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MODELING AND ANALYSIS OF A GENERIC CROSS-DOCKING FACILITY

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ABSTRACT

Many companies utilize a number of complex product distribution networks to transport various types of goods. Most of their distribution networks consist of transporting goods from their suppliers to their Distribution Centers (DCs). In the process of transporting goods from suppliers to DCs, cross docking facilities are utilized to consolidate loads in order to minimize costs. A simulation model of a generic cross-docking facility (CF) was developed to examine the operational risks associated with individual CFs within a company's distribution network under a dynamic environment. The model was tested and validated on a large cross-docking facility. In addition, it was used to examine the effect of increasing demand through the cross-docking facility. The model is generic and can easily be expanded to model other cross-docking facilities.

1 INTRODUCTION

Many companies utilize a number of complex product distribution networks to transport various types of goods. Most of their distribution networks consist of transporting goods from their suppliers to their Distribution Centers (DCs). In the process of transporting goods from suppliers to DCs, cross-docking facilities (CFs) are utilized to consolidate loads in order to minimize costs.

The dense network of suppliers, CFs, and DCs throughout large geographic areas creates an issue of assignment of CFs to DCs. With growing demand, companies may need to define new strategic locations for possible CFs or identifying the assignment of CFs to DCs to help determine if more demand can be routed through the existing CFs through expansion.

In this paper, we discuss the development and use of a generic simulation model to represent the operations within a cross-docking facility, specifically the processing of inbound and outbound shipments. The generic CF model can be tailored to model any CF in the company's supply chain network by simply changing the inputs to the simulation model. Each CF can be analyzed individually, thereby reducing the need for a more complicated simulation model that analyzes the entire distribution network. The generic CF simulation model incorporates the following problem aspects: resource contention for dock doors, flexible assignment of loads to in-bound (IB) and out-bound (OB) doors, worker resource requirements, material handling contention, and outbound load building.

In the following section, we provide background and motivation for the use of simulation on problems in logistics and distribution. Then, we provide a basic overview of the operations of a CF and describe those aspects of a CF that were incorporated into the generic CF simulation model. We then discuss the development and use of the simulation model. Finally, we conclude with some ideas gained from the modeling exercise and how the model could be used in the future.

2 BACKGROUND

Discrete event simulation is considered as one of the state-of-the-art technologies that are critical to success and is commonly used in designing and executing operations within the supply chain (Lendermann and McGinnis 2001). It is one of the effective methods used to represent complex interdependencies between organizations (Swaminathan et al. 1994). Simulation is considered one of the best means to analyze and deal with the dynamic nature of the supply chain (Schunk and Plot 2000) and can represent the performance effects of operational factors (Beamon and Chen 2001). Simulation can also deal with supply chain uncertainty and complex systems dynamics. It has the capability of helping the optimization process by evaluating the alternative policies (Ding 2004). Also, simulation can be used to study and evaluate new policies before implementation. It is one of the best tools that can be used to study and analyze the effect of demand changes (Wikner et al. 1991).

Several real life case studies were analyzed and tested using simulation. Information from a real database has been used to distribute vehicles and resources through a network (Dala et al. 2003). Simulation was used to study demand variation as one of the main sources of uncertainty. Yee (2002) considers customer demand variation as a key source of uncertainty in a supply chain. He develops an order-to-delivery supply chain using detailed inputs associated with demand, supply, and production processes. Venkateswaran and Son (2002) develop and analyze multiple simulation models, for different demand patterns, in varying degrees of detail. A set of strategies are then evaluated against each other to find the best strategy for each model across demand patterns.

Simulation has been used to determine the requirements for logistics operations, to allow continuous operations to provide critical decision support (Kuo 2001), to determine the way a change in the size of loading and carrying fleets would affect the performance of the system (Giacaman et al. 2002), to validate and test the adequacy of an expression of technique or to calculate safety stock and the proper replenishment policy (Garcia et al. 2002), and to capture the complexities in the supply chain and produce the entire warehouse or transportation link (Duarte et al. 2002).

