Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669
Research Article
DOI: 10.22067/JSTINP.2023.78113.1017
JSTINP 2023; Vol. 2, No. 1

Analyzing the Manual and Automated Assembly Line Using System Dynamics (SD) Approach

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How to cite this article

Pasha, N., Rabieh, M., Islamifar, G., Razavi Hajiagha, S. H., 2023. Analyzing the Manual and Automated Assembly Line Using System Dynamics (SD) Approach. *Journal of Systems Thinking in Practice*, *2*(1), pp.1-27. doi: 10.22067/JSTINP.2023.78113.1017.
URL: https://jstinp.um.ac.ir/article_43603.html.

ABSTRACT

Improving the responsiveness to customers' orders is the goal of this research. Balancing the manual and automated production lines using proper equipment is crucial for the case study to reduce production costs and increase the quantity. The main problem in this research is responding to orders and demand using the proper equipment and machines in the production line. Using automated equipment can improve productivity and responses, but using advanced technology is not necessarily effective and should be organized in proportion to demands. As in this case study, there are complex cause-and-effects relations; using System Dynamics is very effective. Different productivity factors, delays, orders, etc., are considered to determine the proper production method and equipment in the long term. After that, behavioral reproduction and extreme condition testing validate the model and compare the automated production line equipment percentage usage. According to the volume of orders, the optimum case is suggested. Then, different scenarios related to customer volume are analysed, and finally, the policies are examined. As the simulation results in current conditions and market forecasting indicate, 67.2% of production line equipment should be automated. Any customer order changes can increase or decrease the results, which should be calculated accurately. Considering all the influential factors, the presented model helps the production managers have the best policy for choosing the production method. Using this method, considering some changes in the variables can be used in different industries as optimizing the production line equipment is the main key finding of this research.

Keywords

Manufacturing technology, Master production, Assembly line, System dynamics, Stock and flow diagram.

Article history

Received: 2022-08-10
Revised: 2023-02-23
Accepted: 2023-02-27
Published (Online): 2023-03-15

Number of Figures: 17 **Number of Tables: 4** **Number of Pages: 27** **Number of References: 31**

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1. Introduction

Choosing the proper production method in the manufacturing systems is so high. In this subject, the effective factors are Breakeven Point (BEP), production capacity, and using technology. BEP is one of the evaluation and assessment techniques with an economical approach. In this technique, the relation between cost, income, and volume of production is determined. The costs of production are divided into two categories. One of them is fixed costs (FC), and the other is variable costs (VC) that have a direct relation with production volume fluctuation (Mottaghi and Hosseinzadeh, 2008). The BEP is calculated based on the Benefit-Cost chart, and it's gained from the confluence of benefit and demand probability distribution (Kazemi and Kasaei, 2011). The number of required equipment and human resources calculations is significant, too, and the nominal and actual capacity is required to calculate in proportion to demands (Chase and Jacobs, 2000).

Selection of the technology and production method in different conditions can greatly reduce production costs and capacity growth to respond quickly to customers. When the production volume is high, and the production line works continuously and full-time, the effects of using automated equipment are significant. The flexibility of manufacturing systems in competitive markets has different specifications, such as time of delivery and demand fluctuations (Rezae et al., 2021).

In this research, balancing between manual and automated assembly lines or switching between them is critical to optimize production line processes and accelerate customer order delivery. This research is done in the elevator control panel industry. Responding to the volume of orders in different conditions by choosing the appropriate manufacturing technology and production method is the main problem. Therefore, after the implementation of the model, the type of technology is examined in the form of an analysis of different scenarios to determine the amount of work to be allocated to each line (manual or automated) according to different market conditions.

If the volume of orders is low in the long run, a fully automated line is not justified (because a lot of costs must be incurred to set up a new line), and if it's a manual line and the volume of orders is high in the long terms, the number of lost orders will be increased. Changing the production line to an automated production line according to the calculated numbers is justified. Suppose the capacity difference in the current situation with the orders isn't very high. In that case, switching to another type of production line won't be efficient, and making some changes, such as overtime and shifts, is a better idea. When we face demand fluctuations significantly, it must be concluded that with the existing equipment, many orders are lost. Therefore fundamental changes in equipment technology are needed to increase capacity.

As the problem is complex and has causal relations, the stock-flow variables for materials and products are defined, and the model has different delays. We have these delays during the periods, and the problem variables affect each other. Thus, achieving the answer to the problem is a very complex task, so the System Dynamics (SD) model has been used in this research.

During the research, in section two, theoretical foundations and research background is done, and that part refers to the concepts of automation, production planning policies, and product control. In section three, related SD research and their used factors are investigated. The research methodology section explains the concepts of SD, simulation steps, and their definitions. Then the steps of this method are used in a case study in the electronics industry. After creating and validating the SD model, different scenarios are examined, and the results are investigated.

2. Theoretical foundations

Production planning is essential in manufacturing systems to utilize the material and human resources allocated to each task. It involves scheduling and organizing the manufacturing processes in a plant. These production processes require long-term, medium-term, and short-term scheduling. Master Production Scheduling (MPS) is medium-term planning related to the company's strategies and operational planning. It includes capacity constraints, forecasting, production planning, lead time, customer orders, etc. (Nabovati and Taherian, 2012). Final assembly scheduling (FAS) or Shop-Floor Control is short-term and generally known as production activity control. The relevant department or production control unit has the task of scheduling and monitoring daily production in the workshop production, as well as sequencing operations and monitoring production processes (Feizabadi et al., 2008). As automated equipment reduces physical work, system interaction is also affected. In this status, workers' goal is growth in automation, and they manage different machines (Frank et al.,2017). Different methods have been proposed to analyze the performance of manufacturing systems, such as assembly lines, lead Time, WIP, demand response, etc., which are the critical factors considered (Park and Jingshan, 2018). Using advanced technology will improve utilization decrease setup time and WIPs, and LTs, so evaluation of this advanced manufacturing systems performance that uses these technologies should be analyzed to get the optimal value of utilization and production throughput (Kashif et al., 2017).

3. Literature review

3.1. The investigated application in the SD area

In Table 1, some samples of research related to SD areas in a manufacturing system, manufacturing technology, demand forecasting, and supply chain are done, and at the end of this table, the main variables and required acts are explained. These seven factors were chosen as they have a lot of effects on this study and considered all of the required aspects for this production line.

All seven factors are used in this study, and the investigation related to production planning variables at all levels, such as SS, Backlog, external factors, capacity, BEP, etc., is done in manual and automated production lines.

3.2. Research gap

SD modeling can be a powerful and useful tool for analyzing a study with complex and nonlinear relations. So, SD can be the proper approach by considering the various variables such as production and material planning and related delays and demands for switching between manual and automated production lines. The production, inventory, and forecasting-related variables have not been used as in the previous research. This paper aims to find the best combination of the manual and automated production lines to reach various policies and scenarios testing with simulation methods to respond to the orders. In addition, it’s possible to add other variables in the future.

