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Value Stream Mapping with Simulation to Optimize Stock Levels: Case Study

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Abstract

Value stream mapping (VSM) is a simple tool used to identify the waste present within the processes by mapping the current state. The future state is suggested to eliminate the waste. However, transition from current state to future state has always been a challenge in real life applications. One of the biggest challenge is to determine where to establish continuous flow and controlled stock levels due to numerous reasons, such as probabilistic characteristics of demand, unexpected behaviors, complexity etc. In this context, simulation is used to assess lean improvements, to analyze the system under scenarios based on suggested improvements and to optimize an objective, subject to constraints or requirements. In this paper, a simulation-based optimization approach is proposed to determine optimum stock levels in lean manufacturing, and a case study was carried out for a filter manufacturing department of a tobacco company. The results showed that stock level could be reduced by 50% while reducing the number of machines.

Keywords: VSM ; Simulation ; Optimization ; Lean ; Stock level;

1. Introduction

Lean concepts have gained a lot of attention in order to identify, eliminate, and optimize non-value added (NVA) activities within business processes (Porter, 1985; Govindarajan, 2008). In this context, there are various lean methodologies, such as Just-in-Time (JIT), total productive maintenance (TPM), single-minute exchange of dies (SMED), 5S etc. that have been used widely[3, 4].Value stream mapping (VSM) has been used as a tool to identify current state and to design the future state of the processes based on lean methodologies. However, transition from current state map to future state map has been a challenge due to lack of verification. To overcome this challenge, simulation models are used. Besides reducing the risk of failure, simulation models enable researchers to design the future states in an optimum way even for the complex systems. In general, simulation models can be used for the purposes of validation, decision making and optimization. In this study, simulation modeling is used to optimize controlled stock levels with the objective of building continuous flow. To the best of our knowledge, there is no stepwise guideline where practitioners can design future state maps via simulation-based optimization technique to determine controlled stock levels. In this context, contribution of this study can be listed as follows:

- A stepwise approach from current state map to future state map in VSMs to optimize the controlled stock levels via simulation-based optimization method and
- A case study in filter manufacturing department of a tobacco production company.

The rest of the paper is arranged as follows: In Section2, literature where simulation is being used together with VSM in different types of industrial areas. In Section3, proposed stepwise approach is explained. In Section4, a case study is demonstrated to design a future state in filter manufacturing department of a tobacco production company. Finally, the conclusion from this study is given in Section 5.

2. Literature Review

Value chain was first described by[1], and it is a set of activities that a company performs in order to deliver valuable products. (Govindarajan, 2008)define that the value chain is the interconnected set of all activities that create value, from a basic source of raw materials, through component suppliers, until handing over the final product to consumers. Value stream mapping (VSM) is a value chain tool to illustrate, analyze and improve the activities in production in a way to categorize them value added (VA) or non-value-added (NVA) from customer perspective. In the book titled “Learning to See” [5], transition from current state map to future state map has been described in a stepwise approach for a factory. The book titled “Creating Leveled Pull System "introduced the implementation of pull system in an automotive part supplier thanks to VSM. In addition, it benefits the steps of book “Creating Material

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Flow" [7]in order to provide transfer system of materials, Kanban cards and trays.

Practices revealed that transition from current state to future state needs to be validated before implementation. In this context, researchers attempted to use simulation techniques to enhance VSM approach. There are case studies where simulation models are applied with VSM in various industries such as food [9], furniture [10], automotive [11], painting[12], glass [13], construction [14] etc. Authors of [15] presented about inputs and outputs that could be used for the simulation model and future state map. Simulation is considered as an assessment tool for different future state designs before implementation[16]. Researchers of [17] suggested three different configurations of independent variables, such as setup time, changeover time, routine checks, worker allocations etc. Based on these variables, process performance metrics such as process scrap rate, motion waste, average lead time, work-in-progress (WIP) stocks etc. are compared within the simulation environment. Authors of [18] used multivariate factorial analysis to design future state with to objective of minimizing the average lead time and WIP stocks via production leveling (heijunka) in microelectronics assembly line. ANOVA is applied based on simulation outputs for the different configurations of number of pitch times and arrangement of orders in pitch times. Similarly, [19] have used full factorial analysis to identify the best future state design for the minimization of throughput rate in an assembly line of a construction and mining equipment manufacturer. Researchers of [20] designed future state map with lean methodologies, such as total preventive maintenance, setup time reduction, switching from push system to pull system within steel production factory. They have analyzed single and interaction effects of these improvements via ANOVA. They have emphasized that focusing on only the lean methodologies that have significant effect has also increased the management team's commitment. In the study of [21], design of experiments have been used for the production unit, pacemaker process, production sequence and number of the batches in fishing net manufacturing. According to each scenario, simulation-based optimization tool is used to find the best supermarket sizes. Based on selected supermarket sizes, response values of service level and WIP inventory level is noted for each scenario. Optimum results are obtained via Taguchi method.