Lately simulation is considered to be one of the most important techniques used in manufacturing and logistics systems (Wenzel et al. 2003). Both simulation and optimization/heuristic models are needed to meet the challenges of transportation and logistics/supply chain problems of today and the future. Simulation has been used in warehousing and inside the distribution centers (Carson II et al. 1997). Burnett and LeBaron (2001) to develop a flexible simulation model for the Ryder System, Inc., to validate automated warehouse designs, predict resource requirements, and determine operational throughput capacities for its E-channel operations. Carr and Way (1997) developed a flexible dynamic simulation model that describes the loading, staging, travel, and unloading of rail cars at a Tropicana facility and two distribution centers. The model output and analysis enabled management to optimize rail car availability and crew sizing. Takakuwa et al. (2000) developed simulation models of complicated and non-automated distribution warehouse. Their method consists of two phases: the program for generation parameters and the simulation program. They demonstrate the applicability by illustrating an actual case study. A simulation model for universal warehouse storage using the ProModel simulation language was developed by Macro and Salmi (2002). The model was used to analyze the storage capacity and rack efficiency of the warehouse. They considered the model to be scalable and can be modified to simulate any warehouse.

As can be seen from the many applications of simulation to warehousing and distribution, simulation is an excellent tool for analyzing situations with complicated demand patterns. For analyzing the changes caused by reallocating demand within a distribution network, it was felt that a generic CF simulation model was needed. This would enable a flexible modeling approach that enables analysts to examine the operational risks associated with individual CFs within the network under dynamic conditions.

3 SYSTEM DESCRIPTION AND MODELING OVERVIEW

Often the suppliers for a company are situated at some distance from the location of final demand. For example consider a retailing network consisting of suppliers, distribution centers (DC), and store locations. Whenever a store requires a stock of goods, the store places an order at a DC. The DC collects orders from many stores in its vicinity and places a purchase order (PO) with the respective suppliers. Demand is such that the goods from a supplier will not necessarily fill an entire truckload (TL) shipment. Further, each supplier cannot send a less-than-truckload (LTL) shipment the entire distance to the DC due to transportation costs. As a result, suppliers send the goods as LTL shipments to intermediate consolidation facilities, termed cross-docking facilities (CF). The CF consolidates all goods going to the same DC, and fills an outbound truck. When this occurs, outbound trucks may remain docked at the CF until 1) additional demand arrives for the truck to form a full load or 2) the truck has been waiting for a threshold-hour time window, whichever occurs first and then the load is sent to the destination DC (when either of the conditions occur, the truck is then dispatched to its destination DC). Figure 1 is an illustration of the position of the CF in such a supply chain network.

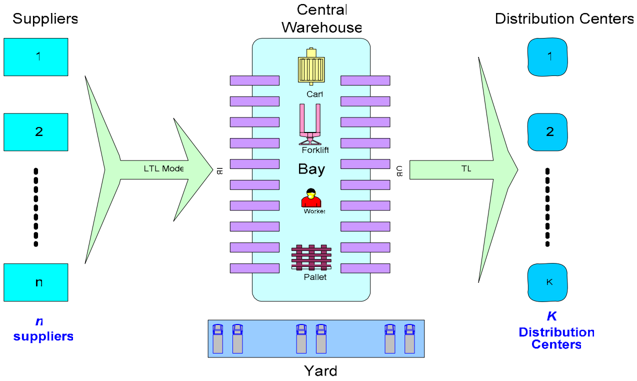


Figure 1. CF Supply Chain Network

As soon as an LTL shipment enters the CF, it is registered as an incoming load. The LTL trailer is then placed in the dock. When a door in the CF is free and the dispatcher decides to unload the LTL shipment, a yard driver is assigned to bring the LTL trailer to a specific door. Workers within the CF are then assigned the task of unloading the trailer. The workers may use forklifts, clamps, and carts during this process. During the unloading process, the goods are either directly loaded onto an outbound truck (if there is one available at the outbound doors of the CF) or placed on the bay to be loaded later.