Table 1. Researches investigation related to SD application in supply chain and manufacturing systems

Researches	Factors							Research variables
	Environmental and Governmental Factors	Demand Forecasting	Demand Forecasting and Capacity	Manufacturing Systems	Supply Chain	Production Planning	Manufacturing Technology	
(Yongan et al., 2012)		✓	✓		✓	✓		Proposing a breakpoint in the leagile supply chain to improve the information system between components, agile the production, and standardize it
(Deif, 2015)				✓			✓	Investigating the variables of production demand rate, production cost, demand diversity goals, scalability cost of technology use, capacity scalability delays, production rate, etc.
(Hoseini et al., 2016)		✓	✓		✓			Checking the variables of warehouse and retail demand, customer demand, factory warehouse, production rate, order rate, distribution changes, reliability storage, consumption rate, etc.
(Rabieh and Yasubi, 2017)		✓	✓		✓			Checking demand fluctuations and variables of WIPs and raw material inventory, inventory of products, orders, delivery time, delivery rate, etc.
(Tama et al., 2017)		✓			✓			Using inventory and demand variables in the model to optimize the profits
(Gallego, and García, 2018)		✓		✓			✓	Investigation of forecast variables, demand, capacity, production time, maintenance, and repairs
(Fontesb and Freires, 2018)		✓	✓		✓			Investigating the variables of resources, demand, production, capacity, overcapacity, and orders in areas related to sustainable and renewable energy supply chain
(Olivares-Aguila, 2019)		✓			✓	✓		Examining unpredictable information variables, active and responsive strategies, distribution planning, and orders
(Jahanian et al., 2020)		✓			✓			Investigating the variables of demand response rate, delivery cost, etc., in the subsystems of demand, sales, and investment

4. Methodology

The system approach means having an integrated view of systemic thinking, including system goals, system elements, system environment, feedback, casual-loop relations, behavior pattern and system delay (Ghobadi, 2011). SD is used in this paper because it's a valuable tool to identify the causes of dynamic behavior in different systems based on system thinking (Bastan and Zarei, 2021). In general, the steps of the modeling process include the 5 main steps of problem definition, mathematical relations, dynamic hypotheses, formulating, testing, and finally, policy design and evaluation (Sterman, 2000). The primary purpose of the research is to select the appropriate share for the production unit for the case study from each technology. In other words, it's related to identifying the proper combination of manual and automatic production methods. So, the main variables in this model have produced products and their cost in manual and automatic modes. Figure 1 shows the research steps.

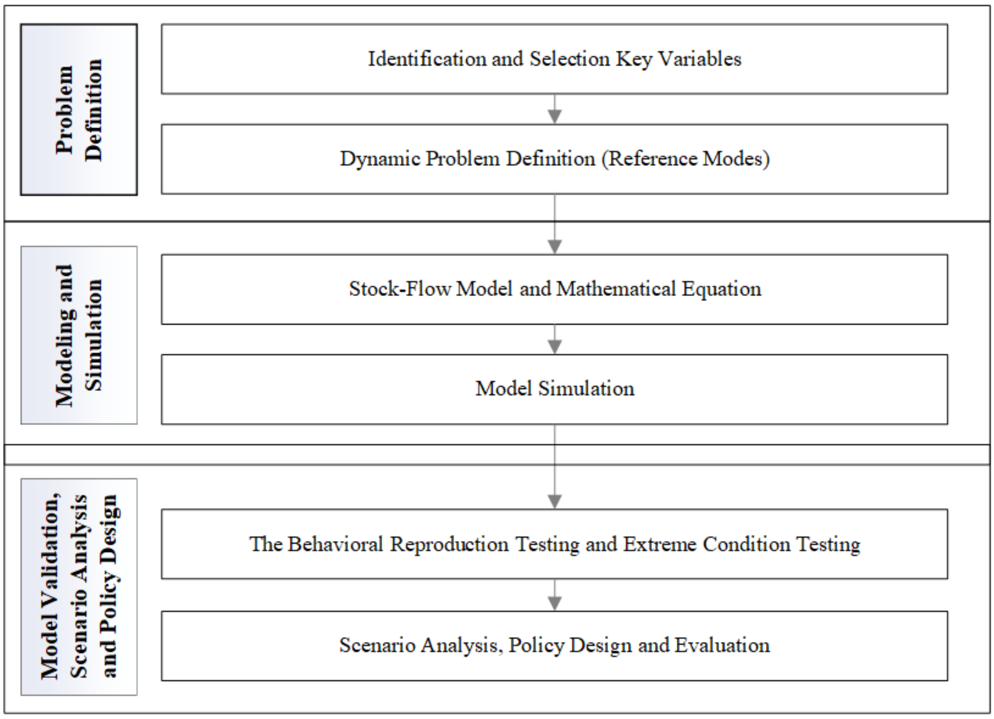

Figure 1. Study steps

The volume of production and the number of customers' demands should be matched. For lean manufacturing, the primary inventory period needs to be minimized (Mehraban, 2005). In the Stock-Flow diagram, the visible inventory is calculated from the deviation of the output rate and the raw material entering rate. The production planning is set based on the demands. Other variables such as Safety Stock (SS), Lead Times, and BEP are effective on them. Based on the production flow variables of two production lines, there are some product delivery influences

DOI: 10.22067/JSTINP.2023.78113.1017

on the demand variable, as the mathematical formulas show. Also, production planning is calculated based on that.

4.1. Problem definition

In this study, balancing the manual and automated production lines and specifying the share of each method for growing the production capacity in proportion to the demands is the main problem of the factory. This balance leads to more customer satisfaction and market development.

The output of two manual and automated production lines is very important to set in proportion to demands. So, which method can better respond to customers and increase the production capacity at a lower cost should be investigated.

Figure 2 shows the data about orders and lost ones in the last seven periods to show the market status.

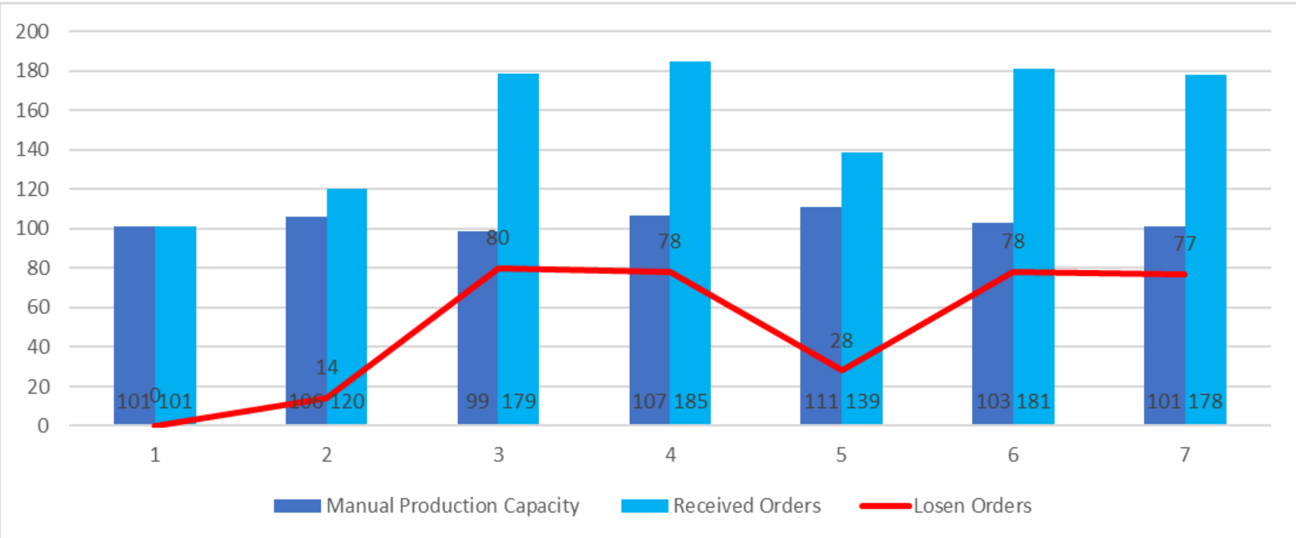

Figure 2. Orders and loosen customers

Figure 3 shows the case study production capacity comparison in the two statuses of production lines. This production line simultaneously has had both manual and automated systems in the past because of the nature of its products. One part of the product has less complexity in manufacturing processes and needs fewer tests.

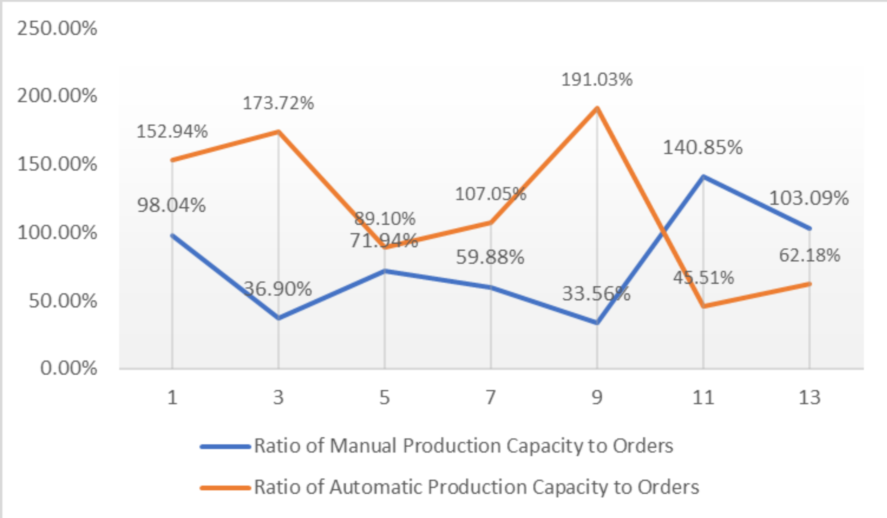

Figure 3. Orders and production capacity comparison

As there is high fluctuation in orders and production capacity is limited to switch from two production line methods, it's imperatively to investigate this accurately that is it possible to hold the production line in the manual status and have other policies such as overtime mechanism or add shifts to response the demands or not. In this case, changing the production line does not cost much; both can be used simultaneously.

