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LEAN DISTRIBUTION ASSESSMENT USING AN INTEGRATED FRAMEWORK OF VALUE STREAM MAPPING AND SIMULATION

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ABSTRACT

Distribution centers play a critical role in maintaining supply chains efficiency, flexibility, and reliability. Given the limited financial and physical resources of today's businesses, distribution enterprises have begun to embrace the far-reaching value of lean paradigm. Value Stream Mapping (VSM) is prescribed as a part of lean implementation portfolio of tools. It is employed to visually map value streams' material and information flows seeking to identify the sources of waste and non-value added activities. Integrating simulation with VSM introduces a whole new dimension for lean implementation and assessment processes given its ability to dynamically model systems complexity and uncertainty. This paper shows a value stream mapping–based simulation framework that is used to assess two basic lean distribution practices, pull replenishment and class-based storage policy, of a tire distribution company.

1 INTRODUCTION

Distribution Centers (DCs) often perform more than a single function in supply chain networks including make-bulk/break-bulk consolidation function, cross docking function, product fulfillment center and depot for return goods (Higginson and Bookbinder 2005). In addition, they offer different customer support services such as product installation and offering space for retail sales to end-consumers (i.e., factory-outlet store). However, DCs face many challenges in an environment characterized by globalization, and increasing competitiveness. The quest to offer high level of service to customers while keeping a worthwhile profit margin under these challenges urges DCs' managers to apply lean distribution concept in order to survive in today's competitive market.

Lean philosophy is defined as a concept that effectively eliminates or at least mitigates systems' waste (Womack and Jones 2003). Extending lean thinking beyond manufacturing into distribution centers enhances the responsiveness to customers demand with minimum cost which in turn provides a great competitive advantage for supply chains (Reichhart and Holweg 2007). In order to successfully implement the lean thinking, there is a need to effectively track systems' leanness performance. To date most of the presented lean assessment models are based on subjective methods of assessment which ultimately create difficulties in consistently assess or benchmark companies' leanness levels (Ray et al. 2006).

Hence, the purpose of this paper is to present a quantitative lean assessment framework that integrates VSM with simulation in order to objectively assess the leanness level of a tire distribution company. A current and future state models under two lean practices – pull replenishment and class-based storage policy– are evaluated against a set of lean distribution performance metrics (i.e., total order cycle time, throughput rate, inventory capacity, labor capacity, and equipment capacity).

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2 VSM-BASED SIMULATION APPROACH

Value stream mapping (VSM) was employed in several applications due to its simplicity and effectiveness (Duggan 2002). It was carried out in the distribution environment aiming to map firms activities, assess supplier relationships, and identify improvement opportunities (Hines et al. 1998). Although its efficiency, several criticisms against VSM were addressed. Standridge and Marvel (2006) stated that VSM is unable to effectively handle systems' complexity. Wan and Chen (2008) also concluded that applying VSM on its own could not provide an effective evaluation for the leanness level. Various publications showed the necessity of integrating VSM with simulation. Sullivan et al. (2002) indicated that simulation supports VSM by handling systems' variability in a dynamic nature (i.e., based on timing routine). In addition it has the ability to concurrently evaluate various performance metrics regardless their different measurement units. This kind of in-depth analysis enables simulation to model companies future state showing the ideal performance that is pursued over time (Mahfouz, Hassan, and Arisha 2010).

VSM-based simulation was applied on a wide variety of manufacturing and non-manufacturing applications. Simulation was integrated with VSM in order to support the lean implementation in a steel mill and textile industry (Abdulmalek and Rajgopal 2007). In other study, two simulation models were developed to support VSM in evaluating two scenarios of push and pull manufacturing systems (Lian and Van Landeghem 2002). In 2007, both authors have discussed the application of VSM-based simulation in a low-volume and high-variety component production job shop. McDonald et al. (2002) presented an application of VSM based simulation to a dedicated product line in an engineer to order motion-control products manufacturing plant. A new approach known as a "simulation-aided Value Stream" (SA-VSM) was introduced and applied on a global engine manufacturer by Narasimhan, Parthasarathy, and Narayan (2007).