3. Methodology

This study presents a stepwise methodology to design future map via using simulation-based optimization. After current state map is completed, following steps should be applied to design a future state with continuous flow in production environment:

a) Calculate takt time – is calculated by dividing total available working time in a day to daily customer demand. It represents the frequency of demand arrival.

b) Estimate cycle time – is estimated for each process according to product proportions. Cycle times should be compelling with takt time. Understanding of cycle time and takt time concepts are very essential to increase the efficiency in future state designs[22].

c) Identify and schedule pacemaker process– If full continuous flow is not possible in the system, a supermarket or FIFO line should be established between last process of system and customer arrival. Based on the type of this flow, pacemaker process that will be scheduled according to pitch levels should be defined.

d) Identify controlled stocks–First aim is to build full continuous flow but most of the time, it is very difficult to build full continuous flow due to various constraints in the system. Therefore, controlled stock areas such as FIFO lines or supermarkets can be used. Optimizing the level of these stock units is the main objective of this paper.

e) Identify process metrics and assumptions of simulation model – Process metrics that have effect on objective function or constraints of the optimization problem should be identified. To simplify simulation model, some assumptions can be considered.

f) Build simulation model – Input analysis should be applied for the demand arrival and machine breakdown and maintenance activities of the processes. For input analysis, Minitab [23] and Easy Fit [24] are used. AnyLogic[25] simulation software is used to build simulation model. Any Logic is based on Java programming language which capable to model even complex systems via using the benefits of object-oriented programming. After simulation model is built, it should be executed to identify the steady-state point. There are broadly four methods for dealing with the initial transient [26]: (i) The model is run-in for a warm-up period until it reaches a steady-state and the data from the warm-up period are deleted. (ii) The initial conditions of the model are set in such that the model is in steady-state from the beginning of the run. (iii) The model is run for a very long time, making the bias effect negligible. (iv) The steady-state parameters are estimated from a short transient simulation run[27].

g) Build optimization model – This process consists of repetitive simulations of a model under different configurations of parameters[28]. AnyLogic's optimization model uses with OptQuest [29] optimization engine. Using grid search algorithms, the OptQuest Engine varies controllable parameters from simulation to simulation to find the optimal parameters for solving a problem[29]. To optimize a simulation model following items should be defined;

I. Decision variables –Initial levels of controlled stock units,x_i^0, are decision variables of optimization model.

II. Objective function – Let x_i^t denote the total number of stock levels in controlled stock unit i during the simulation time t after steady-state point, then the goal of the optimization model is to minimize the average controlled stock units in the system.

$$\min z = (\textstyle\sum_t \sum_i x_i^t)/T \text{ where t} = \{0, 1\ldots\text{T}\} \quad (1)$$

III. Constraints and requirements – Let d^t denote the service level to customer during the simulation time t, then minimum service level requirement r^t should be satisfied:

$$d^t \leq r^t, \forall \text{t} = \{0, 1\ldots\text{T}\} \quad (2)$$

4. Application

A tobacco manufacturing company's filter manufacturing department is considered to apply proposed methodology. The company has a manufacturing facility located in Turkey. Due to legal reasons, name of the company is mentioned as ABCTobacco in this paper. Product and process information is presented with converted values. In the company, production planning department is responsible for scheduling. 30-60-90 days of demand forecasts are received via e-mail. Weekly schedule is prepared in an ERP system. Daily orders are sent to the departments based on weekly schedule. Facility works every weekday. The company works two shifts and each shift is 8 hours. There are breaks in the shifts but during breaks, production is going on with replaced workers.

