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Abstract: **In response to global recession and increased competition, organizations have tried to become more efficient by decreasing costs and streamlining operations. To achieve this, the philosophy of lean management has gained in popularity. The main obstacle organizations face when implementing lean is deciding which activities to implement lean principals on. A well known lean practice, value stream mapping, is a very effective tool in mapping the current and future state of an organizations lean activities. Limitations in calculating variability information that describe system variations and uncertainty means more powerful analytical tools are needed. Simulation offers a more thorough analysis of a system's data, including the examination of variability and has the ability to change certain parameters and measure key lean performance indicators. Using a tire distribution company as a case study, this paper has developed a framework that uses discrete event simulation as an integrative layer between current and future value stream mapping. The framework maps current state value and non-value activities in the company and through simulation has highlighted the activities that should be used when developing the future state map. This paper has highlighted simulation as a crucial middle layer in value stream mapping that will generate more accurate future state maps than the more common practices of using random estimates and experience alone.**

Keywords-Value stream mapping; distribution center; lean management; discrete event simulation

I. INTRODUCTION

The theory behind lean philosophy is to create more value with less. Over the last decade, competition between organizations has become a matter of not only productivity, but also of overall supply chain performance [1]. Delivering the right quantity of products to the right place and at the right time has become a necessity for supply chain survival in an ever-more-acutely competitive atmosphere [2]. The quest to offer high levels of service to customers, while keeping a worthwhile profit margin, has forced managers to think of new ways to eliminate waste from their internal operations. Lean thinking is one of the most effective techniques managers can use in this ambition.

The 'lean' strategy represents a holistic attack on all negative aspects of resource consumption, and seeks to achieve streamlined and waste-free operations [3]. While the focus of lean thinking literature has essentially been on production systems, the notion can also be stretched to cover every management activity. Recent research [4], [5] attention was directed into the use of simulation modeling in lean implementation and assessment processes due to many reasons including:

1. Identifying the factors and parameters involved in the manufacturing process.
2. Exploring the various opportunities of process improvement.
3. Predicting the impacts of the proposed changes before implementation.
4. Reducing the risks associated with lean implementation process.
5. Mapping the future state of organizations' – value stream mapping.
6. Assessing the interaction influence between system's components and parameters.

Based on the above reasons, primarily 1,3 and 5, and through case study application, this paper has developed a framework (Fig. 1) that uses simulation and modelling as an integrated layer between current and future state value stream maps. To achieve this, Section II will give a background overview of lean management, generally and from the case study perpective of distribution. This is followed by a detailed profile of the case study industry; tire distribution, and the case study tire distriubtion company (hereafter to be known as TDC) in relation to lean implementation in Section III. Section IV will develop a current value stream map of TDC using data collected through extensive field work in the industry. This map will then be used in Section V to build an accurate simuation model of the TDC system that can be analysed in Section VI to aid in a future state value stream map before conslusions and future work are discussed in Section VII.