When there are enough goods to make a TL to a specific DC in the bay, the dispatcher requests a yard driver to bring an empty trailer to a specific door. Another worker is then assigned to load the trailer from the bay using whatever equipment is necessary for the shipments. Finally, once loaded the TL is sealed and dispatched to the DC. If any POs remain at the CF for more than the threshold hours, they are deemed to be late and should be sent directly to the assigned DC.

The demand that is assigned to a CF, the in-bound and out-bound door assignments, the availability of workers and material handling devices, and the shipment characteristics all effect the ability of the CF to meet its throughput requirements. A simulation model must incorporate these aspects as well as incorporating variability in demand arrivals, origin and destination mixes, processing times, and resource availability. The entire process depends upon a realistic model of the demand placed upon the CF. The generic term “demand” represents LTL shipments and their resulting POs that are sent by suppliers to the CF for cross-docking and consolidation. LTL shipments arrive according to a random process. Each LTL shipment has an origin (i.e. the supplier who sent the shipment). Each LTL shipment carries a number of POs. Each incoming PO has a destination (i.e. the DC who requires the shipment). Each incoming PO has an associated weight and cube. Actual data from real life company for the demand and resources of central warehouse were collected, analyzed, and incorporated in the model as follows.

3.1 LTL Shipment Arrival Process and Origin Modeling

We assume that the LTL shipments arrive according to a non-homogeneous Poisson process (NHPP). We let λ_t represent the mean arrival rate of LTL shipments during the weekdays at each hour in of the day, $t \in \{1,2,3,4,\ldots,24\}$. Let λ_W represent the LTL arrival rate during the weekends. After a LTL shipment arrives, we randomly determine the supplier that sent the shipment according to a probability distribution. Let O be a random variable that represents the origin of the shipment. We model the probability that a shipment comes from a particular supplier according to a discrete probability distribution across the supplier zips, $P\{O = i\} = p_i; \quad i = 1,\ldots,I$ where I is the total number of supplier origins. In the data, supplier origins were associated with U.S. zip-code assignments and results in a probability mass function across the supplier zip codes as indicated in Figure 2.

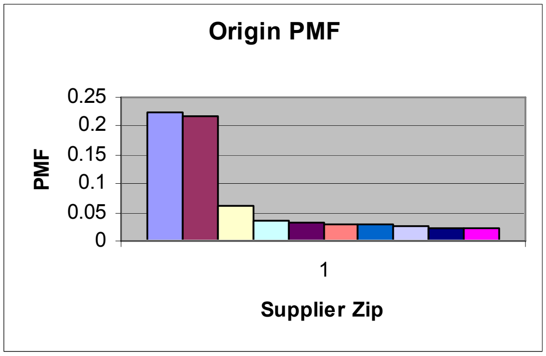


Figure 2: Example Origin PMF

3.2 LTL Shipment Purchase Order Model

In general, the number of POs per shipment may depend upon the supplier and the destination. A model at this level of fidelity would require $I \times J$ distributions to be fit for each of the origin/destination pairs. For simplicity, we assume that the number of POs per shipment is normally distributed with a mean (μ) and a standard deviation (σ) and that it does not depend upon shipment origin or destination. Thus, if Q is a random variable that represents the number of POs per LTL, we have: $Q \sim \max\left(\left\lceil Normal(\mu, \sigma^2)\right\rceil, 1\right)$. In estimating the parameters μ and σ, we simply use the sample average and sample variance of the observed data.

3.3 Purchase Order Destination Model

Each PO requires a destination DC to be assigned. In general, the probability that a PO is destined for a particular DC may depend upon which supplier sent the PO. This would require the estimation of an origin/destination probability matrix, i.e. $p_{ij} = P\{D = j \mid O = i\}$, the probability that a PO goes to destination j given that its origin was supplier i. In order to reduce the data requirements associated with the simulation model, we assume that the destination *does not* depend upon the origin. This allows us to model the probability that any given PO is assigned to a particular DC, as a discrete distribution over the distribution centers, $P\{D = j\} = q_j; \quad j = 1,\ldots,J$ where J is the total number of DCs. We felt that this assumption was reasonable because we are primarily focused on the volume of material flowing through the cross-docking facility. The total volume drives the unloading requirements. The distribution across destinations as we have modeled should still give a good approximation for the waiting that must occur to fill a truck for a particular distribution. The destinations with low probabilities will take longer to fill as one would see in practice. The disassociation between origin and destination will affect performance measures on waiting for particular suppliers, but those are not the focus of this analysis.

