

# Advanced Value Stream Mapping: Development of a Conceptual Model Considering Variability in Production Processes

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## Abstract

Recently, lean manufacturing (LM) practices are being combined with tools and techniques that belong to other areas of knowledge such as risk management (RM). Value stream mapping (VSM) is a well-known tool in showing the value, the value stream, and the flow, which represents the three lean principles. VSM and RM, when used in tandem with one another, are more advantageous in covering VSM issues such as the variability of production processes. In this article, a conceptual model that integrates the two is shown and explained. The model helps to generate scenarios of current state map (CSM) and future state map (FSM) in a dynamic way by identifying current and potential risks. These risks might happen in the future, bringing with it negative ramifications including not reaching the main objectives within the defined time. The model has been tested in a coffee production company belonging to health and food sector. The proposed model specified the ranges of variability through the drawing of CSM and FSM. This is quite a milestone because one of the challenges of VSM is that it is a static tool, and, as such, process variability cannot be captured appropriately. This new model is expected to overcome this drawback.

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## 1. Introduction

Value stream mapping (VSM) is the most influential lean manufacturing (LM) tools that is usually used as the first step toward understanding where waste is generated. Womack and Jones [1] defined the VSM as a set of established complete arrangements vital to bring about a complete product through a number of serious management tasks. Slack [2] defined it as a nonstop run of product development activities with the nonstop adding of product features such as quality, functionality, and practicality, which directly reported the desires of customers. Rother and Shook [3] simplified that VSM covered all value-added (VA) and non-value-added (NVA) activities that were required to produce a product, starting from raw materials all the way into the hands of the customer.

Fundamentally, VSM is a visual technique that represents the current situation in terms of the flow of information and materials [4]. Using a VSM requires the development of maps—a current state map (CSM) and a future state map (FSM)—both of which show the flow of materials and information.

However, some issues were discovered when applying VSM, and since then studies are looking into combining VSM with other tools to overcome these issues. This article presents an integration of VSM and RM to overcome the variability of data issue in which the traditional VSM cannot identify. A short survey of the literatures showing the importance of overcoming the data variability issue is also given. This article also presents a conceptual model named the variable-VSM (V-VSM) as an integration of VSM and risk management (RM), which has great potential to take VSM to a higher level. The proposed model was tested through a coffee production line as a validation.

## 2. Literature Review

### 2.1. Lean Manufacturing

LM was defined by many researchers. Kim et al. [5] defined it as the incessant conversion of waste into value from the viewpoint of the customers. This is one of the several definitions that can be found in the literatures [6, 7, 8, 9]. LM mainly emphasizes on two key matters: the enhancement of customer satisfaction and the elimination of waste. Waste can be referring to any action in a process that does not add value to the customer [10]. The term “Muda,” represented by the seven categories of wastes, was defined for the first time by Toyota Production System. The types of waste were waiting, transport, overproduction, overprocessing, inventory, motion, and defects [10].

### 2.2. Risk Management

RM is the path of identifying, analyzing, and reporting the connected risks of a project over the existence of the project and in the utmost interest of achieving the objectives of the project [11, 12].

Risk is well known as an incorporation of the probability and the consequence of an unwanted event [13, 14]. Risk identification is the first process that contains sensing and documenting the risks that might affect the project aims and purposes. This is followed by risk assessment, which is supported by either qualitative or quantitative tools/techniques with the intention of comprehend and control the level of each risk, in addition to the likelihood of their occurrences and their impacts. To add, there is risk response planning, where the achiever decides on a suitable plan and strategy to lessen the effect of the sensed risks. Lastly, there is risk monitoring, control, and review processes, where the achiever performs the settled responses, examines their performance, reports to the decision-maker, and fills in the risk assessment data [15].

### 2.3. Value Stream Mapping

The history of VSM is derived from the automotive industry as an analytical aid for material and information flow problems in certain processes. In fact, the actual name of the tool at Toyota is “Material and Information Flow Mapping” or MIFA for “Material and Information Flow Analysis”—not VSM [16, 17]. Oxford English Dictionary [18] defined the phrase “value added” as “the amount by which the value of an article is increased at each stage of its production by the firm or firms producing it, exclusive of the cost of materials and bought-in parts and services.” The value generated in value stream can take the form of any of the attributes illustrated in quality, schedule, and cost, including reduced risk or uncertainty.