3 TIRE DISTRIBUTION INDUSTRY

A tire distribution company based in Ireland is employed as a case study for this research. The company supplies tires for a wide variety of customers ranging from big companies and wholesalers to individual buyers. Its main objective is to eliminate sources of waste in order to respond speedily and accurately to customers demand with the least cost. The company relies on forecasting-based plans to manage its inbound and outbound operations as well as customers/suppliers relationships. However, three main concerns on these plans are highlighted by the company managers including; (1) generating forecasting plans for more than 200 different Stock Keeping Units (SKU) types consumes a considerable time and effort, (2) a high level of inventory is experienced due to applying push replenishment strategy, and (3) high forecasting inaccuracy level is observed because of the fluctuation of customers demand. A pull replenishment strategy is suggested to minimize the reliance on forecasting in developing the company's operation plans.

The company faces another challenge regarding its storage policy, 'random storage policy' (RSP). Under RSP policy, the storage locations are selected according to the free storage spaces regardless the types or classes of items. It often requires less space compared to other storage policies, however pickers often visit several storage locations to pick one type of tires which increases the waste in storage, picking, and transportation time. Moreover, it is not easy to monitor and control the available storage places before and after the storing and picking operations since RSP causes unorganized storage space and shelves. Locating similar types of tires close together, namely class-based storage policy (CBS), is suggested to increase operations efficiency and remove the waste in transportation time and resources utilization (i.e., labors and equipment). Table 1 summarizes the company's challenges and the proposed lean initiatives to deal with them.

Table 1: Operations challenges facing the studied company.

Challenges	Lean Initiative	Initiative Type
• Forecasting inaccuracy. • High inventory level	Decreasing the reliance on forecasting-based plans and apply pull replenishment policy based on customer demand .	Replenishment Management
• Inefficient performance of storing and picking operations.	Storing the similar SKUs near together and applying advanced tracking systems – Class-based storage policy.	Storing Management

4 LEAN ASSESSMENT FRAMEWORK

The proposed lean assessment framework consists of five main phases as shown in Figure 1. The assessment process was started by conducting several preliminary meetings with different operational managers aiming to gain understanding of company's business processes structure, SKUs characteristics, operations time, information and material flow, equipment utilization, labors scheduling, and customers/suppliers relationships. Following these meetings, the five phases of the framework were applied to assess the company leanness level as follows.

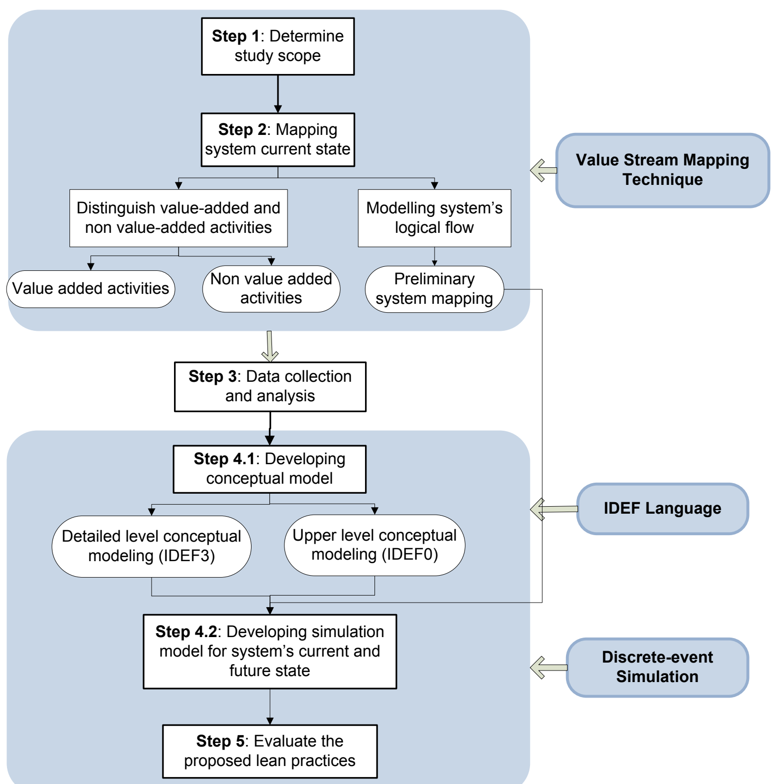

Figure 1: VSM-based simulation framework structure.