II. LEAN MANAGEMENT

Lean management as a philosophy, rather than a stand-alone practice, aims to create a streamlined, high quality system that can achieve a high level of customer service with minimum cost with little or no waste. Originating from Toyota Production System (TPS), lean thinking has become one of the most effective management concepts in the world [6]. Lean processes encompass a wide variety of
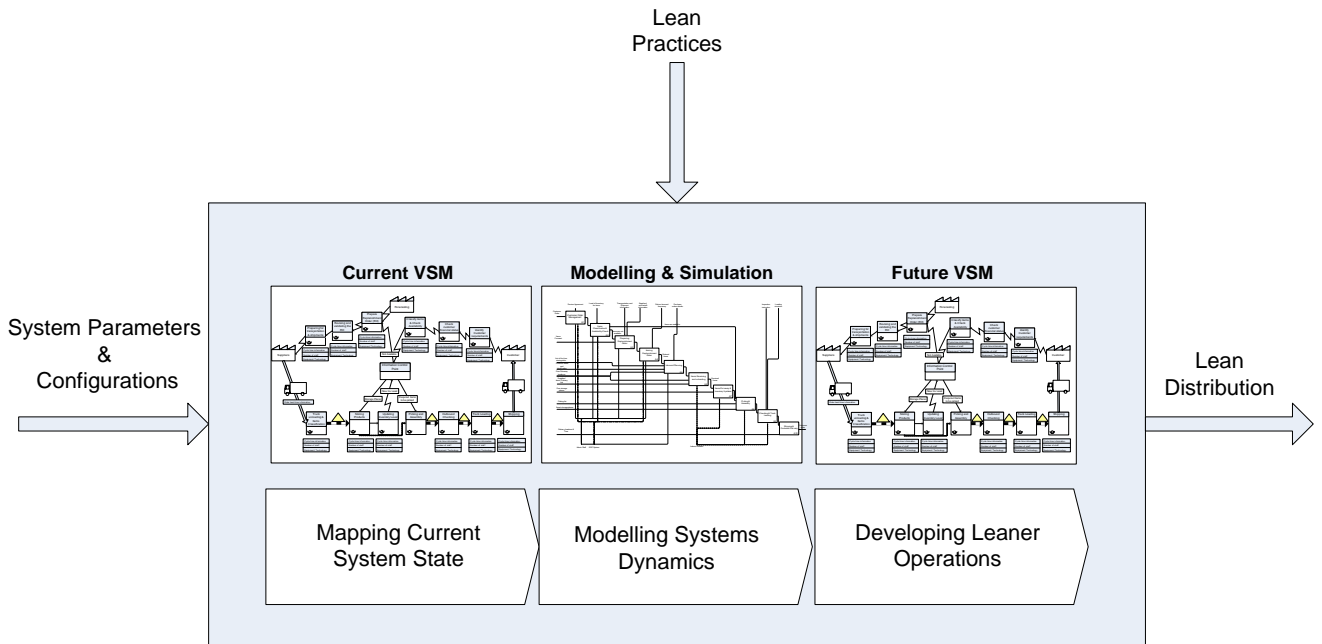
Figure 1. Integrated Value Stream Framework

management practices, and variations in system parameters can have significant impact on its implementation. In the last decade, many authors expanded their lean research beyond manufacturing to include lean services, lean supply chain and lean logistics. As a result, lean definitions became more generic and were identified as a series of activities and strategies that are applied to eliminate operations waste and non-value added processes. Because service applications are subject to a much greater degree of variability than industrial production, new lean practices are required to be applied in service and supply chain environments [7], [8], [9]. Applying lean thinking promotes many changes in system strategies, operational characteristics and human behaviors [10], and has been applied in many manufacturing environments and as many publications have flagged, TPS has given eminent proof of lean capabilities. Survey of the literature reveals the five main principles of lean management to be:

1. Identifying what creates value (from the customer perspective);
2. Identifying value streaming (by understanding all process steps and defining waste);
3. Establishing value flow (without interruption or waiting);
4. Production by pull concept (instead of producing in excess);
5. Achieving perfection (by eliminating all waste elements)

The supply chain environment presented in this paper is that of the distribution center, a strategically critical service provider within the supply chain which has not fully utilized the potential of lean management.

A. Lean Distribution

Despite the continuous growth in academic publications representing the implementation of lean management in service sectors and supply chains, applications of lean on distribution are still scarce [11]. Being the first innovator of lean manufacturing concept in 1960, Toyota is also considered the pioneer in expanding the same concept to other supply chain tiers such as distribution and suppliers [12]. Toyota applied several lean practices on distribution elements such as delivery, ordering, warehouse management, dealers and network structure aiming to reduce the stock level while keeping high service rates [8]. The development of lean practices on distribution by Toyota have been used as the foundations for the development and categorization of lean practices available to the case study company used in this paper.

III. TYRE DISTRIBUTION CENTER CASE STUDY

Intensive global competition, reductions in brand loyalty, increasing tire life spans and high costs of raw materials (e.g., natural rubber, bio-chemical materials) have impacted on tire distributors' financial performance negatively and increased the market pressure upon them. Despite market volumes growing by 2.3% over the seven years of 2003-2008, financial growth was just 2.1% [13], and this unsettled the industry's big players and led to a number of mergers and acquisitions, most notably the alliance of Goodyear Dunlop and Bridgestone/Firestone. In this acute atmosphere tire distributors have had to find efficient ways to cut costs and increase efficiency by reducing waste to survive.

Lean thinking is considered a robust concept to reduce different types of waste, so implementing lean practices acts to promote company competitiveness [14]. The important role that distribution activities play in achieving high customer satisfaction levels has prompted many tire distributors to adopt lean components in full or in part. TDC have agreed to implement lean management techniques to certain activities highlighted using the VSM framework developed in this paper. Because of financial confidentiality reasons, TDC would only allow data to be collected on non-financial specific details therefore total costs could not be measured; therefore this paper has concentrated on information and material flows and the parameters and performance indicators specific to them.