### 2.4. Variability and VSM

Although there are numerous benefits to using VSM, there are few drawbacks as well. One of the issues is the variability of data. The VSM shows an image of the system in a particular time. Therefore, it is subjective as it inclines to change depending on the condition wherein the place of work is in and therefore is affected by working constraints (e.g., machine cycle times) and measures of performance (e.g., takt time) of the engineering system [19, 20, 21]. As such, there is an essential for an integral technique to work with VSM that can quantify the variability during the forming of the CSM [22].

The Oxford English Dictionary [18] identified variability as “a lack of consistency or fixed pattern; liability to vary or change.” Dunn [23] stated in his book, *Process Improvement Using Data*, that life would be unexciting without variability, as well as all the statistics would be needless. Shah and Ward [7] stated that the principles and practices of LM were to eliminate waste by concurrently reducing or minimizing variability.

### 2.5. Variability, Uncertainty, and Risk

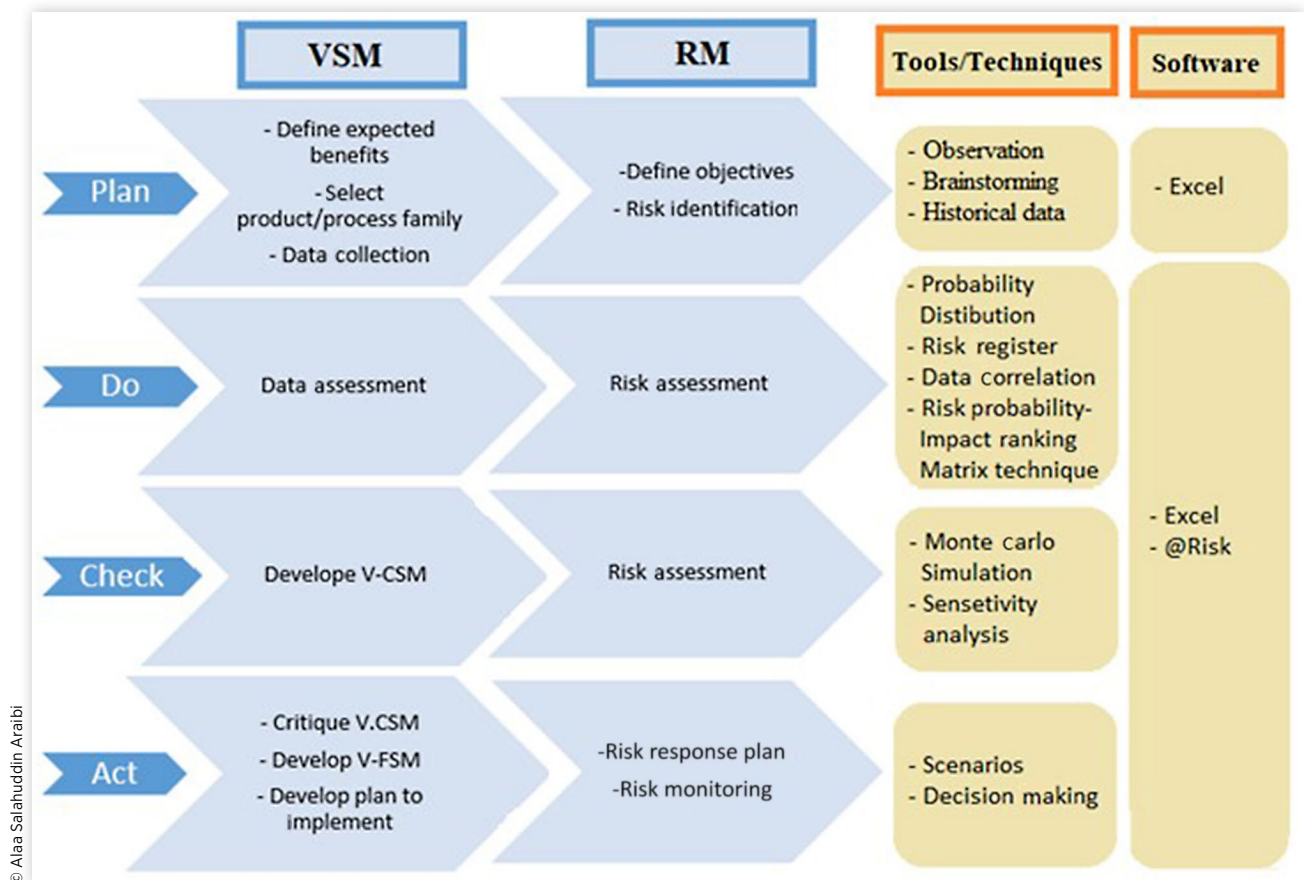
In general, the uncertainty in process may be typified based on reliability issues, lead time (LT) uncertainty, cycle time (CT) uncertainty, breakdowns, and process and/or output yield