4.1 Determine Study Scope

The company encompasses of various functions including marketing, sales, finance, orders processing, customer relationship management, items replenishment, items shipment and delivery, inbound and outbound functions, and others. Different supply chain partners are also engaged in company's processes and have direct impacts on their performance (e.g., customers, suppliers and government bodies). Based on several interviews with the general and supply chain managers, the study focused on three main functions; order processing function (i.e., items replenishment and inbound processes), storing function, and outbound function (i.e., picking operation). The efficient management of these functions leads to minimize the sources of operations waste and provides the company's managers the ability to efficiently deal with the operations' challenges in Table 1.

4.2 VSM for the Company's Current State

The company receives customer orders either from customers directly or electronically through company's website. After receiving customer orders, items availability are automatically checked through an enterprise resource planning system (ERP). For the available SKUs, the picking documents are passed to the warehouse manager triggering set of inbound operations for orders delivery (i.e., picking, assembly, checking, and loading). Otherwise, full truck load replenishment orders with the unavailable items are aggregated and issued to the suppliers. As illustrated in Figure 2, short operations time are taken to process the customer orders – the upper path – thanks to using the ERP system that facilitates orders' information flow and reduces the probability of transaction errors.

An inbound planning process is directly commenced after receiving ordered items from suppliers. This process aims to determine the available storage spaces, assigning storage locations for the received SKUs, printing storage labels, and preparing storing documents. Unloading process is then started where one handling equipment unit and three staff are assigned for each truck. One staff member with a handling equipment unit is then employed to store the unloaded tires in the defined storage locations (i.e., put away). In contrast to the efficiency that ERP provides for customer orders processing, it causes considerable time delay for the inbound operations (i.e., inbound planning and storing operations) due to the inconsistency of inventory and storage locations data.

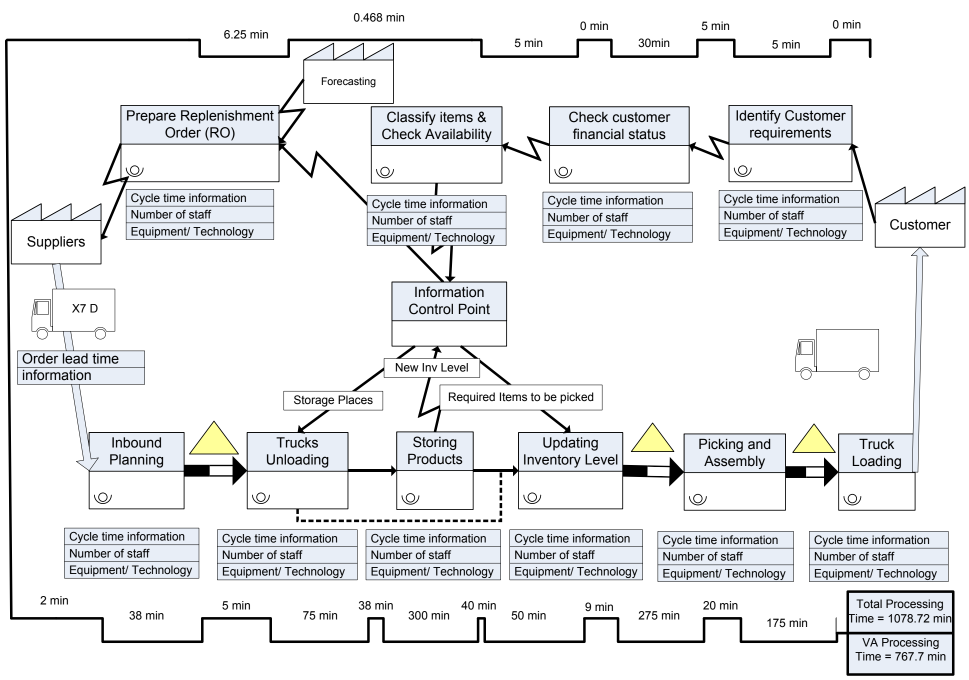

Figure 2: VSM of the current state of the studied company.