A. Tire Distribution Center

TDC is an Irish based distribution center for one of the biggest brand names in the global tire market. It supplies tires for a wide variety of customers ranged between individual customers to large scale companies which in turn impact on the variety of customer orders regarding to items quantities and types. In order to keep as many customers on board, the company's response to its customers has to be fast, accurate, on-time, with the least possible price. Hence, an advanced enterprise resource planning (ERP) system has been applied to link the customers directly to the distribution internal operations, replenishment process and item availability, providing improved transparency and efficiency for orders manipulation (i.e. information flow). The company also provides the proper capacity of equipments, labor and storage spaces to prevent operations bottlenecks and improve item flow. However, many supply chain and operational

challenges has risen that prompted the company to think about applying different lean practices as noted in Table I. The lean practices represented in Table I have direct impacts on the distribution operations and can be quantitatively evaluated in terms of time and customer satisfaction.

B. Lean Initiatives on TDC Company

During this study, three of the illustrated lean initiatives in Table I are used in the proposed VSM framework. The selection process of these initiatives was based on a series of interviews, focus group and quality circle of the company's planning and operational teams and managers. The selected initiatives are:

1. Aggregate similar tire types in the replenishment process: Receiving large quantity of similar tire types facilitates the unloading and put-away operation. It also results in an easier planning process for put-away as similar types will be stored close together which in turn accelerate the picking and assembly process. The main drawback of this practice is that the replenishment order might take a longer time to be aggregated under this policy which consequently increases order cycle time.

2. Evaluating staff numbers and increasing labor hour productivity: Low utilization of labor hours can be seen as an operational waste. Non-value adding time (also known as vertical time) where staff is still getting paid increases operational cost and cycle time. Reducing duplication of work, unnecessary staff and increased training can increase staff utilization.

3. Increasing the maintenance services frequency for handling equipments: The breakdown of handling equipments negatively impacts on

TABLE I. LEAN INITIATIVES IN TIRE DISTRIBUTION CENTER

Challenges	Lean Initiative	Initiative Type
Details about item's inventory level, replenishment and delivery process are not clear to customers during processing their orders	Applying ERP system linking the ordering information with items' replenishment and delivery information	Customer Satisfaction
The major company's supplier impose restrictions on supplying particular items due to production restriction in his site	Identifying alternative suppliers even with highest price	Customer Satisfaction
High level of variation in customer's order details (e.g. types of items, items quantities) causes a high variability in picking processing time	Leveling customer demand to isolate the variation of customer orders.	Internal Operations
Low utilization and duplication of TDC staff resources.	Identify where staff utilization is poor and combine jobs to decrease staff numbers.	Internal Operations
Supplies send shipping trucks with high variety of tire types and quantities leading to increasing variability in storage plan and put-away processing time	Aggregating similar tire types in one replenishment order	Replenishment order
Long time is taken to create a full truck load before issuing the replenishment order	Decreasing the lot sizes and increasing the frequent of replenishment order	Replenishment orders
The frequency of the breakdowns for handling equipments is very high	Increasing the frequency of maintenance services for such equipments	Quality and Maintenance

items flow and equipments utilization. Applying regular maintenance services in fixed intervals contributes in decreasing the equipments breakdowns and underutilization.

After discussing the proposed lean practices in TDC, the implementation process of the VSM framework took place with the aid of the company's planning and operational staff. The framework (Fig. 1) was applied as follows:

1. Determine the scope of the study

    Various processes are involved to manage TDC's value stream, starting with receiving customer orders and ending with delivering the products to the end-customers. These processes include marketing, sales, finance, forecasting and planning, inbound and outbound operations and shipment. Lean principles can be employed to eliminate the waste and non-value added activities and isolate sources of variation from company entities – processes and parties –, however the scope of this paper will just focus on sales, planning and forecasting, internal operations and delivery processes in addition to the relationships between TDC and their customers and suppliers. This scope matches TDC points of interest and strategic goals.

2. Mapping the system's current state using VSM approach

    The value stream of TDC is similar to the generic distribution value stream of any distribution center. The company has two main ways to receive orders (1) sales team and (2) online purchasing. This area will be discussed in more detail in Section IV.