variability. Normally, supervisors protect against the effect of process uncertainty by manufacturing larger masses and through upholding inventories from which their contractual requirements can be encountered. Obviously, this derives at the outlay of enlarged production and holding costs which was clearly not lean thinking [24, 25]. Uncertainty leads to the introduction of variability within the process itself, which amplified the risk of not meeting goals [26]. It is important to differentiate between variability and uncertainty. Although both are presented as ranges, uncertainty denotes not knowing the outcome of some quantity. Whereas variability denotes the various values a quantity has at diverse sites, times, or occurrences. Probability distribution is the way to quantify both variability and uncertainty, which carries a main cause of misunderstanding. To be clear, uncertainty relates to the level of experience and the state of data by the decision-maker about the likelihood of the uncertain quantity. Furthermore, variability relates to the rates of various instances of the quantity, resultant from experimental data. Another related term is risk. A risk is a type of uncertain event which itself, or its, consequences, is considered negative to someone in a given context.

### 3. Conceptual Model of Advance VSM

The suggested V-VSM model in this article is under LM and RM theories as shown in Figure 1. The model uses quantitative/qualitative tools and techniques belonging to these two knowledge sets. Such tools and techniques include VSM, Monte Carlo simulation, risk register, probability distribution, risk probability-impact ranking matrix technique, sensitivity analysis, tornado graph, scatter plot, and finally plan-do-check-act (PDCA) cycle as a base of integration. The use of these tools and techniques brings an additional analysis to generate scenarios of CSM and FSM in a manner to take on variability into VSM. The variability is represented through the CT, LT, and work-in-process (WIP) time. It also includes identifying all the potential risks that may occur and the impact of these risks on time, cost, and WIP. These risks can be considered as potential non-value-added (PNVA) activities. Moreover, the V-VSM shows the variability in both variable-CSM (V-CSM) and variable-FSM (V-FSM) drawings.

**FIGURE 1** The integration of VSM and RM into PDCA to build V-VSM model.



As shown in [Figure 1](#), the plan phase is the understanding and identification of the predictable benefits and aims of applying V-VSM followed by collecting the available data from the decision-maker. The do phase is the submission of quantitative and qualitative assessment techniques along with collecting additional appropriate data represented by risks for each process or step along the production processes. The check phase is the summarization, analyzation, and review of a scenario of data through Monte Carlo simulation. Moreover, the V-CSM will be drawn through this phase. Finally, the act phase will be through communicating the results with the decision-maker. If the results are appropriate, the V-FSM will be built through optimizing the V-CSM and within the dynamic manufacturing environment, these phases will be continuously repeated to get continuous improved results. After inserting the collected data into the model, the expected outputs for each phase are shown in [Figure 2](#).

## 4. Validation of the Model, Results, and Discussion

A health and food industry placed in Kedah/Malaysia was selected to validate the developed model (V-VSM). The collected data were from the time a customer places an order until the delivery of that order. A team consisting of the researcher and three employees inside the coffee production department was made and participated through the application of the model. Company visits were scheduled for seven days in one month.

### 4.1. Plan Phase

The first step in this phase was to determine which product families would be the focus of using the V-VSM model. In choosing the product family, the aim was to focus on the most highly demanded products, which are coffee products. The chosen family was highly recommended by the company CEO

as well as the employees. The family consists of six products of different types of coffee having the same flow of information and materials through the shop's various work cells.