4.3 Data Collection and Analysis

A significant field work was carried out to investigate, collect and analyze the required data for applying the framework. Demand planning manager was interviewed to gather general information about the company and the characteristics of its supply chain, as well as an overview of its current awareness of the lean concepts and practices. A number of interviews were then held with different operation managers and supervisors, followed by two observational visits of the company, aiming to accurately identify the input and output variables and collect the data of the company's parameters and processes.

4.3.1 Identifying Input and Output Variables

Five main variables were determined representing the main inputs of the company; (1) processing times, (2) equipment availability, (3) inventory capacity, (4) labor capacity and (5) equipment capacity. The total processing time was calculated using VSM in Figure 2 and recorded 17.97 hours/order. Based on maintenance manager and supported by equipment breakdown and repair reports, the equipment availability was set as 70%. Total inventory capacity was estimated by 60,000 tires with an approximate capacity of 300 tires for each type. Finally, the company employs 13 staff excluding top managerial staff, and 6 handling equipment units with different sizes.

Since lean is a multidimensional philosophy, a single or specific group of output variables (i.e., metrics) will contribute partially in evaluating the leanness level. Based on a literature review and several meetings with distribution and supply chain academics, an initial set of lean distribution performance metrics was developed. The metrics were then validated with the company managers who selected a smaller set of metrics that evaluate company's leanness performance. The selected metrics include orders cycle time, orders throughput rate, resources utilization, inventory level, distribution cost (i.e., inventory holding cost, ordering cost and stock-out cost), and number of lateness jobs.

4.4 Modeling Current and Future Value Streams

4.4.1 Conceptual Models

In order to highlight the company's main functions and processes, detailed conceptual models for the current and future states were developed. Given its ability for modeling complex systems, integrated definition language (IDEF) was used. Its hierarchical nature provides a comprehensive understanding for system's details (Mahfouz, Hassan, and Arisha 2010). Each function was modeled in two different levels of details; The generic level using IDEF0 modeling language which shows the sequence of the main functions as well as their inputs, outputs, controls and mechanisms (i.e., utilized resources), Figure 3. Each function was then broken down into-smaller sub functions illustrating the detailed objects flow and the decision points using IDEF3. Figure 4 shows an example of IDEF3 model for the 'Inbound Planning' operation.

4.4.2 Simulation Models

Two simulation models were developed for the current and future value streams – *CVS* and *FVS*. While CVS model was developed to mimic the current system's configurations and policies, FVS simulated the new company's configurations under the proposed lean practices. The model assumptions are (i) no supplier disruptions are considered and (ii) all received items from suppliers are accepted (no return for item damage or wrong quantities). Simulation software based on Java and XML technology was used to build the proposed models providing object-oriented hierarchical and event-driven simulation capabilities (Mahfouz, Hassan, and Arisha 2010). The resources were characterized by their availability and breakdown frequency, whereas the product entities were attributed by arrival time, processing time, and products characteristics (e.g., processing routing and products type).