3. Collecting data concerning TDC processes and resources

    Three input variables are addressed in the VSM-framework; (1) operations processing times, (2) labors/staff hours and (3) equipment capacity (hours). Despite cost being an important dimension in the leanness measurement process; it was not included in the proposed model due to the confidentiality reasons. The data collection process has focused on three input variables by conducting series of interviews, focus groups, and quality circles of planning and operational teams in addition to observations of the operational activities in the distribution center. Historical data about arrival times of customer orders, the quantity of items in each order, the frequency and items quantities in the forecasting process, the breakdown rates of handling equipments and their repair time are also collected and statistically analyzed as a basic requirement for the simulation stage in the next step.

4. Simulation model for current TDC state

    Creating a conceptual model focusing on the relationships between system's components (i.e.

entities and resources) and illustrating their interactions is the first step towards developing a simulation model for the TDC. IDEF language is selected for building the TDC conceptual model where IDEF0 is used to model the upper level of the system illustrating the inputs, outputs, controls and utilized resources for the main functions. This will be discussed further in Section V.

IV. VALUE STREAM MAPPING

A value stream is defined as the collection of activities (value added and non-value added) that are operated to produce a product or service or a combination of both to a customer [15]. These actions consider both information and materials flow within the overall supply chain [16]. The logic behind lean thinking is pursuing the optimisation of the value streams from the consumption point of view by eliminating the waste and non-value added activities. In order to identify the sources of waste, non-value added activities and opportunities of improvement, value stream activities have to be mapped using systematic tools and techniques – value stream mapping technique [15]. The VSM technique demonstrates the material and information flow, maps out value-added and non-value-added activities and provides information about time-based performance. This VSM technique is based on generating a current state map that shows the current performance and conditions of the studied systems and a future state map which serves as the target of improvement actions.

Given VSM features and capabilities, the tool is utilized in the first stage of the framework seeking to map the distribution activities and the types of waste and non-value added actions that are embedded in them (Fig 2). Identifying a generic process structure for the distribution function is the initial step towards creating a generic distribution value stream map. A senior manager in TDC, with 35 years operational experience in a variety of departments was interviewed to gather general information about distribution in TDC and the current shape of its supply chains and activities. The industry's current awareness of lean concepts and practices was also a key topic in the discussions and interviews. Meetings were also held with a number of supply chain and logistics professionals with the aim of determining the essential process structure in distribution sectors.

Initial findings from these discussions led to 14 standard operations in a distribution business, classified into three main categories, outlined in Table II. The operations have been modeled based on the standard operations in Table II yet modified to match TDC processes.
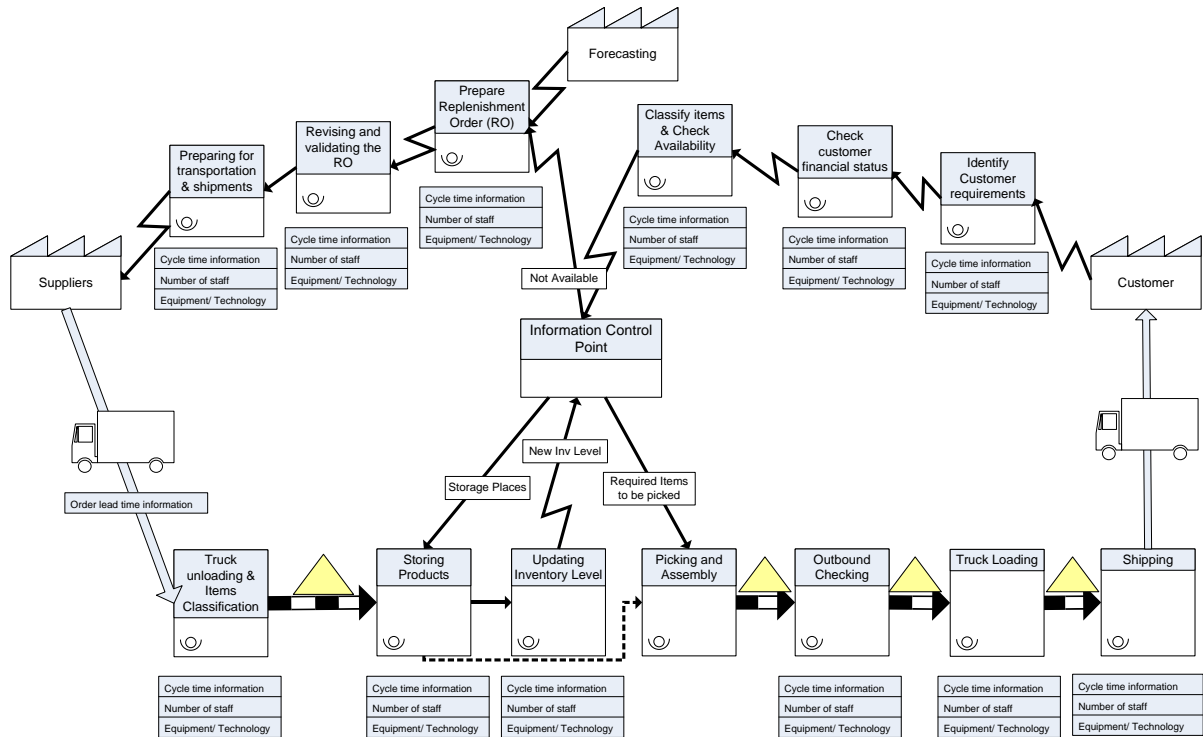
Figure 2. Current State Value Stream Map for TDC