As Figure 3 shows, the high volume of customers' orders is lost in the manual production system, and the low production capacity is the reason. Currently, the production line in the manual status provides a limited number of products, and its capacity is less than the automated status, leading to losing many customers. Besides, Figure 4 determines the production capacity ratio for both product lines to the manual one; obviously, responding to all demands and orders is impossible. There is an important notice that shifting the production method should be done in proportion to the demands. If the volume of products is not very high, using the automated equipment will cost a lot and have higher depreciation. So, choosing the manual and automated production lines or both of them to increase production capacity to better respond to customer's orders is the primary goal of this research. The balancing between the production capacity in both assembly lines should be considered. Relation between modelling and literature are:

4.1.1. The model's internal variables

Safety Stock, Master Production Scheduling (MPS), Material Requirement Planning (MRP), Shop-Floor Control (SFC) and required delays are the internal variables considered in the model.

Safety Stock is the volume of inventory in the warehouse stored to prevent the probable shortage of material during their consumption in the production line. The equation of Safety Stock is SS = Z.σ (Korponai et al., 2017).

Another considered variable in this model is manufacturing technology. Using the equipment, machines, and vehicles for the automation of manufacturing processes is very important to increase the productivity of the production line, and it's called automation (Mottaghi and Hoseinzadeh, 2008). Technology development is divided into three periods of the industrial revolution, the primary status, the emergence of semi-automated systems, and the replacement of advanced technologies can be divided (Kazemi and Kasaei, 2011). Using automation in the production management systems, using automated equipment in the manufacturing systems, information systems, etc., and designing the drafts of products is Computer-Aided Design and Manufacturing (CAD/CAM) (Mottaghi and Hoseinzadeh, 2008). The software EPLAN is a CAD software to design the control panel and the automated equipment of Rittal company used to manufacture the products based on the drafts designed using ePlan (www.rittal.us).

4.1.2. The model's external variables

Governmental and environmental factors, customers' demands, and other costs are the model external variables considered in the model.

* Using the Input Analyzer of Arena Rockwell Software estimates the statistical distribution (Keceli and Aydogdu, 2013). After entering the input data and observing the histogram chart and its results, the nearest statistical distribution is chosen (www.arenasimulation.com). For instance, this software shows the fitted statistical distribution in the Normal distribution with μ average and σ standard deviation and Z value (Ross, 2010).

5. Simulation, data analysis, and results

Modeling includes five primary stages problem definition, mathematical relations, dynamic hypotheses, formulating, testing, and finally, policy design and evaluation. These steps include (Sterman, 2000).

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5.1. Model description

This model investigates each of the internal and external factors for the assembly line of electrical panels and revision boxes. One production line is manual, and another is automated (as various robots work in this line) and use Rittal Company devices.

This model considers different factors such as human resources factors, production method, equipment, raw materials, and money (which are different in the two types of assembly lines). In addition, BEP in the single product type and production planning is also considered in the model. Thus, in this production line, BEP, according to the calculations, is different for manual and automatic modes, which have also been modeled. This dynamic model will be simulated for 100 times by VENSIM software. Then the behavior of stock and flow variables and other auxiliary and exogenous variables will be examined.

Reviewing the observed problems and delays, the required corrections are proposed and their impact on the system is investigated. Parameters affecting the observed problems in the two classifications of internal and external factors described are examined and based on them and the identified relationships, effective solutions are provided. In this model, two assembly lines to produce electrical panels and revision boxes are examined and the factors of each are identified. Some variables in this model are used in both product lines. For example, raw materials in supply chain planning, government factors and legislation, and the factors influencing them have been used as a common variables. Still, most of these variables have been examined separately for each process and production line.

In revision box assembly line production, ePlan CAD software, and wire-cutting machines, CAM software is used to spend less time and manpower. However, these devices' procurement cost is much higher as we surveyed Rittal company (www.rittal.us).

5.1.1. Production line 5Ms

The reason for considering 5M factors in this model is that these factors influence internal production processes and their capacity. Based on the internal factors affecting the production of products in this case study, their sub-factors are prepared in the following table. These factors have different relations for the two manual and automatic production lines, and their formulas and mathematical relationships are specified in the appendix. For example, the equipment used in the automated production line and the production method in this line has a completely different process from the manual line. In the manual production line, manpower is used for wiring the control panels. Still, in the automated production line, according to the planning and control panel wiring drafts, manpower is different (although some of them have been modelled according to the needs of the case study company, and in their opinion, other factors do not affect the results of the current model that can be added to the model in the future. For example, the variety of products, returns, and rework products, deficits consideration, new products development, etc.):

– The list of BOM and delivery time are reviewed for both assembly lines. Each factor affects the production system separately, which is examined separately in the modeling section.

5.1.2. The subsystem and model boundary diagram

In this section, factors outside the organization, such as laws enacted by the government, are examined. Figure 4 shows two production line subsystem diagrams for this case study.

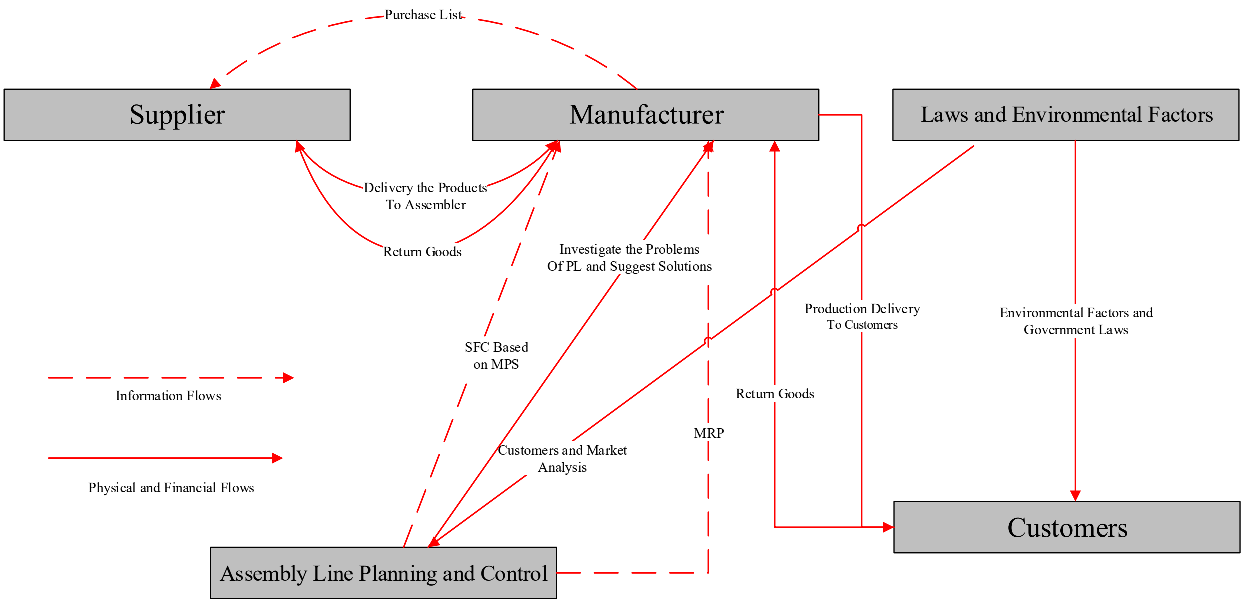

Figure 4. Subsystem diagram for this case study

Table 2 shows the model boundary diagram.