The facility consists of three departments known as Primary Manufacturing Department (PMD), Filter Manufacturing Department (FMD) and Cigarette Manufacturing Department (CMD). PMD and FMD provide semi-finished products to the CMD that produces finished good.CMD is considered as internal customer of FMD and PMD. In FMD, there are two types of machines: filter maker machines (FMM) and combiner machines (CM).FMM makes base rod filters and CM combines few base rod filters based on some proportions. Raw material of base rod filter is called a stow. There are other materials used in filter production, such as tracetine, charcoal, adhesive, plug wrap etc. however, illustrating one raw material is enough to express current state for simplification. There are two types of filter base rods produced in FMD:mono and charcoal. These products are known as MN2 and CH1 respectively. The combined filter of these two base rods is known as MNCH1.MNCH1has 446 million stick demand in last 100 days. This amount is %80 percent of total demand.

4.1. Current State Map

In machine FM35, product MNCH1 is combined from two base rods: MN2 and CH1. MN2 is produced in machine FM80. CH1 is produced in both machine FM70 and machine FM90. Both combined filters use material named Tow2. Base rods are carried in the trays that contain 4500 filter sticks. There are 28 base rod trays in each base rod pallet. There are 32 trays in each combined filter pallet. Daily demand of MNCH1 is 993 trays. In one tray of MNCH1, there are 1/3 trays of CH1 and 1/3 trays of MN2.In one tray of CH1 there is 2.7 kg Tow2 and in one tray of MN2 there is 3.5 kg of Tow2. According to these proportions, it can be calculated that in one MNCH1 tray, there is 2.1 kg of Tow2. Stock levels are observed while current state map is drawn. These levels are just a snapshot of corresponding day. Figure presents current state map of MNCH1.All stock levels are converted to time unit. This conversion is done based on Little's law [30], which asserts that waiting time in the queue (stock area) is calculated by dividing the inventory amount to daily requirement. Daily requirements should be calculated based on product proportions of MNCH1 as stated in **Table 1**.

Table 1: Conversion of Stock Levels to Time Unit

Material/Product	Stock Level	Daily Requirement	Waiting Time (minute)
MNCH1	3359 tray	993 tray	4871.1
CH1	1600 tray	331 tray	6960.7
MN2	530 tray	331 tray	2305.7
Tow2	95000 kg	2085.3 kg	65602.1