Process Category	Processes
Orders Management	Orders identification
	Replenishment orders preparation
	Transportation arrangements
	Orders validation
	Orders financing
Inbound Management	Inbound planning
	Tipping
	Put-away
Outbound Management	Outbound planning
	Picking/Assembly
	Checking
	Loading
	Outbound Admin

A set of processes usually starts once replenished items are received. The physical flow (i.e. items flow) in this stage is combined with the information flow throughout the whole process starting from items unloading and classification from the received trucks and ended by loading customer trucks with the required orders. Information and physical flows are interacted in various locations in this path; in the storing process for instance the workers receive information of the storage locations that they should use to store the received products and items. Another interaction is observed when information of the items that need to be picked is passed to the picking and assembly staff to start the picking process. Various buffers are built up between some processes due to the variation in their completion times and labors capacity, for instance the buffers between picking,

checking and truck loading processes. The associated data blocks for each process illustrated in the generic state map have shown three different input variables used to distinguish the value added and non-value added status of the modeled processes; total cycle time, number of process staff and resources availability rate (i.e. equipments and technology packages).

VSM has a high quality way of presenting system's parameters such as operations' cycle time and resources capacity and availability; however it does not have the ability to analyze the system settings impact on performance. Similarly, it is also difficult to know if the best future state regarding to the desired level of system performance is achieved. Moreover, value stream maps do not include information regarding variability (i.e. system variations and uncertainty) [17]. Hence, it is required to integrate VSM with another technique that can handle system's variation, show dynamics between system's components, and validate the future state before the real implementation of the improvement steps. Modeling and simulation capabilities can fulfill this requirement. The simulation capabilities will also be represented using the generic distribution structure and parameters mentioned above.

V.   MODELING AND SIMULATION

Simulation can be used to master new business concepts such as agile and lean management [18]. The benefits of using simulation as part of lean and six sigma projects was emphasized by [19]. It has

been published that simulation can be used to 'master Simulation offers more thorough analysis of a system's data including the examination of variability, the determination as to whether the data is homogenous, and the estimation of the probability distribution that fits the data patterns. This kind of in-depth analysis of data enables simulation to be used to support continuous improvement [4] and to model systems' future state map showing the ideal state that the system can pursued over time. The advantage of utilizing simulation approach in lean context is not limited to the phase of developing a future state map but is extended to selecting the best alternative to the current system status. This is not within the scope of this paper, but such selection is done by a carefully designed simulation experiments integrated with optimization tools such as Taguchi and response surface methods.

Based on the simulation capabilities and the potential important role it can demonstrate in the leanness assessment process, a generic simulation model mimics distribution operations and displays the interaction between its components, will be associated to the aforementioned distribution VSM. The model represents the general structure of the distribution processes, operations rules, items flow and resources and is developed through two main phases; (1) creating the conceptual distribution model using Integrated Definition Language (IDEF0) (Fig. 3) and (2) using the discrete event simulation to mimic the general features of the distribution systems.