Table 2. The model boundary diagram for the case study

Endogenous variables	Exogenous variables	Ineffective factors in the current model
Production Capacity of Manual and Automated Production Lines, Production Cycle Time of Products, SS and Material Deficit Productions, Master Production Scheduling and Shop Floor Control (SFC), WIPs in production Line and Raw Materials, Production sales of products	Customer Orders and Needs, Fixed Costs, Variable Costs	Production Delivery and Distribution, Raw Material Ordering Method, Design and Development of Products, Operator Learning Rate

5.2. Stock and flow diagram of the case study

Figure 5 shows the primary model of the factors affecting the production line that has been prepared and implemented. As shown in the model, 5M factors are considered in the production line. Factors related to orders and central production planning, such as MPS and SFC, are also considered in the model. WIP or product inventory in the production line and production capacity are also considered in both manual and automated assembly lines. Entry of material depends on production amounts starting from workstations with greater volume from obtained BEP (because this number must be more than the BEP, so it should benefit the company). The amount of MPS and then SFC to respond to the market needs too. It should be noted that currently, some products are done manually and some are done automatically.

Formulating model: Regarding the internal mathematical relations between two manual and automated production lines and the system boundary mentioned, the final model is drawn in Figure 5. The upper production line in the figure is manual and the lower production line is automated. The mathematical relationships of the model and their units are also explained at the end.

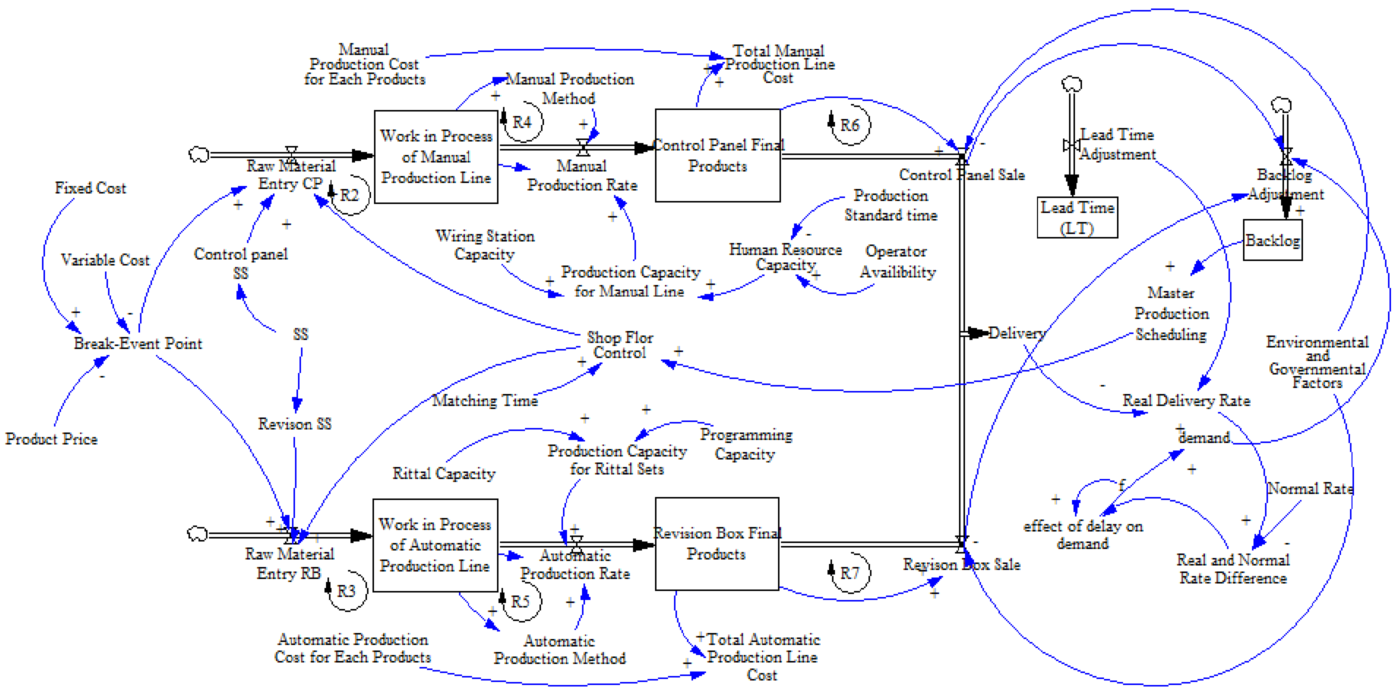

Figure 5. Model of the system (stock and flow diagram)

Also, by comparing the 5M factors in the two manual and automatic assembly lines and their details, all the influential factors that have a significant impact on production performance are considered in this dynamic model. These factors are gained from the interview and meetings

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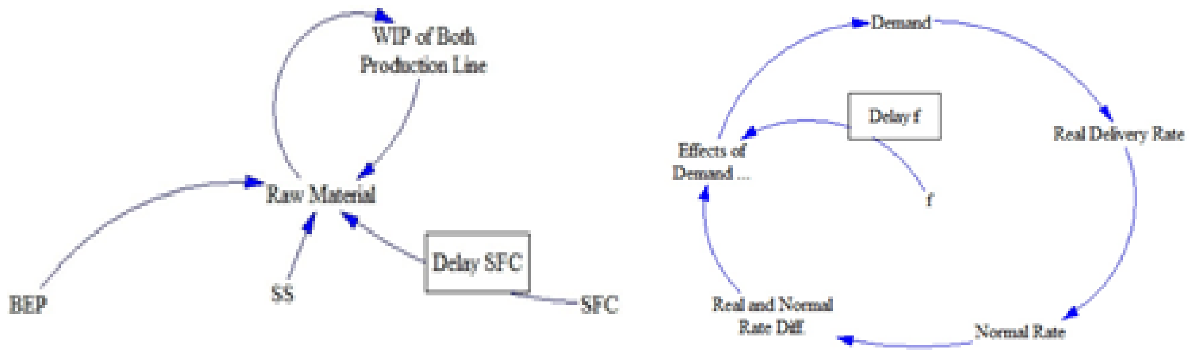
with managers and experts in the production system, and their relationships are considered in the model. Therefore, classifying these factors has given a complete view of the production system to define the variables.

The defined loops in the model: Loop related to raw materials entering the production line and flow and stock variable mode of WIP products in the production line, loop of WIP and production rate of products, flow and stock variable loop with product delivery in two manual and Automated production lines as defined.

Defined delays in the model: The variable of raw material entry in the manual and automated production line as calculated from MPS, SFC, and the effect of demand which is Delay1 type. These delays are defined as the plans are organized, for example, until receiving the next steps, getting orders and announcing to the production line, or preparing the material. So, these delays are considered. Their detailed formulas of them are explained in the appendixes. Figure 6 shows production line and order delays considered in the model.



Manual and automated line delays

Orders delays

Figure 6. Casual diagram for the considered delays

5.3. Model simulation

In this section, the simulation results are investigated separately for all variables. In this model, the Input Analyzer section of Arena software has been used to calculate the statistical distribution of variables based on the previous data gathered. VENSIM software is used to model the problem. This software has been used to calculate the results, prepare reports in different views, and compare graphs for both production lines according to our needs. Figure 7 shows the model, which is the VENSIM software output:

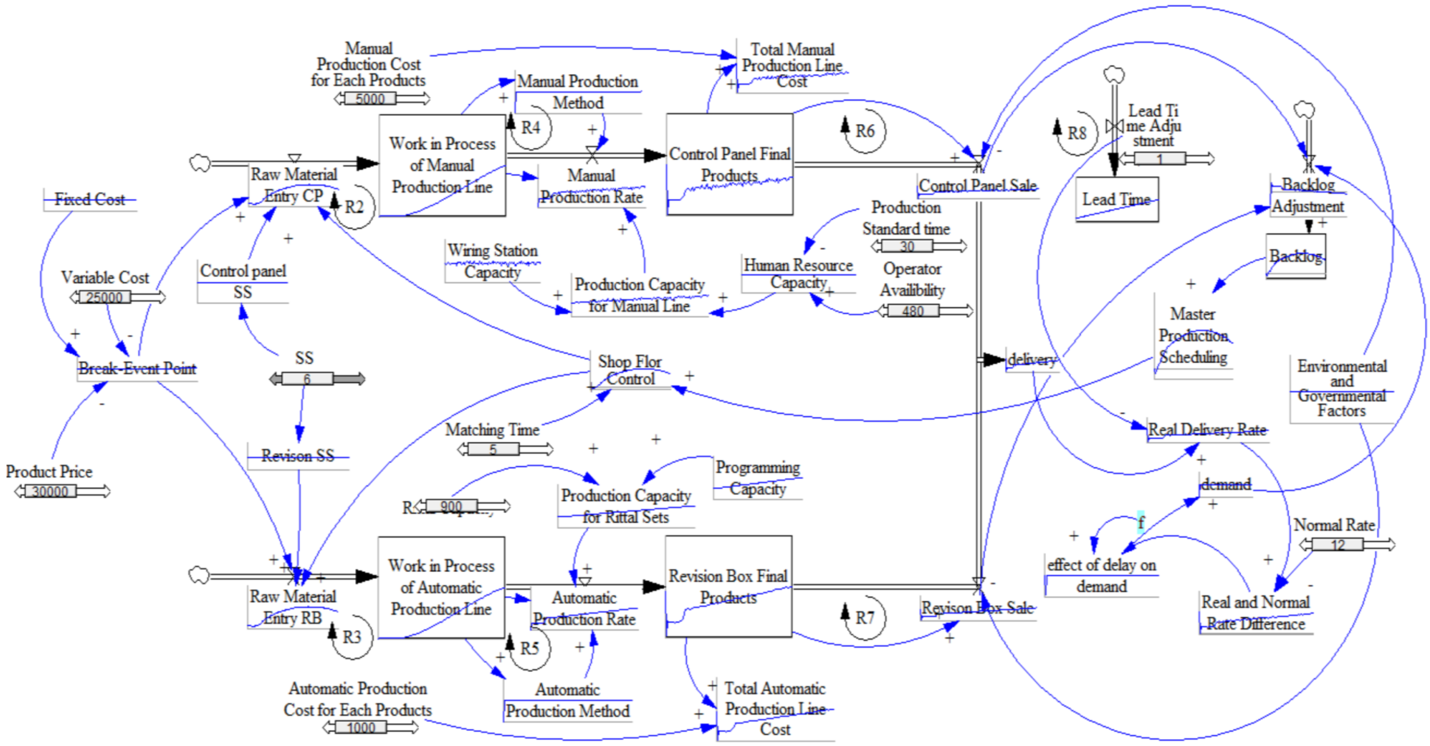


Figure 7. Model simulation by VENSIM software

Figure 8 shows the initial times and costs of implementing automated production machines. But after the period (App. 20 times), the production process will be routine, and the capacity will increase. In manual mode, the production capacity growth is so slow. Thus, this also shows the changing of the production line from manual to automated. Of course, changing some parts of the manual line to an automated one can be another option for production managers.

Also, according to the Figure 8 and based on past evidence from the sales unit, the average level of orders in this production line is close to the amount of revision box production. In general, as the behavior of variables shows, the manual line cannot respond to the orders in the current situation according to the volume of orders considered in the model. Also another goal of this model is to minimize the value of the Backlog.

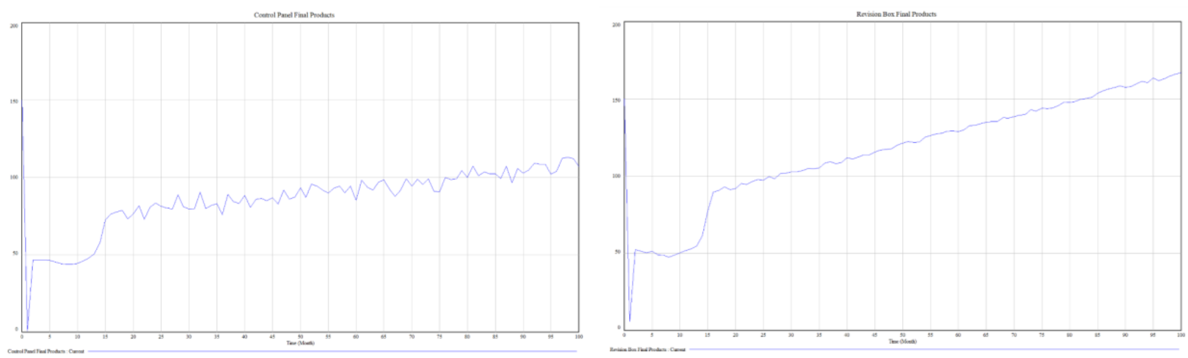

(a) Control Panel Final Products (b) Revision Box Final Products

Figure 8. Comparison of the number of finished products in two types of manual and automated production systems

Figure 8 compares the number of final products in two types of manual and automated production systems.

5.4. Model validation

Behavioral reproduction testing is one of the tests to check the model validation. So in this test, it will be determined whether the model can reproduce the behavior shown by the real system (Menassa and Peña, 2009). This way, the behavior is reproduced to ensure the simulation results are near-real. To perform this test, the real prepared data must be checked with the model simulation results (Sterman, 2000). This model uses behavioural reproduction testing, and the real data related to production capacity are examined with the model's simulation results. A comparison of model simulation results for manual production mode variables and real mode variables is specified in Figure 9.

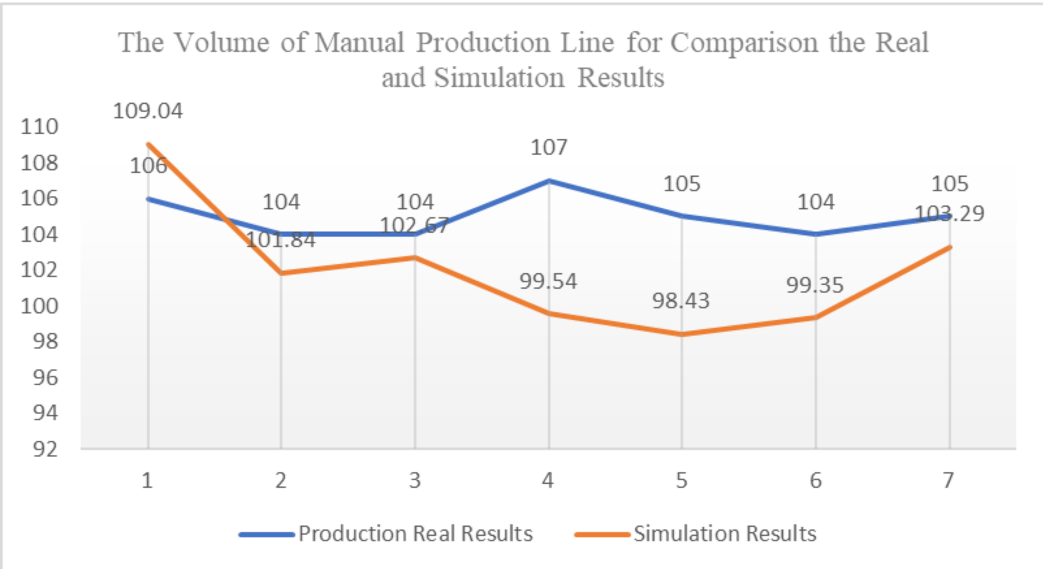


Figure 9. Comparison of the model of simulation results for stock variables in manual production mode and obtained real results

Table 3 shows the calculation of the mean square error relative to the comparison of real and simulation results of the model:

Table 3. Table of mean squares of error (MSE)

f_i	y_i	
109.04	106	$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}(f_i - y_i)^2$
101.84	104	
107.6	104	$f_i =$ Value returned by the model
99.54	107	$y_i =$ Actual value
98.43	105	N = The number of data points
99.35	104	
103.29	105	MSE = 19.86

The relation between this diagram and Figures 4 and 5 also shows frankly that the manual production line cannot respond to production orders in the current situation. Also, due to the above chart and unlimited customer orders, the manual mode imposes many lost customer costs on the system. Of course, by automating the production line, production capacity will also be increased (to 160 products), which should be proportional to the volume of orders. In other words, in this case, 67.2% of the automated mode is better. The behavioral reproduction testing and comparing the orders with the capacity of the manual mode indicates that traditional and manual production is not a good option for the current situation, according to the orders.

