Distribution Center material flow control: a line balancing approach

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Abstract. Distribution Center (DC) operations entail several steps and processes to deliver the product/service to the customer. With processes that entail several steps, it is expected that flow issues will arise. One of the most troubling issues in DCs is the material flow balance, especially in DCs with semi-automated facilities. In such facilities, there is so much reliance on the machines to do the work more efficiently. However, if we do not understand the logic of the machines and the flow, the process become inefficient and we create more bottlenecks and unbalanced production flow between input and output. The objective of this paper is to highlight the DC flow issues in semi-automated flow. More specifically, the paper focuses on the issue of running daily production/material flow based on the number of available people and not the output number required per day. We applied the line balancing approach as one of the lean techniques in managing flow. We developed a line balance tool to help practitioners control the production flow more efficiently.

1. Introduction

Production flow control via lean principles has been widely implemented in manufacturing. More and more implementations of the lean principles are evident in other non-traditional manufacturing processes. For example, lean principles are being implemented in healthcare, banking, and other industries. In this paper, we identified material flow issues and applied one of the lean techniques, namely line balancing, to control material flow issues in Distribution Centers (DC).

Distribution Centers are an important component of the supply chain as they play an important role in overall supply chain management efficiency. Similar to manufacturing processes, DC operations entail several steps and processes to deliver the product/service to the customer. With processes that entail several steps, it is expected that flow issues will arise. One of the most troubling issues in DCs is the material flow balance, especially in DCs with semi-automated facilities [1]. In such facilities, there is so much reliance on the automation to do the work more efficiently. However, if we do not understand the logic of the automation and the flow, the process become inefficient and we create more bottlenecks and unbalanced production flow between input and output.

This paper is a continuation to our previous research addressing one of the recommendations, “for the DC to achieve higher productivity, it must work on reduce Processing and Overtime where production was run based on the number of people and not the required amount of production” [1]. The objective of this paper is to highlight DC flow issues in semi-automated flow. More specifically, the paper focuses on the issue of running daily production/material flow based on the number of available people and not the output required per day, based on lean manufacturing principles. Finally, we developed a line balance tool to help management control the production flow more efficiently.
Lean manufacturing philosophy has been widely implemented in many different organizations to eliminate non-value added activities [5, 7, 13, 16, 17]. The concept of lean manufacturing was developed to maximize the resource utilization through the minimization of waste [6, 14]. There are five main lean principles which include identifying a value stream, mapping the value stream, creating flow, establishing pull, and seeking perfection [11]. Furthermore, [14] presented the lean road map which gave the detailed guideline for lean manufacturing system implementation. The road map consisted of nineteen elements of lean manufacturing; scheduling, employee perception, value stream mapping (VSM), Takt time, bottleneck process, group technology, cellular manufacturing, U-line manufacturing system, line balancing, flow manufacturing, single minute exchange of die, small lot size, inventory, pull system, Kanban, production leveling, quality at source, Kaizen, and standardized work.

Some of the material flow issues arise from the absence of a holistic view of the systems and a lack of formal procedures [9]. Some of these procedures include the staffing and scheduling of daily production. In scheduling production, one must take into account the production line capacity and try to balance the flow. There are several methods to balance the flow, as well as eliminate waste [8]. For example, [10] practiced line balancing in sewing the line operation of the garment industry. The authors tried to balance the cycle time for various operations and minimize workstations by using a multi-stage integer programming model. [4] reviewed solution methods for the design and balancing problem of production lines, such as assembly and disassembly lines. [3] applied line balancing in process planning and configuration design. [2] applied line balancing to maintain workload smoothing. More recently, [18] presented an optimal layout design by applying line balancing and simulation models. This demonstrates the potential of modeling and simulation as an analysis base for material flow as it does not impact the real production system [12].

Distribution Center (DC) is becoming an integral part of supply chain management with fully automated and high technology operation [1]. Failure to balance material flow in DCs leads to an increase in the throughput time and increases idle time, which leads to material flow inefficiencies, higher production costs, and lower customer satisfaction [15]. There is a paucity of research papers that address DC material flow issues from the lean principles perspective. In this paper, we tried to add to the DC material flow body of knowledge.

2. Methodology
This section presents the data collection method used in our study and the approach. A process map was developed and explained in the first part of this section. Later, the approach in designing the line balancing tool is discussed.