3.4 Purchase Order Weight and Cube Model

Each PO may have its own weight and cube. We assume that the weight and cube requirements *do not* depend upon the destination. This leaves us with $2 \times I$ distributions to model the weight and cube for each of the suppliers. Rather than attempt to collect the data required to fit $2 \times I$ distributions, we assume that each of the $2 \times I$ distributions can be modeled with triangular distributions. The Pareto principle was applied to identify the top 20% of the supplier zip codes that account for 80% of the POs passing through the CF. For this top 20%, an individual estimate of the parameters for each of those supplier zips were developed. The weight and cubic volume of the POs coming from the rest of the suppliers was assumed to be well modeled by one standard set of parameters for the triangular distribution. For example, the weight distribution for one of the top 20% suppliers was, triangular(24, 2227, 23620) pounds and the corresponding cube distribution was triangular(3,289, 2625) cubic feet. There were approximately 400 suppliers.

With the demand modeled and incorporated into the generic CF simulation model, we now present how the resources within the center point are modeled.

3.5 Center Point Resource and Process Modeling

Within the generic CF simulation model, we simplify resource modeling to only include the following characteristics: 1) resources involved in loading, and 2) resources involved in unloading. Specifically, we model resource contention for dock doors, workers involved in loading and unloading, material handling equipment used during unloading and loading (fork trucks, clamps, and carts), and travel distances within the CF. When a worker is assigned the task of unloading a LTL shipment, they will pick up the load and drop it off either in the cross-docking bay or at the designated outbound trailer.

The model requires information on the number of dock doors, number of workers, number of fork lifts, clamps, and cart, the length of the facility, and the width of the facility. In addition, each truck arrives with a loads that can be handled in a certain way. Loads are either floor, pallet, or slip types. A distribution across these types was developed. The capacity in terms of cubic feet and pounds was also specified for fork lifts, clamps, carts, and slip movers. The processing time requirements will vary according to the type of load. We assume that the time to unload (from the transporter) or to load (on the transporter) a shipment can be modeled according to a triangular distribution. The velocity of the transport device was modeled by a triangular distribution. For example, the unloading time distribution for the cart was triangular(52, 265, 375) seconds.

3.6 In-bound and Out-bound Shipment Dispatching

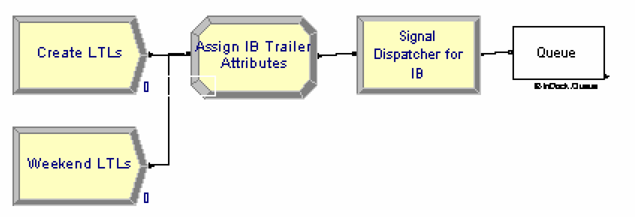
Currently, when a door is freed, we randomly determine whether or not the door will be assigned for loading or unloading. based on the volume of demand consolidated by the CF. Currently each CF has a consolidation ratio of approximately 3 to 1. In other words, based on the volume of demand, it is seen that for every 3 LTL's entering the CF, 1 TL is formed. Thus, we assume that when a door becomes available that 75% of the time it will be set up for LTL and 25% of the time it will be set up for TL. It is important to understand that these percentages do not represent the percentage of the total doors currently dedicated to inbound (LTL) or outbound (TL) freight. Since outbound freight takes longer to load because the TL requirements must be met, on average a CF may have more doors dedicated to TL than to LTL at any given time. By assigning a free door to LTL shipments 75% of the time, we are in essence giving preference or priority to LTL shipments to receive the open door. In reality, the decision to allocate a free door is made by the dispatcher based on the number of inbound and outbound purchase orders that are presently on the bay and in the yard, as well as other factors. Rather than model this complicated decision logic at this time, we decided to give priority to inbound freight such that the consolidation ratio is approximately met.