A. Simulation Model

The stochastic technique for discrete-event simulation is selected due to its capability of dealing with the uncertainty resulted by customer demand patterns, the variability in operations times and resources availability in addition to high variance in handling systems [20]. A computer simulation model based on the IDEF0 conceptual model shown in Figure 3 was developed. The model assumptions are (i) no returnable items are modeled (ii) the resources availability rates are based on data collected from managers and (iii) the model focuses on the generic features (Table II) of the distribution activities. The model uses entities to describe the items movement through the distribution center, while resources represent the handling equipments, tools and labor that modify the entities. Resources are characterized by their capacity and availability, whilst the attributes of the entities are arrival time and processing time. Logical entities simulate the decisions for creating, joining, splitting, buffering and branching entities. Each product type has its own information (i.e. level of inventory, safety stock level, forecasting range and its supplier). As previously mentioned, the original purpose of the model is to accurately assess the system's leanness by handling its variability and uncertainty as well as clearly estimating the system's future state after lean practices implementation.

Both the current state VSM parameters and the future state VSM parameters will be simulated measuring the following performance indicators:
1. Cycle Time
2. Number of Late Jobs
3. Labor Utilization

The current state VSM has one scenario simulated; before lean implementation, which has no changes to current inputs. The future state VSM runs under
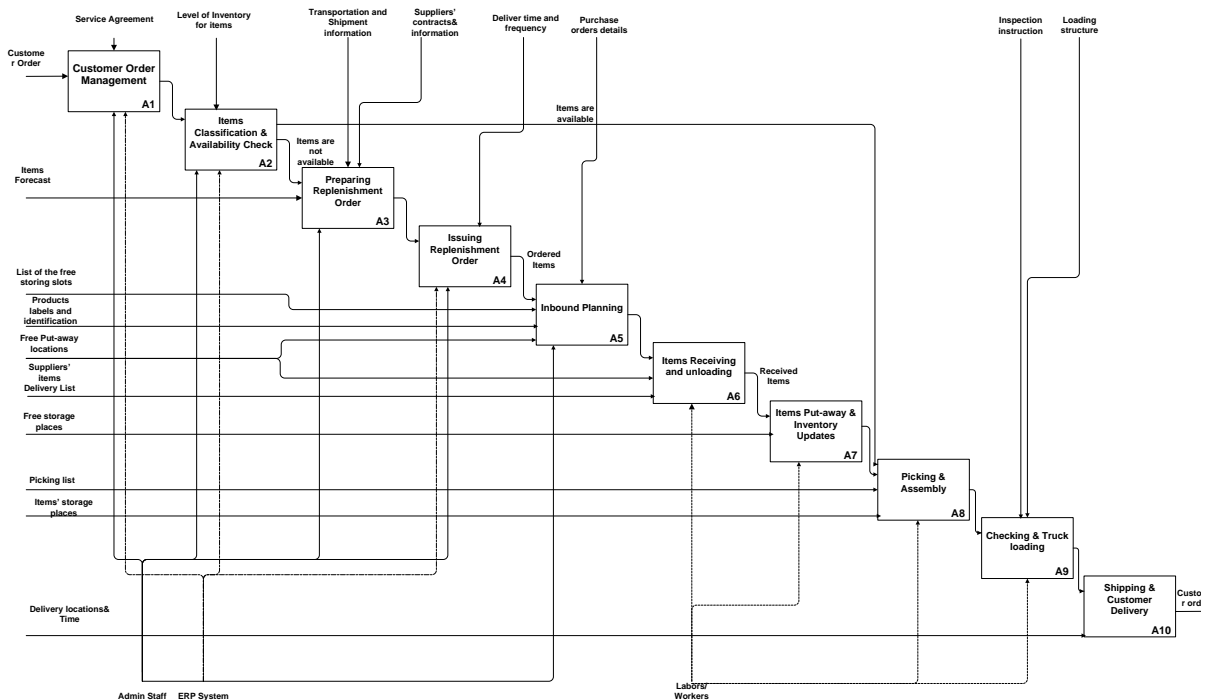

Figure 3. IDEF0 Model of TDC Operations

three different lean management scenarios as discussed in Section III. They are; aggregated orders, maintenance and labor resources. The process parameters included in the new scenarios are; truck load quantities, equipment downtime and number of staff respectively.

For the model to reach its steady state condition, the warm-up period was found to be 48 hours. Every simulation run represents one month of actual timing. Each experiment result is an average of twelve independent replications

The simulation model used to model the distribution processes has used a generic package of simulation and customized it using Java and XML technologies. This selection provides flexible and efficient simulation model for three reasons; (1) it helps to provide object-oriented hierarchical and event-driven simulation capabilities for modeling such large-scale application, (2) It utilizes breakthrough activity-based modeling paradigm (i.e. real world activities such as assembly, batching and branching), and finally (3) it also used to customize objects in the package to mimic the real-life application characteristics.