2.1. Data collection and material flow mapping
We collected data for one month in a DC operation in a major retailer’s facility in the United States of America. Figure 1 depicts the material process flow of the DC operations. The material process flow map helps in understanding the complexity of operations flow and the behavior of different types of conveyors. Based on the process flow, there are twelve receiving lanes connected to roller and belt conveyors and four to one merge. Thus, there are three four to one merges, which converge into another merge, referred to as an eight to two merge. There are five depalletization stations with label printers. These stations are connected to a conveyor, which merge into the eight to two merge, as illustrated in Figure 1. Once cartons arrive at the eight to two merge, they are transported into two separate belts, which then converge into a two to one merge. The two to one merge has an overhead bar code scanner, which directs boxes to the designated shipping/palletizing lanes. There are forty shipping and palletizing docks. In addition, cartons with problems, such as unclear bar code or unknown destination, would be directed into a trouble lane (TL). There is a re-circulation lane after the shipping lanes, where cartons have to go back to the eight to one merge and then to a two to one merge in case the inline belts of the shipping lane are full. The lines in Figure 1 represent conveyors with variant speeds. Conveyors are equipped with sensors and a stop/move mechanism. Some of the conveyors are belt-based, while others are roller-based.
2.2. Tool development

To help us balance the material flow from the inbound operations to the outbound operations, we needed to have a visual tool to simplify the concept of line balancing for the management and supervisors of the DC. To do so, we developed a flow simulation model in our previous study [1] to understand the available capacity of the DC (to understand the simulation model details [1]). In this paper, we expanded the simulation model developed in our previous study to include the line balancing concept. To do so, we developed a detailed flow analysis using the same simulation model developed in our previous paper to incorporate additional data. Figure 1 presents additional columns with data required for each operation of the DC material flow. There are two types of data, the first type of data is input by the supervisor in the daily production plan which is explained later based on her/his estimate. The second source of data presented in the columns is coming from the simulation result. For example, Depal1 operation has a capacity of 1,791 cartons per hour. However, the supervisor recommended assigning an operator with a maximum output of 468 cartons per hour. This is presented in the last two columns. The first two columns under Depal1 present the simulation model recommended data, so one can compare the recommendations of the supervisor and the simulation model for better planning, and so on.

The detailed material flow analysis presented in Figure 1 was fed from the line balancing tool named “Daily Production Plan/shift.” The line balancing tool presented in Figure 2 illustrates data related to the material flow from the inbound operations all the way to the outbound operations. In the line balance tool, a supervisor must key-in several pieces of data to visualize whether or not the material flow is balanced or not. There are two bar charts provided with the balance tool to visualize whether the line is balanced or not. The line balancing here is based on the lean concept of Takt time. Takt time is defined as time required, per unit, to meet the customer demand. For example, if we work for 1,000 minutes and the customer demand is 2,000 units per shift, then the Takt time is half a minute, which means we have to produce two units every one minute (1,000 minutes/2,000 units). The Takt time for the example given in Figure 2 was calculated to be 2,092 cartons per hour. Therefore, once the supervisor, or whoever is using this tool, inputs the inbound required production per day, manifested in receiving and Deplas processes, the tool automatically calculated the output (outbound) based on the number of staff recommend by the supervisor and compare it to the simulation model’s recommended output, both numerically and graphically. For example, in Figure 2, the supervisor input 15,000 cartons per shift as the required processing for that shift from receiving, and 15,000 cartons for Deplas to be processed to outbound. The next step is for the supervisor to input the estimated number of staff required for each operation and compare the results with two parameters, the simulation recommendation and the Takt time shown in the bar chart. The supervisor must ensure that the production output meets the Takt time without creating any bottlenecks. Therefore, in our example presented in Figure 2, based on the 30,000 cartons required to be processed per shift, the simulation model recommended a total of 39 operators distributed to each operation as illustrated in each operation. However, the supervisor recommended 35 to make sure that the Takt time is met and not exceed the maximum capacity of the bottleneck presented in the bar chart (8 to 2 merge receiving and Depal). The supervisor should modify the number of operators taking into account the bottleneck and Takt time until reaching the optimal stage of meeting the daily production as efficiently as possible.
Figure 1: detailed material flow analysis

### Detailed Flow Analysis

| Step | Cap Staff Prod/hr | Total staff Prod/hr |
|------|------------------|---------------------|
| Mech | 3223 3223 | 2553 2553 |
| Depal 1 | 1761 468.18 | 2267 2467 |
| Depal 2 | 1757 468.18 | 2341 2547 |
| Depal 3 | 1600 468.18 | 2547 2547 |
| Depal 4 | 1329 468.18 | 2547 2547 |
| Depal 5 | 1137 468.18 | 2547 2547 |

**TOTAL** 2340.9 2809.08

| Step | Cap Staff Prod/hr | Total staff Prod/hr |
|------|------------------|---------------------|
| Mech | 95495 95495 | 2221 2215 |
| Receiving 1 | 425 425 | 2125 1700 |
| Receiving 2 | 425 425 | 2125 1700 |
| Receiving 3 | 425 425 | 2864 2548 |