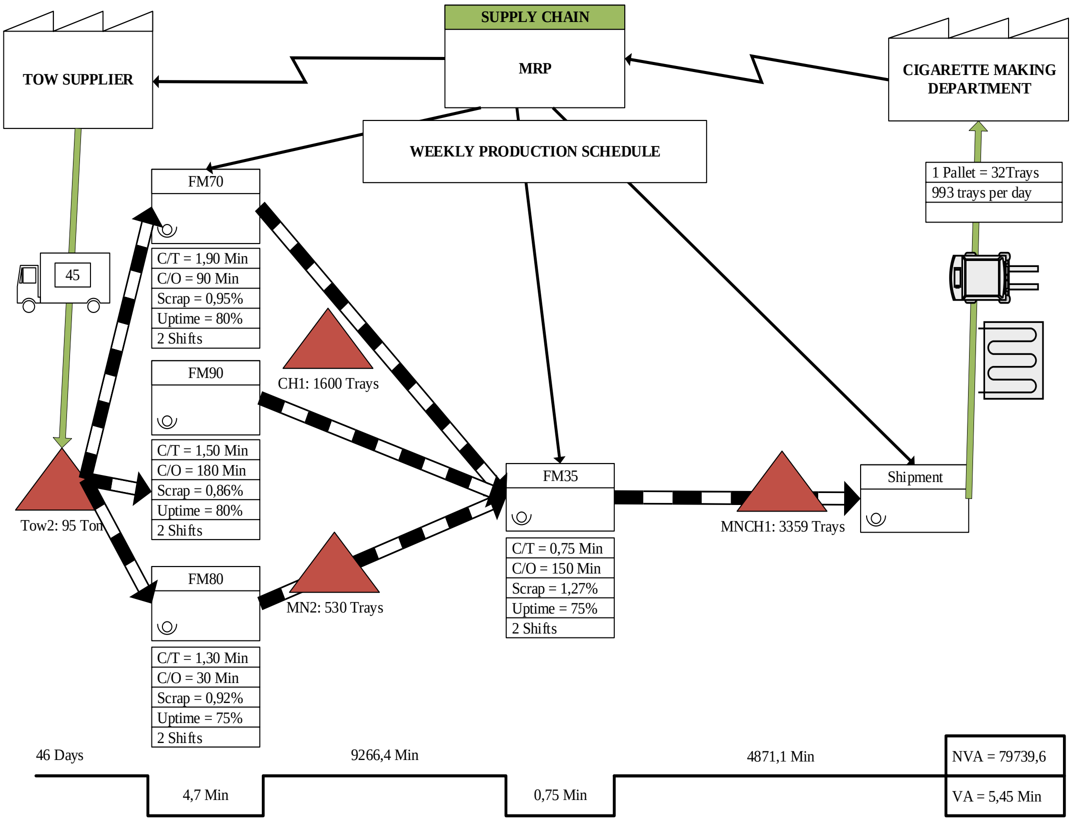

Figure 1: Current State Map of MNCH1

Total non-value added activities for MNCH1 is 79739.6 minutes (apprx. 46 days). Total value added activities take only 5.45 minutes for a tray. The efficiency of the process is percentage of VA activities in whole activities:

$$\text{Efficiency}=\frac{5{,}45}{79739.6+5.45}\times 100=0.007\% \qquad (3)$$

4.1. Future State Map

Future state map is a design that contains suggested improvements to eliminate wastes in current state map. To draw a future state map, proposed stepwise approach is used:

a) Calculate takt time

Takt time shows the frequency of demand arrivals from customer. Takt time for MNCH1 is:

$$\text{Takt time}=\frac{\text{Total available working time(second)}}{\text{Daily demand(tray)}}=$$

$$\frac{16\text{x}60\text{x}60}{993}=58\ \text{(second/tray)} \qquad (4)$$

Customer demands one tray of MNCH1 in each 58 seconds. FMD should work based on this time frame to satisfy customer demand.

b) Estimate cycle time

Cycle times are estimated based on product proportions (Table 2).It demonstrates that cycle times are below the takt time. Since both FM70 and FM90 machines work below takt time, only one machine (FM90) can be assigned for charcoal filter production.

Table 2: Estimated Cycle Times

Work Center	C/T (second/tray)	Proportion in Combined Filter	Estimated C/T (second/tray)
FM70	114	1/3	37.62
FM90	90	1/3	29.70
FM80	78	1/3	25.74
FM35	45	1	45.00

c) Identify and schedule pacemaker process

Pacemaker process that manages the tempo of the system, should be closest process to the customer. FM35 is pacemaker process of FMD. There should be controlled WIP stock area between machine FM35and shipping department, and FIFO rule should be applied there.

Ideally, FM35 should produce each tray at once. This is called as every part every interval (EPEI). When customer demands one tray, the tray should be produced immediately in that interval. This is very difficult due to facts, such as expected and unexpected stops, demand variation, rejects, changeovers, scraps etc. In this study, unit of product is tray and unit of container is pallet. Each pallet should be produced in each interval. Pallet size is decreased from 32 trays to 16 trays in order to work with smaller lot sizes. The leveled time intervals that FM35 should produce is called as pitch (required time to produce one pallet). Pitch of pacemaker process is calculated as:

$$\text{Pitch}=\text{Takt Time}\times\text{Pallet Size}=58\times 16=$$

$$928\ \text{sec}\cong 15\ \text{mins} \qquad (5)$$

FM35 should produce 16 trays in every 15 minutes. The pitch interval is calculated by using the equation:

$$\textit{Pitch Interval}=\textit{Available Time in a Shift}\div\textit{Pitch}=(8\times 60)\div 15=32\ \textit{intervals} \qquad (6)$$

In a shift, there should be 32 production orders for FM35 to produce to FIFO line. In order to visualize the production orders, visual management tools such as Heijunka boxes can be used.

d) Identify controlled stocks

Supermarkets should be established between pacemaker process and upstream processes. Supermarkets should be set for each type of product or material. There will be one supermarket for each CH1 and MN2.In FMD, supermarkets are located next to the pacemaker process (FM35). Base rod machine operators and supervisors can track the stock levels instantly thanks to manufacturing execution system.

Raw materials should be stored in controlled stock areas. Since tow suppliers are located different countries, batch orders should be applied. After pull Kanbans are collected reach to reorder point, supply chain department will order new batches from tow suppliers.

e) Identify process metrics and assumptions of simulation model

Objective function of optimization is based following process metrics:

- Average stock level – is the average of inventory levels of Tow2, MN2, CH1 and MNCH1 in whole system during simulation run.
- Average service level – is calculated by dividing total satisfied customer demands into total demand.