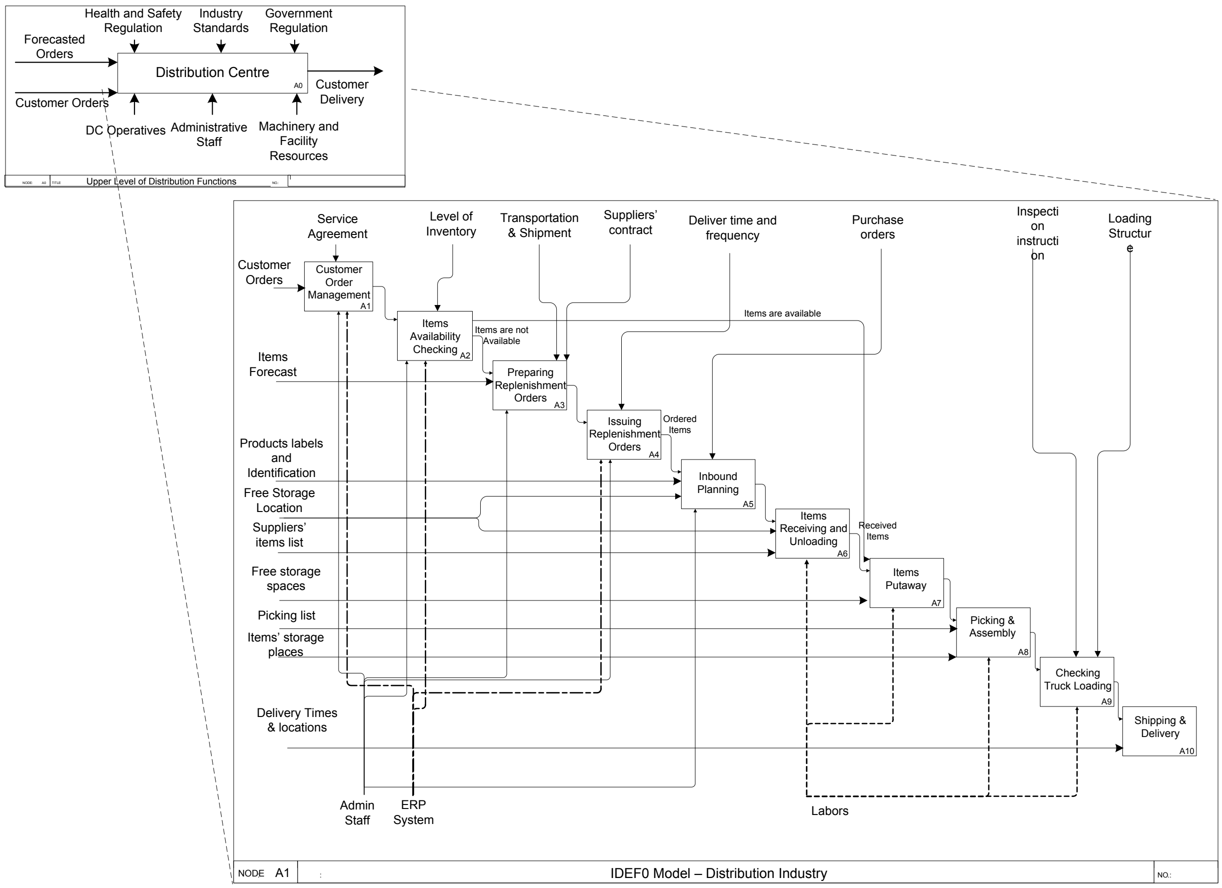

Figure 3 : IDEF0 conceptual model of the company's current value stream (CVS).