Another critical issue that should be considered is whether reducing the volume of orders in the automated system is still suitable. Certainly, In this model, it is possible to examine this issue in detail. By changing the volume of forecasted orders, it is possible to understand how many orders and the manual production system is sufficient. In this model, we considered the BEP and production scheduling (obtained from the volume of orders), and the production line capacity differed in both manual and automated modes. Still, in this case, the volume of orders is so high. And also, manpower and the traditional manual method are very expensive and unfeasible.

By reducing the market needs for the software, Table 4 is obtained that it includes the comparison of automating the production line according to the market demand, which is obtained as follows:

Table 4. Investigate and compare the percentage of automated production line equipment according to the volume of orders

Current status according to the volume of orders							The degree of automation of the production line according to the orders			
Demand		Output	Remained Orders	Automated Production	Manual Production	% of Remained Orders	% of Automating the Production Line as Needed	% of Manulling the Production Line as Needed	Perfect Production in Automated PL	Perfect Production in Manual PL
Demand -40	180	131.15	48.85	157.4	104.9	27.14%	43.100%	56.90%	118.209	61.96
Demand -20	200	134.45	65.55	162	106.9	32.78%	55.600%	44.40%	151.242	48.738
Demand	220	137.85	82.15	166.8	108.9	37.34%	67.2000%	32.80%	184.65	35.36
Demand + 20	240	141.75	98.25	172.4	111.1	40.94%	79.8000%	20.20%	218.127	21.965
Demand + 40	260	145.7	114.3	178	113.4	43.96%	92.2200%	7.78%	251.43	8.63
Demand + 50	270	149.05	120.95	183.6	114.5	44.80%	97.4000%	2.60%	267.55	2.19

The numbers in the above table are obtained from the software output and are calculated after changing the amount of market demand. However, due to the cost of transferring some part of the automated production line to the manual type or vice versa, it is recommended to change the complete production line to the automated type in the current situation. As Table 4 illustrates, in the current situation and according to the results of the model, 83.45 number of products is the difference between the sum of variables (based on the order) minus the production line delivery, so after balancing between two production lines, it will be possible to increase the capacity in proportion to the orders and customers' need.

The model must be stable in extreme condition testing. This test can be done in two methods. Direct inspection of equations is the first method, and simulation is another (Sterman, 2000). Extreme conditional testing is related to some basic behavior tests. This test is related to the correct operation of stock variables. In this method, all the equivalents of the model are examined separately (Barles, 1996).

At the end of this paper, in the "appendix" part all of the used equations are described. Equations 3 and 8 are related to the single product case study; accordingly, the BEP is calculated. Still, the number of materials that should be entered into the production line is the maximum of BEP and the number of SFCs, so this logic is the same for both manual and automated production lines. It should be considered that the case study production system is Make to Stock (MTS).

Equations 4 and 5: The production process begins for manual and automated production lines based on the raw material entering the system.

Equations 6 and 7: WIPs, after the completion of production processes, become the final products, and the sold products must be reduced from them. Also, the production method, production capacity, and also labor of the two production lines are different, which are also considered in the model.

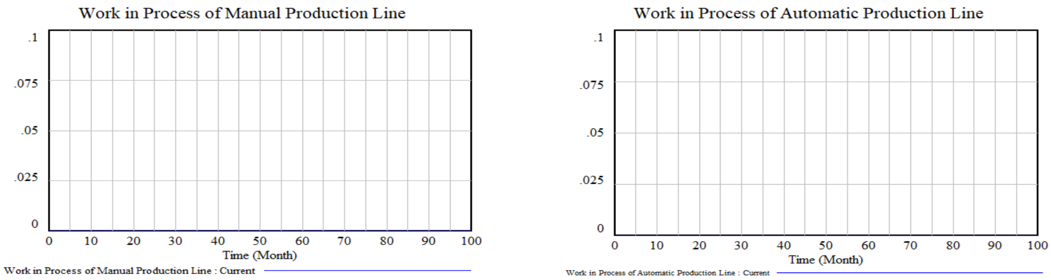
Equation 22: This equation relates to deficits that accumulate in the Backlog Adjustment.

Equation 23: This equation is related to the period from order to delivery of the raw material, which is Lead Time Adjustment accumulated with the initial value of 1.

The extreme condition testing for the case study model is considered as follows:

The following figure shows three graphs related to each case's extreme condition testing results. By minimizing the model inputs, the results are compared with the main results of the problem. The results of the leading and final model are marked in red color and the results of the model related to the input of the model minimization are marked in blue color.

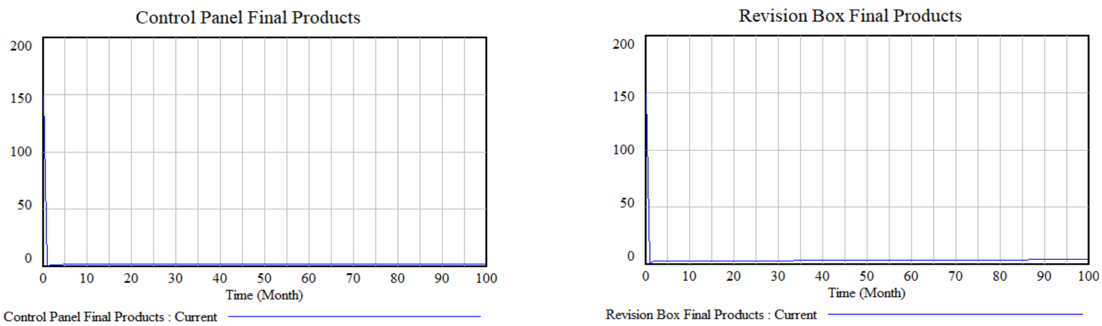
1. Reduce the interval of raw materials to zero (for both manual and automated production lines): A very small number of materials should enter the production line. The MPS and SFC are set, but no material enters the line, so we do not have production. In this case, the production and inventory of products are zero. Hence, the behavior of the stock variables in the inventory mode for products in both manual and automated lines was as follows (Figure 10).



(a) WIP of Manual Production Line (b) WIP of Automated Production Line

Figure 10. Comparison of the results of model in extreme condition testing with zero level of raw material

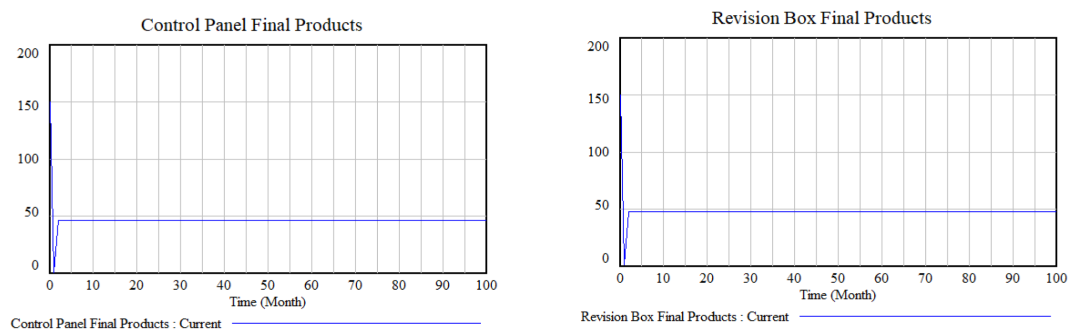
2. Reduce the capacity of the production line to minimum volume (for both manual and automated production lines): In this case, we have demand and purchase order, but the capacity of the manual production line means person/hour, and the capacity of the automated production line means the production capacity of automated machines is reached to minimized level. In this case, the model behavior for produced products in manual and automated lines was as follows (Figure 11).



