnG or CL) based on the product type. For example, tank B is a CL type tank for product 1 (finishing train 1) and an LnG type tank for product 2 (finishing train 1).

Table 1: Product-Tank configuration table

Train	Product\Tank	A	B	C	D	E	F
1	1	"LnG"	"CL"		"CL"	"LnG"	"LnG"
1	2	"LnG"	"LnG"			"LnG"	"LnG"
2	1	"LnG"	"CL"		"CL"	"LnG"	"LnG"
2	2	"LnG"	"LnG"			"LnG"	"LnG"
2	4		"LnG"	"CL"			
6	7	"LnG"	"CL"		"LnG"	"LnG"	"LnG"
6	2	"LnG"	"LnG"			"LnG"	"LnG"
6	1	"LnG"	"CL"		"CL"	"LnG"	"LnG"

Table 2 shows a product-tank assignment table created in Excel®. This table lists the priority index for each product tank assignment. The shaded cells represent which product-tank assignments are feasible. For example, Product 1 can be assigned to Tanks A, B, D, E or F. In this case, the subject matter experts decided to store Product 1 in tanks A and F. The priority index represents where a product should be assigned first, if there is capacity available in the storage tank. For example, product 1 on train 1 should be first tried to be assigned on tank A, and then on tank F. If there is no priority index assignment, then a product cannot be loaded on a specific tank.

Table 2: Product-Tank assignment table

Train	Product\Tank	A	B	C	D	E	F
1	1	1					2
1	2		1			2	
2	1	1					2
2	2		1			2	
2	4			1			
6	7				1		
6	2		1			2	
6	1	1					2

Some of the key output parameters generated by the simulation model were quantity received (Metric pounds)/ product/ finishing train, quantity shipped (Metric pounds) / product/ finishing train, unsatisfied quantity (Metric pounds)/product/finishing train and unsatisfied percentage/product/ finishing train.

After development, the simulation model was verified to check for logic consistencies. Some of the key points that were checked were making sure a CL type tank is not loading/ unloading at the same type, LnG tank unloading does not start unless minimum quantity levels are reached, product-tank configurations and assignments are correct, minimum tank levels for starting LnG unloading are correct, and two different products do not load/unload to a tank simultaneously.

The number of simulation runs and model run length was evaluated next. Interested readers can refer to Law and Kelton (2000) for a detailed discussion on determining the appropriate run length and number of simulation runs. Based on our analysis, the simulation run length was chosen to be 1 year and the number of simulation runs was found to be 30. After the model was verified, current performance of the tank farm was evaluated. The results for the evaluation are presented in the next section.

4 PRELIMINARY RESULTS

The DSS model developed was used to evaluate the existing performance of the tank farm operations. The actual tank farm consisted of more than 60 product families, and more than 80 different tanks. The product families were being transferred from more than 6 finishing trains, resulting in a need for more than 80 total allocations on more than 80 different tanks.

Table 3 shows a sample report generated from the DSS. Please note that the data reported in the table does not represent actual numbers due to confidentiality reasons. In order to facilitate the data analysis, the output from ARENA was exported into Excel® and customized reports were then generated. In addition to this report, some other metrics such as total quantity received and shipped out from a tank, average tank level and tank utilization were also reported.

Table 3: Sample DSS report

Product	Finishing Train	Total Production order Received		Total Quantity Received (Metric Lbs)		Total Quantity unsatisfied (Metric Lbs)		Percentage unsatisfied (%)
		Mean	HW*	Mean	HW	Mean	HW	
1	1	20.15	0.17	75000	400.00	10000	300	13%
2	1	45	0.31	28000	100.00	1000	150	4%
2	2	25	0.00	48000	800	12000	50	25%
3	2	20	0.24	20000	100.00	500	50	3%
1	3	32	0.00	6000	62.00	0	0	0%

*HW: 95% Half width

The main objective during the preliminary analysis was to determine the overall performance level of the tank farm operations. That is, what production orders were getting unsatisfied with the given product-tank allocation and tank configuration settings. This exercise also led to validating the results of the simulation model against the historical results, and helping in highlighting critical products. It must be pointed here that the subject matter experts were aware of some of the issues identified by the models, but a formal analysis resulted in a more thorough investigation of the root causes. At the end of the analysis, some additional changes relating to adjusting the product-tank allocation, and minimum LnG level for unloading were also evaluated. The total annual product quantity received and shipped from the DSS was evaluated against historical numbers, and the results were found to be very close to the actual numbers. It must be pointed here that the simulation model did not account for turnaround periods, so the production lost during those days was adjusted for such an evaluation.

5 SUMMARY AND FUTURE WORK

This paper presents a discrete event simulation based decision support system (DSS) for evaluating opportunities that could reduce capital expenditures and assist in decision making for assessing the impact of additional production capacity, finishing line configurations, extending loading schedule and tank failures on tank farm operations. The simulation based DSS provides a general framework for modeling the tank farm operations and evaluating the effect of different decisions.

We present a general framework for the DSS and some preliminary results on the analysis of tank farm operations involving more than 60 different products, more than 80 storage tanks and more than 6 finishing trains. The DSS successfully validated the performance of existing product-tank allocation and assisted in identifying key factors contributing towards unsatisfied quantities. In future, the DSS will be used to evaluate the effect of additional products that will be added to different finishing lines and evaluate the effect of "product consolidation". In addition, the DSS will be used to evaluate the effect of replacing out-of-service storage tanks, and evaluate new product-tank allocations.

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