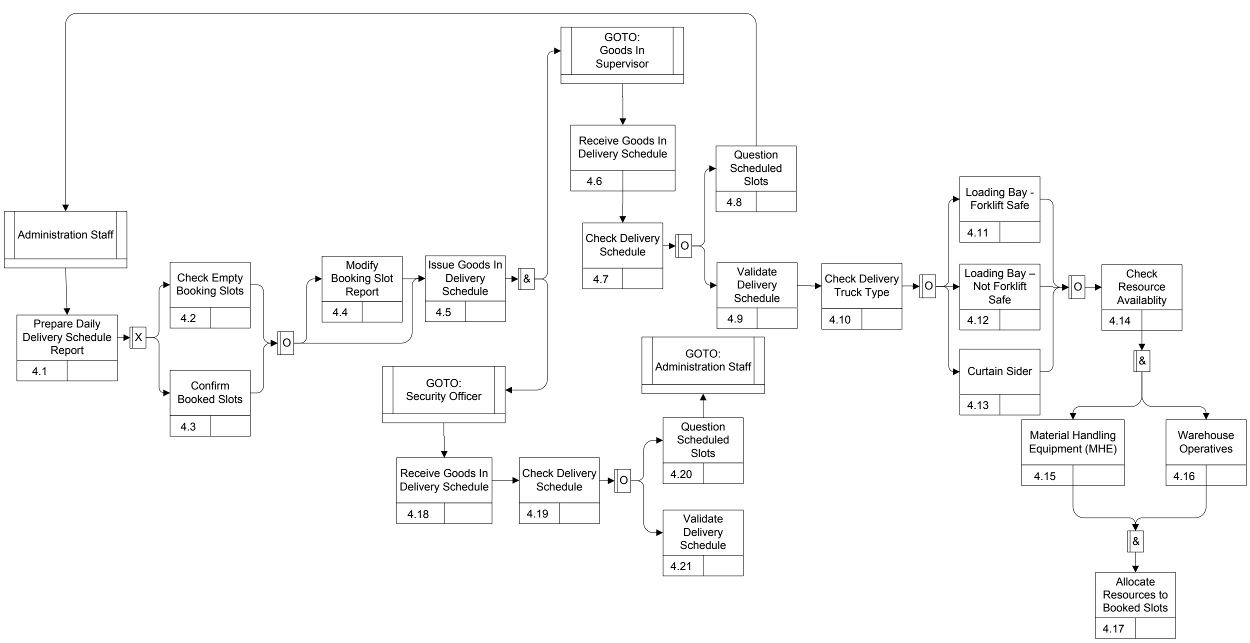

Figure 4 : IDEF3 conceptual model of 'Inbound planning' operation.

In order to manage the stochastic nature of the system parameters, a theoretical statistical distribution approach was employed. Based on historical records of the sales volume, customer orders arrival rate is exponentially distributed with a mean of 8 orders a day. The service time was proportional to SKUs quantities and followed a normal distribution. Suppliers lead times were constant based on supplier's locations and delivery conditions. The rates of breakdown occurrences and repair times have different distributions for every used equipment in the warehouse.

In an effort to develop a simulation model that accurately mimic company's operations and functions, various verification and validation methods were employed. For the verification phase, decomposition method (i.e., verify every group of blocks), and built-in simulation debugger were used to avoid any coding bugs. Three validation methods were then applied on three phases of the simulation models; data collection, conceptual modeling development, and finally simulation results analysis. Validation of the data collection phase was aiming to ensure that; (1) no measurement errors are occurred in the data collection process, (2) the generated data match the pattern of historical data and (3) the identified attribute values are within specified range. To achieve that, a detailed examination for the quality and consistency of the data documentation was done with the cooperation of the involved managers. The conceptual model was then validated to ensure that all specified processes, structures, system elements, inputs and outputs are considered correctly. The modeling team also examined the accuracy and consistency of the conceptual model to the problem definition. Finally, "Face Validation" approach was performed by interviewing managers and operations teams to validate the simulation final results. "Comparison Testing" was also used by comparing the model output with system's output under identical input conditions. The variation between actual and simulated results recorded 15% average percentage based on a sample of 50 sales orders.

4.5 Evaluation of Lean Distribution Practices

4.5.1 Pull Replenishment Strategy

The high fluctuation of customers demand leads to a high level of forecasting inaccuracy which in turn increases the sources of operations and inventory waste. However in today's competitive market, the company cannot risk its customer satisfaction by totally replace the forecast-based plans (i.e., push replenishment) by a pull replenishment strategy. Therefore, an integration between the two strategies is proposed in order to compromise between customers satisfaction level and operations cost. Various changes on the company's current state are taken place to model the suggested policy;

- *Decreasing the consumed time for suppliers negotiation*: by developing long term suppliers agreements that clearly illustrate items price, payment methods and delivery conditions.
- *Establishing new collaboration with alternative suppliers*: aiming to decrease transportation lead time and hence respond efficiently to the rush and unexpected orders.
- *Reducing replenishment lot sizes*: in order to decrease total inventory levels and costs.

Various input variables are modified on the As-Is simulation model – CVS – to mimic the new configurations and changes of the company parameters under the pull replenishment strategy (i.e., To-Be simulation model – FVS1). These modifications include reducing order processing time, increasing replenishment orders frequency, and decreasing order lot sizes.

4.5.2 Class-Based Storage Policy

Although 'Random storage' policy is simple to apply and often requires less storage space, it increases the distance travelled by the pickers to collect the required SKUs and in turn reduces the efficiency of storing and picking operations. It also requires a continuous monitoring and updating for the availability of the warehouse storage locations before and after storing operation which increases the non-value added processing time of the operation. 'Class-based storage' (CBS) practice on the other hand provides easy tracking for SKUs, accelerating storing process, eliminating transportation waste, and increasing the efficiency of storing and picking operations. Under CBS, all SKUs are ranked according to their types and then partitioned into different storage classes where a warehouse location is assigned for each class. According to the company's operations manager, applying CBS results in more efficient performances for storing and picking operations since it helps in eliminating the waste in processing and transportation times of both operations. Various changes are applied on the current state simulation model to represent the new CBS system's configurations (i.e., To-Be simulation model – FVS2). The main changes in FVS2 are decreasing storing and picking operations processing times, transportation time, and resources capacity (i.e., number of labors and handling machines) by 20%, 30% and 50% respectively.