(a) Control Panel Final Products (b) Revision Box Final Products

Figure 11. Comparison of the results of model in extreme condition testing with minimum demand

3. Reduce the amount of demand to zero: In this case, the amount of MPS and, conversely, the production plan at the workshop level or SFC is adjusted according to the amount of demand, and as a result, the material supply plan is changed accordingly. In this case, only the amount of SS is generated. The model behaviour for the final products produced in manual and automated lines is as follows (Figure 12).



(a) Control Panel Final Products (b) Revision Box Final Products

Figure 12. Comparison of the results of the model in extreme condition testing with zero demand

Also, a system improvement test is done and after increasing the capacity of the automated production line, the number of products in this line has grown.

5.5. Model scenario analysis and policy making to choose best decisions

Defining different scenarios aims to examine the system's behavior in market conditions. That is the basis for considering these scenarios to examine the changes in demand, the amount of MPS, and their impact on the system in this case study. Table 4 compares the percentage of automated production line equipment according to the volume of orders. Regarding the different modes of the system and production methods in these scenarios, the following policies are proposed for the production method.

5.5.1. Scenarios studied on exogenous variables

With increasing or decreasing the external factors and increasing the production volume, if the production line has many changes, it is recommended that the manual production line be located automatically. Because its production cost and capacity are higher in this case, the automated production line does not change and stays automated.

By increasing or decreasing external factors and decreasing the production volume, if the production line does not change much by 20, it is suggested that the automated production line be changed to type manually. Because its production cost and capacity are higher in this case, the manual line should not be changed because automating the line will cost a lot.

Balancing between the manual and automated line is another scenario considered for the production line. In the current production line, transferring part of the technology to the purchase of Rittal company’s automated wiring devices and then training manpower for them can have a lot of side costs, and with a large volume of orders, this work will be recommended, and it is possible.

By increasing or decreasing external factors and decreasing the production volume, if the production line has many changes, it is recommended that the manual line be located automatically. Because its production cost and capacity are higher in this case. The automated line is also recommended not to be changed. Applying the changes to the production line makes it easier to change the programming of devices for automated equipment. Figure 13 shows the production method according to the volume of orders and possible changes comparison in four cases.

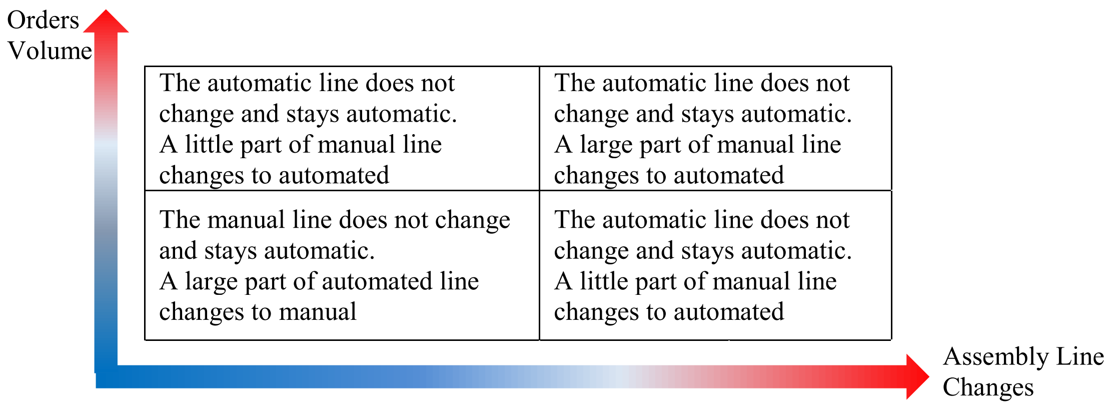


Figure 13. Determine the production method according to the volume of orders and possible changes in the single product line

According to table 4, we investigate the following scenarios with the changes in the normal rate that cause a change in the endogenous variable of demand:

Investigate the first scenario (pessimistic scenario means reducing demand and consequently reducing production): By reducing demand from 20 to 40, the best mode is to have a production line for mode (Demand - 40) with 43.3% automated production system, which in this case 118.2 of products should be produced automatically and 9.61 of products should be manufactured manually, the total number is 180, which fully covers the demand received from customers. The best mode is to have a production line for the mode (Demand - 20) with 44.6% automated mode; in this regard, 151.2 of products should be produced automatically, and 7.48 of them should be produced manually, the total of them is 200, which is fully covered the demand received from customers.

Investigate the second scenario (middle scenario): By keeping the demand constant, the best-case scenario is to have a line with 64.67% automatic mode. Which fully covers the demand received from customers.

Investigate the third scenario (optimistic scenario: it means increasing demand and consequently the profit of the production unit): With increasing demand from 20 to 80, the best case is to have a line for the mode (Demand + 20) with 79.9% automated production, which in this regard 218.1 of the product should be produced in automated line and 21.9 of products should be produced manually, so the total of 240, which fully covers the demand received from customers. The best mode is to have the production line for the mode (Demand + 40) with 92.1% automatic mode, which in this case 251.43 of products should be produced automatically and 8.6 products should be produced manually, the total of which 260 (Figure 14).

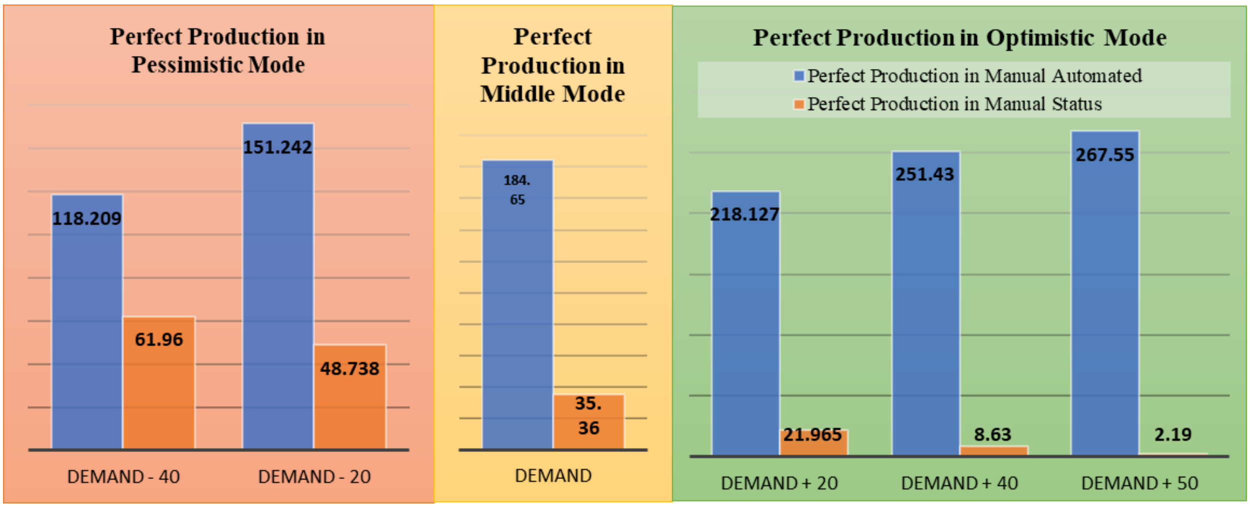


Figure 14. The status of perfect production quantity in three scenarios (pessimistic, moderate, and optimistic)

Investigate the fourth scenario (optimistic state of production capacity): By reducing the production capacity of human resources in the manual line by 0.8 times, the number of manufactured products in the defined conditions in the model for the manual line will be reduced by 90.

Investigate the fifth scenario (pessimistic state of production capacity): By increasing the production capacity of human resources in the manual production line by 1.2 times, the number of manufactured products in the defined conditions in the model for the manual line will decrease by 127.7.