The simulation model provides many metrics associated with purchase order processing such as purchase order cycle time. In addition, the model estimates space utilization, doors utilization, and resource utilization. The percentage of POs exceeding cycle time threshold limit is calculated by tracking an indicator variable:

4 SIMULATION MODEL IMPLEMENTATION

The generic CF model was developed using the Arena simulation modeling environment. A detailed presentation of the Arena logic is beyond the scope of this paper and would require significant space to present. Instead, we present a narrative overview of how some of the issues were handled. The model was documented using detailed descriptions as illustrated in Figure 3.

The simulation model starts with the creation of LTLs at the in-bound (IB) side of the CF, as soon as an LTL enters the CF, the LTL trailer is then placed in a queue for the dock. When a door in the CF is free and the dispatcher decides to unload this LTL, the yard driver is assigned to bring the LTL trailer to the specific door. A worker in the CF is then assigned the task of unloading the trailer. The worker may use forklifts, clamps, carts, and slip load movers in this process. During the unloading process, the goods are either directly loaded onto an outbound TL (if there is a trailer for the destination at another door of the CF) or placed on the bay to be loaded later. When there are enough goods in the bay to fill a TL to a specific DC either because of weight or cube requirements, the dispatcher will request the yard driver to bring an empty trailer to a specific outbound dock door. Another worker is assigned to load the trailer from the bay using the necessary equipment. Finally, the outbound TL will be sealed and dispatched to the DC; however, there are instances when the number of POs destined for a CF do not form a TL, when this occurs the POs will either (1) wait for more POs to arrive or (2) if the threshold of 48 hours of waiting has come, the POs are deemed to be late and should immediately sent directly to the assigned DC. The arrival process of the LTLs was modeled based on a random distribution and resources such as doors, equipment, and workers were used in the loading/unloading process.



Create an IB trailer based on the time of the day
Create the weekend IB trailers
Assign the origin of the trailer based on a discrete distribution
Assign the number of POs of the trailer based on a normal distribution
Assign the load type of the trailer based on a discrete distribution
Assign the IB property of the trailer to 1
Assign the OB property of the trailer to 0
Assign a serial number to the trailer
Assign the IB trailer arrival time
Assign a variable to count the IB trailers
Signal Door Dispatcher that IB trailer available in dock for unloading
Store IB trailer in IBInDock.Queue

Figure 3: Example Model Documentation

4.1 Process Modeling

As soon as an IB trailer is created, the trailer is placed in queue until an available resource is dispatched to process the trailer. Each trailer has a distinct number of POs based on its origin. The load types on a trailer can be either a pallet load, slip load, or a floor load. The loading process begins when a PO has been assigned to a specific OB trailer. A worker will then be assigned to the loading task who will request a transporter based on the load type being picked up (pallet load, slip load, or floor load). The worker will then use the transporter to pick up the appropriate PO from the bay to complete the loading process. Once the worker loads the PO onto the OB trailer, the transporters are returned and the worker is released. If the OB trailer is full at this point as a result of this load, the dispatcher will release the OB trailer so that the door can be free.

The dispatcher in a CF has three main functions; (1) manage the use of doors, (2) assign unloading tasks and (3) assign loading tasks. The model has three logical entities that fulfill each of the functions of the dispatcher. When the door dispatcher is alerted that a trailer is ready to be processed, the dispatcher looks for a free door. If a free door is found, the dispatcher decides whether to use the door for loading or unloading based on the amount of IB and OB products present in the bay and in the dock. When the dispatcher decides to use the door for unloading, the IB trailer is removed from the dock and the dispatcher requests for an empty OB trailer. After assigning a destination, the IB/OB trailer is sent to the respective free door.