To simplify the simulation model following assumptions are stated:

- Tow supplier is capable to deliver an order once in 10 days.
- Arrival time of produced tray from base rod machine to supermarket is 1 minute.
- Kanban signals for production order go to the upstream processes immediately with a manufacturing execution system.
- When a material is demanded from supermarket or FIFO area, it arrives to work station with no variation.

f) Build simulation model

Input analysis is conducted to build the simulation model for the period of 100 days. Daily demand of MNCH1 is noted based on tray amount. Input analysis of demand arrival reveals that demand fits with Poisson distribution ($p = 0.840$, $\alpha = 0.05$, $\lambda=993$). Distributions and parameters of machine breaks and repairs are given in Table 3 based on historical maintenance logs of machines.

Table 3: Distribution of Maintenance Data

Work Center	Breaks Int. Arr. (hour)	Repair Duration (min)
FM70	Triangular(4,5,6)	Triangular(50,60,70)
FM80	Triangular(4,5,6)	Triangular(20,30,40)
FM90	Triangular(4,5,6)	Triangular(20,30,40)
FM35	Triangular(4,5,6)	Triangular(10,15,20)

Any Logic discrete event simulation blocks are used for modeling (Figure2). In the model, WIP_MN2, WIP_CH1, WIP_MNCH1 and WIP_Tow2 represent the decision variables. Warm-up and simulation run length is identified to discover steady-state of the model.