In an effort to make the decisions taken based on simulation models more accurate, efficient methods of verification and validation are needed. For the verification process, in addition to decomposition model (i.e. to verify every group of blocks), a simulation software built-in debugger is used. A decomposition approach is effective in the detection of errors and insuring that every block functions as expected. The studied model has been validated using a 'Face Validation' approach that was performed by interviewing managers and operations teams in order to validate the structure of the generic simulation model.

VI. RESULTS ANALYSIS

The uncertain nature of customer demands and suppliers' lead time makes it difficult to select the best system process parameters that can achieve high level of customer satisfaction (i.e. short cycle time and no late orders) while achieving the goals set out in the VSM. The core theme throughout

this paper was to measure the impact certain individual lean process parameters would have on the system before developing a future state VSM. The average results of each simulation run can be seen in Table III.

Decreasing the aggregated orders by nearly 60% has had a significant impact on both cycle time and late jobs, decreasing by 13 days and 3.5 orders respectively, but not surprisingly has not improved labor utilization. Less time spent waiting to replenish orders decreases cycle time which in turn will decrease the chance of delivering orders late, although this may increase total costs as more orders will be shipped more frequently. On the other hand, management's suggestion that decreasing the probability of breakdowns through applying regular maintenance services in fixed intervals did not materialize, suggesting that equipment breakdowns do not have a significant impact on order fulfillment at present. If management implemented these measures using random estimates and experience alone, it would be a costly mistake to make. Scenario 3 decreased the number of labor hours needed to operate TDC by merging many similar activities such as printing picking notes and picking orders, and sales and customer approval activities. This achieved major economies in labor utilization, increasing by just below 70% and decreasing staff numbers by 2. Although cycle time did not change a great amount due to the fact that the same work was being achieved at the same rate, job lateness decreased by 25%, suggesting the decreased staff numbers were more efficient within the same cycle time. Also, the decreased number of staff and increased labor hour productivity would have decreased operations costs and potentially decrease flow rates in the future.

VII. CONCLUSION

With ever increasing market pressure and competition, coupled with a global economic recession and high operating costs it has never been more prevalent for organizations to operate at an optimal level. In response, organizations have tried to become more efficient by decreasing costs and

TABLE III.   MAIN EFFECT OF LEAN PROCESS PARAMETERS ON PERFORMANCE INDICATORS

	VSM	Process Parameter	Results		
			Cycle time (days)	No of Late Jobs	Labor Utilization
Scenario 0 – Before Lean	Current State	No Changes	28.755266	3.666666667	0.264369636
Scenario 1 - Aggregated Orders	Future State	Decrease Aggregated Orders to 500 Tires	15.8524	0.25	0.270327248
Scenario 2 - Maintenance	Future State	Decrease Equipment Breakdowns by 50%	25.263963	4.416666667	0.28268486
Scenario 3 - Labor Resources	Future State	Decrease Staff Numbers and Merge Jobs	27.376786	2.833333333	0.440828095

streamlining operations. To achieve this, the philosophy of lean management has gained in popularity.

Through in-depth industry research, it was found that the main obstacle organizations face when implementing lean is deciding which activities to implement lean principals on and to calculate how optimized their decisions are. A well known lean practice, value stream mapping, is a very effective tool in mapping the current and future state of an organizations lean activities. Limitations in calculating variability information that describe the system variations and uncertainty means more powerful analytical tools are needed.

This paper highlights the potential of using simulation technologies in implementing lean practices. Simulation offers a more thorough analysis of a system's data including the examination of variability and has the ability to change certain parameters and measure key lean performance indicators. Using TDC as an applied case study, this paper presents a framework that uses discrete event simulation as an integrative layer between current and future value stream mapping for lean management. The framework accounts for the current value and non-value activities in the company and through simulation have highlighted the activities that should be used when developing the future state map.

This paper demonstrates how simulation can act as a catalyst layer in value stream mapping in order to provide a more accurate future state when lean implementation process is taken place.

Potential future work with TDC on the framework will include the evaluation of the interaction between various future state VSM's using design of experiments integrated with optimization tools such as Taguchi and response surface methods. The application of the framework will also consider system dynamics modeling.

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