When IB and OB trailers are assigned to free doors (door dispatcher sub model), a board in the middle of the CF showing which doors are serving which trailers is updated. This board makes it easy for the loaders/unloaders to perform their activities. If the trailer is IB, the dispatcher is alerted to start the unloading process. After unloading, the array is again updated; the dispatcher is then informed that the door is free and that the POs are on the bay.

4.2 Statistical Collection

The output from Arena was used to collect statistics to assess the CF utilizations and other sensitivity analysis. The resource and transporter utilization, The Bay space utilization (BSU), CF utilization (CFU), The % of POs exceeding cycle time threshold limit, Purchase order cycle time, the OB truck waiting time, The ratio between the IB trailers and the OB trailers. The number of late TL is also a statistical output, % of trailers leaving LTL, % of trailers leaving LTL lower than weight criteria, % of trailers leaving LTL lower than cube criteria ,average weight of OB TL, average cube of OB TL, average number of OB trailers at doors, average number of IB trailers at doors, % of doors assigned for OB, % of doors assigned for IB.

5 UTILIZING THE GENERIC CF SIMULATION MODEL

This system start with an empty dock and ends with and empty dock. As a terminating system, the system will start at 7:00 AM Monday and end at 7:00 AM Saturday. The running time for the simulation was set at 120 hours (Five days); this was chosen to imitate the real system, which also runs 24 hours a day, five days a week all year round. A sample size of 20 replications for 95% confidence interval was found to be suitable for the system. The time measurements are in hours. While the simulation is running, random arrivals are initiated and enter the system.

Previously we discussed the fact that each CF has a consolidation ratio of approximately 3:1. In other words, based on the volume of demand, it is seen that for every 3 LTLs entering the CF, 1 TL is formed. To see if our model is capturing the consolidation ratio, we compared the simulation output to data supplied by the leading company. The simulated consolidation ratio was very close to the consolidation ratio which indicates that the model is replicating the actual consolidation ratio. In addition, the percentage of late POs is 0.052 (5.2%) which is very close to the percentage that the company personnel expect (around 5% POs will exceed 48 hrs limit).

5.1 Assessments of the Current System

The current system configurations (number of resources) were fixed while the demand was increased by 10-12% per year. The results are shown in Table 1 show that the door utilization and the Bay utilization will increase as the demand increases. As the demand increases, the PO time inside the Bay will increase (Figure 4) while the OB trailer waiting time will decrease (Figure 5) which makes the PO cycle time almost the same (Figure 6). This happens because as the demand increases, the OB trailers do not have to wait as long to be filled; since the current fraction of demand for a specific DC is relatively small.

When increasing the demand, the percentage of late POs and the percentage of late OB trucks will decrease. This is because the increase in demand will allow more trucks to depart to the destination DC under the current availability of resources (not fully utilized). Also, it is important to realize, with the current demand, while the ratio of late POs is 5.2%, the ratio of late OB trucks is 15.1%, which indicates that the number of trucks that carry late POs (exceed 48 hours) is relatively high. It is clear that when decreasing the threshold value from 48 to 24 hrs, the number of late POs and number of Late TL will increase.

6 CONCLUSION

We have discussed in detail the modeling assumptions within the generic cross-docking facility model and described the implementation of the model within the Arena simulation environment. In addition, we have illustrated the use of the model based on the available data. The model can assist logistics planners who are evaluating changes to the overall distribution network. From a strategic planning perspective, optimization can be used to analyze the network to determine which CF's supply which distribution centers and to determine which CF's should be expanded, contracted, opened, or closed. The results of such an analysis may indicate that additional demand may need to flow through specific CF's within the network. To facilitate analysis of whether or not a specific CF can handle new network configurations, the generic SF model can be utilized with data for the specific CF in question.

Future research will investigate the use of this model for analyzing dispatching rules within CF's. The dispatching rules used in this model were developed to simplify the modeling effort and to approximate the overall flow through a CF. Recent research on cross-docking facilities has indicated that best-practices suggest that companies should utilize sophisticated trailer assignment algorithms and dispatching rules to improve the overall efficiency of their crossing docking operations. We plan to expand the model to investigate such questions.