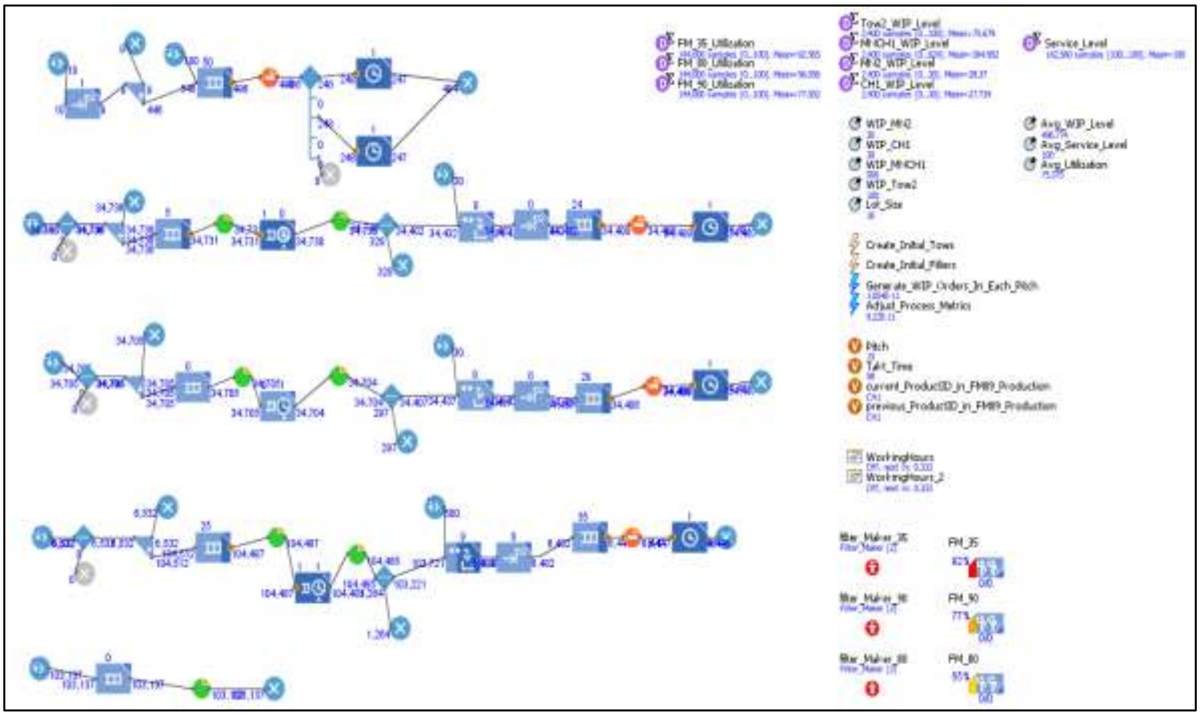

Figure2: Simulation Model for Future State Design

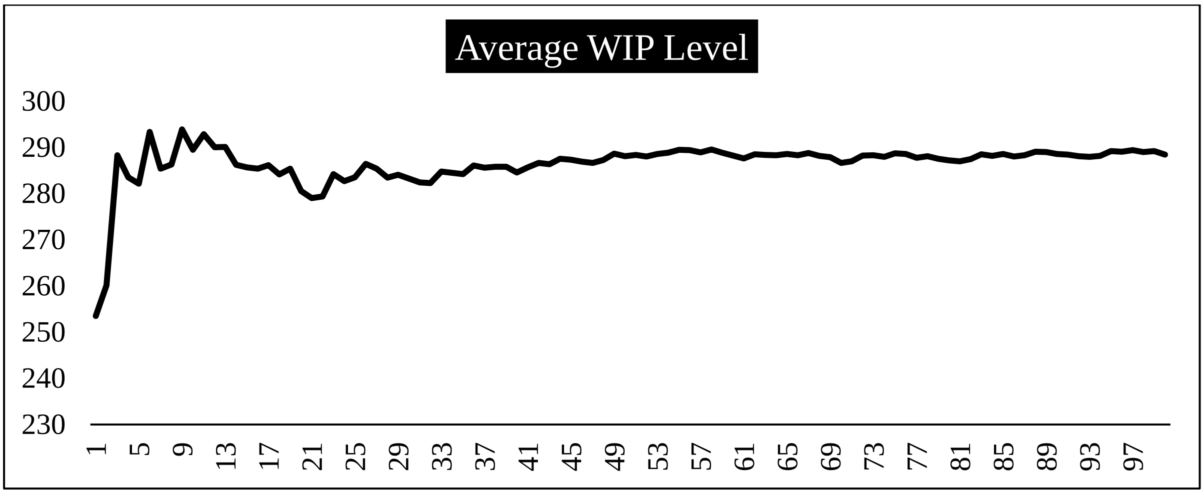

Figure 3: Result of Simulation Run

When simulation run is executed, steady-state for average WIP level is identified as 50th day(Figure 3). Data for input analysis is collected for 100 days, therefore it is enough to have 100 days of output result after steady-state. Since first 50-day period is warm-up period, simulation run length should be 150 days and data should be collected after 50th day after the simulation model reaches to steady-state.

g) Build optimization model

There are 864 iterations that represent different configurations of grid vectors for each controlled stock unit (**Table 4**).Objective function is minimization of the average stock level in the system. Service level constraint is to provide at least 99 percent service level to customer. Optimization model is executed for 150 days (including 50 day warm-up period)with 864 iterations. Data is collected after simulation model reaches to steady state point (50th day).

Table 4: Grid Vectors of Optimization Model

Controlled Stock Unit	Min	Max	Step	Grid Vector
MN2	10	15	1	[10, 11, 12, 13, 14, 15]
CH1	10	15	1	[10, 11, 12, 13, 14, 15]
MNCH1	300	370	10	[300, 310, 320, 330, 340, 350, 360, 370]
Tow2	40	50	5	[40, 45, 50]

When the model is run with a computer featured with 4 GB RAM, 64 bit, it took15 minutes in real time to find optimum solution. Optimum solution indicates that there should be 50 units of Tow2, 10 units of MN2, 15 units of CH1 and 360 units of MNCH1 in the controlled stock areas where 273.16 unit of average WIP stock level in the system. The future state map is drawn based on this solution (**Figure 4**). Future state map reveals that VA time increases from 3.55 min to 5.45 min, NVA time decreased from 79739.6 min to 17910.8 min. Efficiency in future state map (0.02%) is 2.8 times better than current state map (%0.007).Output analysis for the performance metrics of the system is shown (Table 5). Results depict that there is significant improvement in future state not only on inventory levels but also on machine utilizations and service level. Additionally, future state results less variation than current state.

Table 5: Output Analysis of Optimal Solution

Process Metric	**Current State**		**Future State**	
	Mean	**SD**	**Mean**	**SD**
Tow2 Avg. Inventory Level	200.1	20.11	25.77	14.35
MN2 Avg. Inventory Level	1000.9	198.15	8.65	2.14
CH1 Avg. Inventory Level	1499.1	201.66	12.79	3.25
MNCH1 Avg. Inventory Level	3500.0	120.43	236.41	118.43
FM80 Avg. Utilization	54.6	0.13	56.19	0.07
FM90 Avg. Utilization	55.5	0.80	77.61	0.10
FM35 Avg. Utilization	92.6	0.20	94.36	0.13
Avg. Service Level	95.0	13.10	99.11	9.40