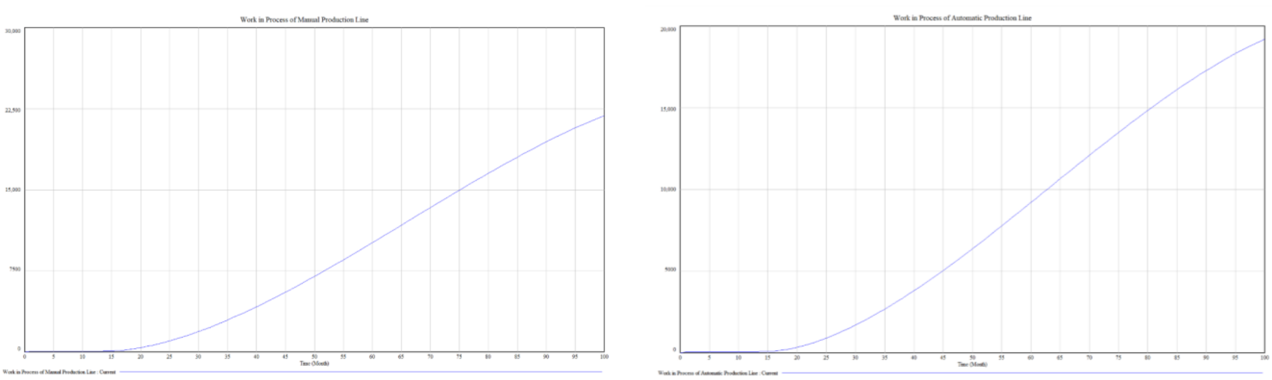
Manual production has much less capacity than automatic mode and human resources capacity in manual mode is minimal. Still, in automated mode, it can be adjusted and programmed according to a specific schedule and work full time. The following diagram compares the workforce capacity of workstations and the production capacity in an automated manufacturing system programmed in the software. By reducing the number of human resources or production capacity, the production capacity of the manual production line will decrease.

DOI: 10.22067/JSTINP.2023.78113.1017

5.5.2. Policies examined on endogenous variables

The proposed policies in this case study that are related to changing the structure of the model and affecting the parameters are as follows:

Policy to change the volume of products in the MPS period and, therefore, its number of products variety each time the program is optimized and examined. Delay reduction policy considered from the MPS to the SFC level to accelerate the response to orders. Figure 15 shows the WIP inventory in two manual and automated production lines in the 100-time units. The charts in Figure 15 compare the WIP inventory in two manual and automatic production lines.



(a) WIP of Manual Production Line

(b) WIP of Automated Production Line

Figure 16. WIP inventory analysis in two cases manual and automated production line

6. Conclusion

The research gap in this paper is using SD to consider the various variables to switch between manual and automated production lines properly. This research aims to find the best combination of the production line equipment to pass demands on time.

In this model, different factors related to production planning are considered. Also, this model can be used for choosing the advanced manufacturing equipment that distinguishes this research from previous ones. However, another variable can be added to this as that system needs. Migrating from basic technology to the next generation of the industry can be very important, so developing this model with more related variables can be possible for future studies.

In summary, the percentage of using automated equipment in the current status of demand is 67.2%, and, in this status, the perfect automated and manual production are 184.6 and 32.2, respectively. Different factors such as BEP, MPS, SFC, backlog, raw material lead time, delivery rate, demand, production capacity for each status of production, and production costs are used in the SD model to solve the problem. Then, the behavioral reproduction testing for this model is investigated to validate the model, and the production volume in the manual method is compared with simulation results. One of the main parts of this research is choosing the proper production line to balance the user manual and automated equipment in proportion to customers' demands.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendixes: Mathematics formulas details in the model

In this model, BEP is considered for the production planning, and for production from the first production station, the maximum break event-point point and the number of production plans obtained from the master production scheduling are considered. Also, in this model, the BEP is considered for the single product mode (Esmaeili, 2012), the formula of which is obtained as follows:

BEP = Fixed Cost / (Price – Variable Cost) (2)

Other processes considered for modelling are the used material, the production line, the production capacity of operators and devices, as well as the production method. The master production scheduling is obtained from the difference between the market needs and the orders produced, and its output is planned at the workshop level, based on which the materials will enter the line. This program is obtained with some delay from the MPS.

The formula below shows the input rate of raw material in the automated manufacturing method:

Raw Material Entry CP = MAX ("Break-Event Point", Shop Flor Control) +Control panel Deficit+DELAY1(Shop Flor Control, 4)/2 (3)

The stock variable for Work-in-Process in manual manufacturing methods is:

$$\text{Work in the process of Manual Production Line} = \int_0^{100} (Raw\ Material\ Entry\ CP - Manual\ Production\ Rate), Stock(t_0 = 0) \quad (4)$$

The stock variable for Work-in-Process in automated manufacturing methods is:

$$\text{Work in the process of Automatic Production Line} = \int_0^{100} (Raw\ Material\ Entry\ RB - Automatic\ Production\ Rate), Stock(t_0 = 0) \quad (5)$$

The stock variable for products in manual manufacturing methods is:

 DOI: 10.22067/JSTINP.2023.78113.1017

$$Control\ Panel\ Final\ Products = \int_0^{100}(Manual\ Production\ Rate - Control\ Panel\ Sale), Stock(t_0 = 150) \quad (6)$$

The stock variable for products in automated manufacturing methods is:

$$Revision\ Box\ Final\ Products = \int_0^{100}(Automatic\ Production\ Rate - Revision\ Box\ Sale), Stock(t_0 = 150) \quad (7)$$

The formula below shows the input rate of raw material in the automated manufacturing method:

Raw Material Entry RB = MAX (Automatic Minimum Production + "Break-Event Point", Shop Flor Control) +Revision Deficit+DELAY1(Shop Flor Control, 4)/2 (8)

Master Production Scheduling and Shop Floor Control are calculated as the formulas below. Besides, between these two variables, there is a delay function:

Master Production Scheduling = (Environmental and Governmental Factors + Backlog)/10 (9)

SS = Safety Stock (10)

Error = Master Production Scheduling-Shop Flor Control (11)

The quantity of control panel and revision box are:

*Revision Box Sale = Revision Box Final Products-Environmental and Governmental Factors*3* (12)

Control Panel Sale= Control Panel Final Products-Environmental and Governmental Factors (13)

Other essential formulas of manual manufacturing are:

Human Resource Capacity = Operator Availability/Production Standard time (14)

Wiring Station capacity = RANDOM NORMAL (11, 17, 14, 0.75, 1) (15)

*Production Capacity for Manual Line = MIN (HR Capacity, Wiring Station Capacity) *5+RAMP(0.352,100)* (16)

The units of all human resources variables are Iranian Rials. Other important formulas of automated manufacturing are:

Programming Capacity = 4+RAMP(0.2, 16, 1000) (17)

Production Capacity for Rittal Sets=MIN(Programming Capacity, Rittal Capacity (18)

To calculate the production costs, the below formula is defined:

*Total Automatic Production Line Cost =Automatic Production Cost for Each Products*Revision Box Final Products* (19)

*Total Manual Production Line Cost = (Control Panel Final Products)*Manual Production Cost for Each Product* (20)

The units of all variable costs are Iranian Rials.

The orders variables of this model have the below formulas:

Real Delivery Rate = Delivery/Lead Time Adjustment (21)

Real and Normal Rate Difference = Real Delivery Rate-Normal Rate (22)

effect of delay on demand = f(Real and Normal Rate Difference) & f = [(-2,0)-(2,2)],(-2,0.2),(1.00917,0.307018),(0.275229,0.622807),(0,1),(0.238532,1.49123),(0.715596,1.77193),(1.27829,1.91228),(2,2) (23)

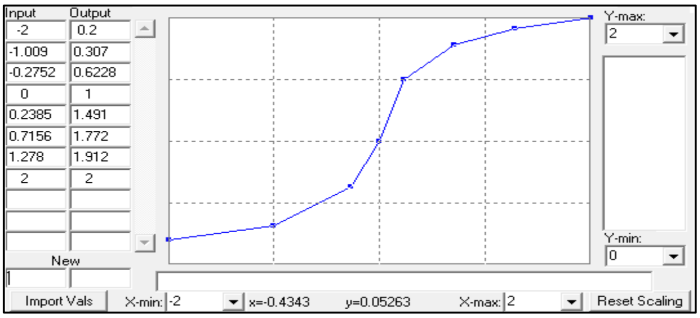

Figure 17. Effect of delay on demand

Backlog= INTEG (Backlog Adjustment,0) (24)

Lead Time= INTEG (Lead Time Adjustment,1) (Unit: Day) (25)

DOI: 10.22067/JSTINP.2023.78113.1017