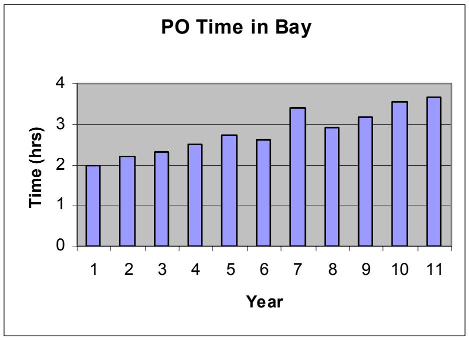


Figure 4. PO Time in CF

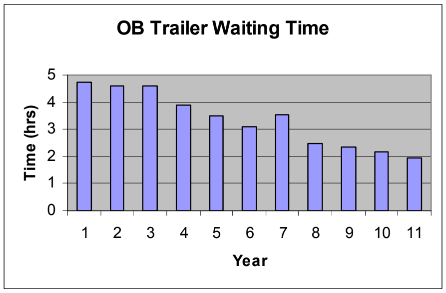


Figure 5. Average OB Trailer Waiting Time

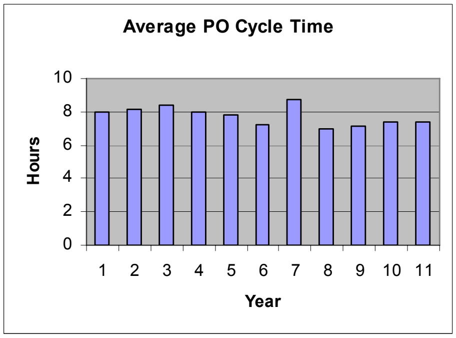


Figure 6. Average PO Cycle Time

Table 1. Results of Current System Assessment

Metric	**Current**	**Y*1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**	**Y10**
Percentage of Late POs	0.052	0.055	0.051	0.053	0.045	0.036	0.045	0.026	0.027	0.032	0.025
Percentage of Late TL	0.151	0.14	0.093	0.101	0.063	0.103	0.073	0.042	0.063	0.048	0.049
IB to OB Trailer Ratio	2.754	2.893	2.991	3.297	3.87	4.463	4.578	5.468	6.396	6.818	7.082
PO Time at the Bay	1.996	2.197	2.318	2.502	2.731	2.613	3.417	2.903	3.188	3.539	3.654
PO time Inside CF	3.3	3.595	3.811	4.062	4.295	4.102	5.166	4.455	4.818	5.281	5.418
PO Cycle Time	8.016	8.191	8.42	7.973	7.808	7.209	8.724	6.945	7.152	7.433	7.383
OB Trailer Waiting Time	4.716	4.596	4.609	3.91	3.513	3.106	3.558	2.49	2.335	2.152	1.965
Doors Utilization%	0.829	0.832	0.834	0.837	0.842	0.845	0.848	0.852	0.854	0.858	0.863
Workers Utilization%	0.106	0.116	0.138	0.152	0.157	0.155	0.196	0.183	0.214	0.264	0.282
Forklifts Utilization%	0.014	0.015	0.018	0.022	0.021	0.022	0.03	0.023	0.031	0.042	0.047
Clamps Utilizations%	0.043	0.043	0.051	0.063	0.064	0.063	0.091	0.069	0.09	0.125	0.142
Carts Utilization%	0.038	0.039	0.046	0.053	0.054	0.055	0.074	0.062	0.083	0.111	0.123
Bay Utilization%	0.036	0.044	0.05	0.06	0.067	0.072	0.102	0.092	0.113	0.144	0.147

Y*: Year

Table 2. Performance Measures with 24 hrs Limit

Metric	**Current**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**	**Y10**
Percentage of Late POs	0.075	0.071	0.067	0.073	0.064	0.05	0.063	0.048	0.037	0.053	0.037
Percentage of Late TL	0.259	0.227	0.167	0.123	0.061	0.089	0.054	0.033	0.038	0.037	0.068

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