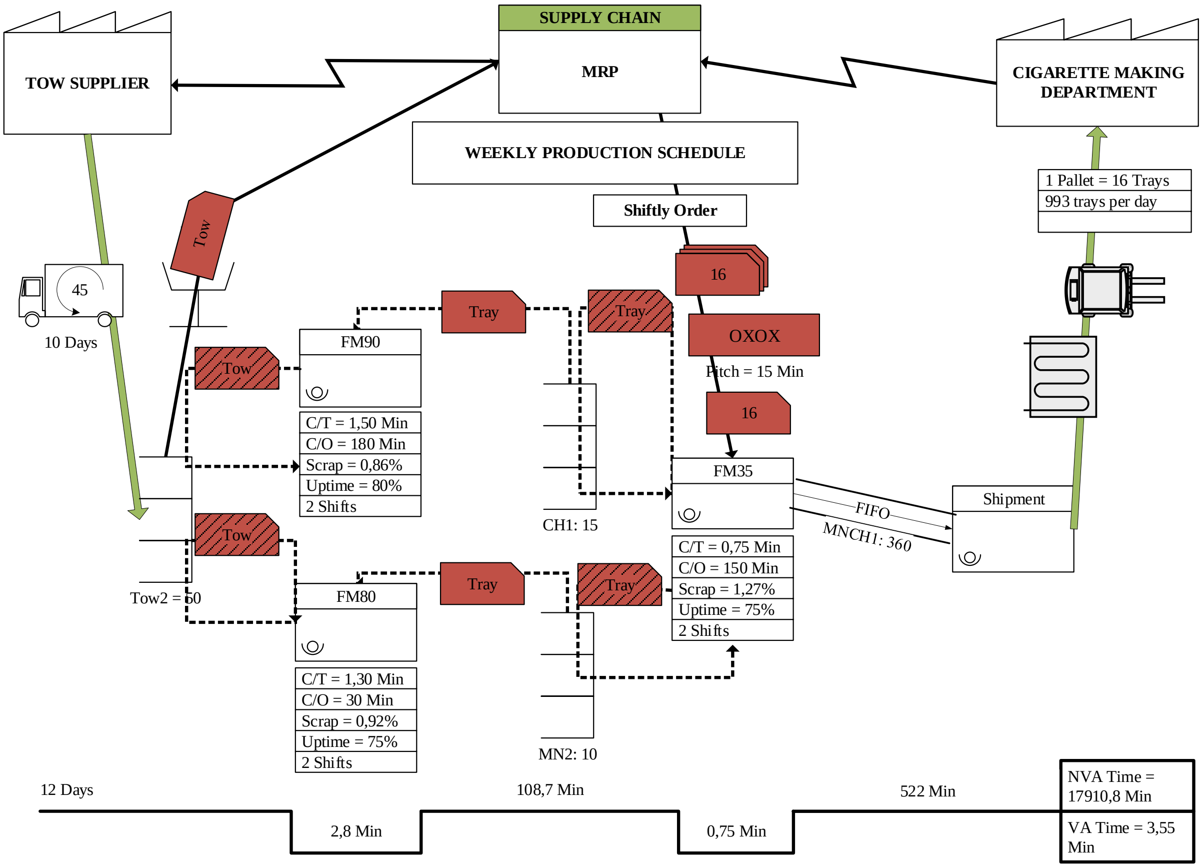

Figure 4: Future State Map of MNCH1

5. Conclusion

In this paper, transition from current state to future state in value stream mapping, has been taken into consideration. After current state map is drawn, stepwise approach is presented to design future state via using simulation-based optimization approach. In this context, filter manufacturing department of a tobacco production company is considered as case study. In the case study, controlled stock areas instead of batch production have been proposed to provide continuous flow within the organization. Levels of controlled stock areas have been determined with simulation-based optimization model. After optimum results of future state design is implemented to simulation model, outputs show that there is significant improvement for inventory levels, machine utilization and service level. Additionally, deviation of current state process metrics is higher than future state process metrics. This demonstrates that future state is working in more stable manner. To sum up these improvements, number of machines assigned to production has been decreased 25%, lot size in the production has been decreased 50%. As a result, efficiency of the system has been improved 2.8 times.

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All data underlying the results are available as part of the article and no additional source data are required.

Consent

There is no written participant data or information in the article.

Competing Interests

No competing interests were disclosed

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