5 RESULTS ANALYSIS

For the models to reach their steady state, the war-up period was stated by two months. Every simulation run represented a year of actual timing. In order to reduce the variance between the experiment's results, each experiment result is an average of ten independent replications with confidence interval 95%.

CVS model (AS-Is model): The results showed an overall poor performance for the company in its current state. This can be explained due to four main reasons; (1) the high fluctuation of customers demand, (2) the long processing time of storing and picking operations, (3) the high frequency of equipment breakdowns and (4) resources overcapacity (e.g., labors and equipment). The reliance on the push replenishment strategy with the high variation of customers demand has increased the inventory level and the number of lateness jobs. The inefficiency of the storing and picking operations under the random-storage policy had a negative impact on the orders cycle time, labor utilization and the throughput rate. On the other hand, equipment utilization was negatively affected by the lack of a regular maintenance plan for the warehouse equipment which leaded to a high level of equipment breakdowns and repair time waste. The second column in Table 2 summarizes the output variables' results under CVS model.
FVS1 model (To-Be model 1): In general, applying pull replenishment strategy resulted in better values for orders cycle time, number of lateness jobs, inventory levels and throughput rate, Table 2 . The results indicated that pull replenishment strategy has an advantage over push replenishment strategy under two conditions; (1) providing a short supplier's lead time by establishing a robust collaboration with company's suppliers and (2) achieving efficient replenishment process – starting from receiving customer orders till sending replenishment orders to suppliers – with a short replenishment cycle time. Without realizing the two conditions, pull replenishment strategy cannot efficiently deal with the high fluctuation of customers demand and causes a huge loss in customer satisfaction and distribution cost. Labors and equipment utilization have also shown an improvement under the pull replenishment strategy due to the increasing in the frequency of issuing the replenishment orders.
FVS2 model: As shown in the third column of Table 2, a better values for order cycle time, throughput rate, labor utilization, equipment utilization, number of lateness jobs and inventory level were obtained comparing to the CVS model results. The results indicated the importance of enhancing storing and picking operations in order to obtain efficient company performance. Applying class-based storing policy reduced pickers travelling distances and in turn minimized the transportation waste. Storing SKUs based on their classes had also positive impacts on the warehouse organization which contributed in reducing the

motion, waiting and over-processing wastes. It also decreased the number of damaged parts in the storing and picking operations.

Table 2: Results of As-Is and To-Be simulation models.

Output variables – lean metrics	Results of CVS simulation model	Results of FVS1 simulation model	Results of FVS2 simulation model
Total Order Cycle Time	30.00	22.00	17.82
Throughput Rate	2.46	3.00	2.82
Labor Utilization	30%	68%	55%
Equipment Utilization	40%	63%	50%
Number of Lateness Jobs	301	240	101
Total Inventory Level	13304	7500	10000

6 CONCLUSION

Inefficient distribution performance tends to cause a serious challenge to the achievement of a streamlined and waste free supply chain network. Despite the critical role that distribution industry plays in supply chain networks, few publications addressed the lean distribution concept. Without an efficient evaluation for the lean practices effects on the systems performance, lean implementation process could be failed. For this purpose, a value stream mapping and simulation model are integrated in a lean assessment framework to quantitatively evaluate two lean practices – pull replenishment and class-based storage policies .

The study results provide a clear vision of the consequences of applying the two lean strategies on the studied lean metrics. It was concluded that pull replenishment and CBS policies have respectively reduced order cycle time by 26% and 40%, increased the throughput rate by 21% and 16%, decreased the number of lateness jobs by 20% and 66%, reduced inventory level by 40% and 25%, enhanced labors utilization by 38% and 25%, and finally increased equipment utilization by 23% and 20%.

Future work is to include the evaluation of the interaction between different future state VSMs using design of experiments techniques (e.g., ANOVA). The application of the framework can also consider using system dynamics approach for strategic decisions analysis.

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