**TOTAL** 2125 1700

### Receiving

### Shipping

### Palletization

### Inbound

| Step | Cap Staff Prod/hr | Total staff Prod/hr |
|------|------------------|---------------------|
| Mech | 2891 2891 | Throughput 2121 1697 |
| Receiving 1 | Veli 425 | Throughput 2125 1700 |
| Receiving 2 | Veli 425 | Throughput 2125 1700 |
| Receiving 3 | Veli 425 | Throughput 2125 1700 |

**TOTAL** 2125 1700

### Merge

**8 To 2 Merge (Depal)** 2516 2864

**2 To 1 Merge** 2548 1700

### Recirc

**BSL**
3. Results and Discussion

It was important to apply the lean principle of line balancing for the daily production plan to minimize the flow bottlenecks and meet the daily customer demand. The daily production plan presented in Figure 2 shows how important it is to have a visual tool to help balance the lines. As part of the visual tools, the upper left section of the tool determined the daily production requirement. The production goal section is determined by the planner/supervisor on what needs to be processed on a daily basis. For example, in Figure 2, the goal was to process 15,000 cartons from the receiving area and 15,000 from the depalletization area to the shipping area. There are also some parameters a planner needs to take into account, such as what percentage of the material flow was based on operators picking cartons by the unit from the storage area, and what percentage of the material was based on picking an entire pallet from a single location in the storage area. As we can see in our example, 20 percent is case pick and 80 percent is pallet pick. The planner has to assume the percentage of the recirculation rate based on previous runs. The recirculation rate is the percentage of cartons that missed the shipping lanes on the conveyors due to shipping lanes being full and having to continue moving on the conveyor until a shipping lane is available. One last piece of information the planner has to input is the working hours per shift.

![Daily Production Plan/Shift](image)

Figure 2: line balance tool for the daily production plan/shift

Once the data is input by the planner, the tool automatically calculated the numbers presented in Figure 2. There are two sets of information generated by the tool. The first set is based on the simulation model developed in our previous research [1]. The second type of information is based on what the
planner recommended. Referring to Figure 2, the middle section is where the recommended number of people is populated from the simulation model and input by the planner. In the first part of the “staffing-simulation model recommendation,” the tool generated the number of operators required in the upstream process of receiving and palletization, 15 operators in this case. The simulation model also recommended four operators/drivers to move pallets from the shipping lane to the storage area. Four case pickers were recommended by the model, where case pickers drive forklifts and pick the order carton by carton from different locations. Depalletization is in the downstream area as illustrated in Figure 1; five operators were recommended. Finally, 11 operators were recommended by the simulation model for the shipping area upstream, where there are divert confirm for the shipping lanes and direct store delivery (DSD).

Having the numbers generated from the simulation model alongside other important material flow information, such as Takt time and output/outbound, helps the operator make a comparison and better plan and balance the material flow based on the Takt time and bottlenecks. The graph serves as a visualization tool to see the horizontal line representing Takt time and the bars representing both inbound and the main bottleneck in the flow, as discusses in our previous paper [1]. See Figure 1 for clarifications.

In our example presented in Figure 2, the supervisor input a different number of the required operators to balance the flow. For instance, the model recommend five operators for receiving but looking at the bar chart we can see that the number of cartons processed in the receiving operation is below the Takt time based on the supervisor recommendation, but higher in the Takt time from the depalletization operation, and also higher than the “8 to 2” merge capacity. Thus, the number of outbound for the palletization is less than the recommend number from the simulation model and less than the required output, as it is clearly shown under “Outbound” in Figure 2. This requires the planner to go back and modify the number of operators to meet the Takt time required of 2,092 cartons per hour, which is also calculated on the planning sheet, as shown in Figure 2.

From the example presented above, it is clear that a planner for the material flow should have the necessary information about daily production such as the Takt time and bottlenecks to be able to better balance the material flow. However, having a visual tool with graphs depicting the capacity of the bottlenecks next to the required production helps in visualizing the issues and speeds up the daily production plan to balance the material flow. It also helps to have simulated data to help with the balancing decisions to minimize the risk of making wrong flow decisions and ending up with cartons spending a tremendous amount of wasted time traveling on conveyors or waiting in queues to be processed. This addressed the issue of running production based on the number of people and not the required amount of production, which is the objective we were trying to achieve with this paper.

4. Conclusion
In this paper, we address one of the material flow issues in semi-automated DC operations that prevented higher productivity. More specifically, the paper focused on the issue of running daily production/material flow based on the number of available people and not the output required per day, based on lean manufacturing principles. A detailed process map was developed to understand the material flow and bottlenecks presented in the flow. Once the material flow map was created, a line balancing tool was created based on the lean concept of Takt time. The tool took into account the daily production parameters and presented a visual tool where a planner could modify the number of operators to make sure that demand is met.

This paper contributes to the warehousing body of knowledge by highlighting important DC material flow issues in a semi-automated environment. This paper also helps practitioners address the material flow issues by applying the developed tool to reduce waste and increase productivity.

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