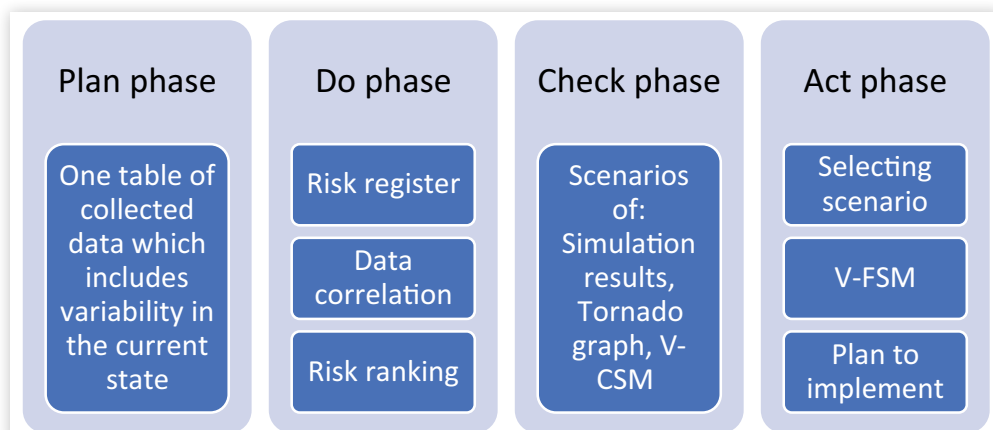
Since the coffee product family is in high demand, the expected objectives were to enhance the production flow and find ideas to reduce LT and WIP time. The company is highly restricted to deliver all the orders on time; however, in some cases when the order is high, the delivery date would vary. The company expects to develop a flexible FSM to meet any demand on time.

For this case, the customer demand was 1155 sachets of coffee per week. The production processes were in sequence such as weighting the ingredients for the coffee mixture (Weighing), mixing the ingredients (Mixing), packaging the mixture in small sachets (Packaging I), placing the cover, packaging the number of sachets in one pack (Packaging II), sealing, stamping the expiry date, and boxing. There are two inspection processes in between the production processes as showed in [Table 1](#). The company works 6 days per week, two shifts per day, (4, 4.5, 5) hours per shift, and 1 hour of break time per day.

[Table 1](#) shows the first part of collected data that needed in order to build the V-CSM. The data includes the eight processes needed to produce the coffee as well as two inspection processes in between. The second column is showing the number of employees needed for each process. The VA was represented by the CT, which was collected through a stopwatch and recorded videos for each process. The CT was collected repeatedly for three times to record the variability in performing each process under minimum (Min), mean, and maximum (Max) time. Wastes and inventory (WIP) represented the NVA time, which were, as similar as the CT, collected in range (min, mean, and max time).

The second part of data collection was shown in [Table 2](#). The table includes the anticipated risks within each process and their probability, impact. The occurrences of these risks would bring potential wastes defined as potential-non-value-added (PNVA) events. These potential wastes would bring additional time and cost, which is unwanted in LM system since they will cause an increase in the LT. The risk's impact

**FIGURE 2** Expected outcomes from each phase of V-VSM model.



**TABLE 1** Production process data collection.

Processes	Employee	VA			NVA			WIP (sachet)			WIP time (hour)			
		CT (second)			Wastes (second)			Min	Mean	Max	Min	Mean	Max	
		Min	Mean	Max	Type	Min	Mean							Max
Receiving					Transportation time	263	270	275				49	53	57
Weighing	1	55	71	82								0.22	0.25	0.31
Inspection	1					8	10	11				-	-	-
Mixing	2	1905	1930	1955	Waiting	340	388	424				0.8131	1.14	1.215
Packaging I	1	0.85	0.99	1.1					315	350	398	11.34	14.525	18.5866
Inspection	1					11	14	16						
Placing the cover	2	2.8	4.03	5.7	-	-	-	-	320	355	422	11.52	14.7325	19.707
Packaging II	2	30.02	44.19	55.3	-	-	-	-	319	342	402	11.484	14.193	18.77
Sealing	1	5.82	9.75	14.55					341	400	452	12.28	16.6	21.11
Stumping the expiry date	2	6.5	11	17.1	-	-	-	-	182	200	225	6.55	8.3	10.5
Boxing	2	65.99	71.88	89.77	-	-	-	-				14	15	17
Total		2072	2143	2221		622	682	726				117.9	137.59	174.9
Total LT												117.9	138.4	180.8

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on time and cost were collected, according to employees and the company CEO, in range (min, mean, and max time) to show the variability within each event.

## 4.2. Do Phase

**4.2.1. Quantitative Analysis** Quantitative analysis techniques consisted of three steps that are needed to be done in order to run Monte Carlo simulation as follows:

### a. Fit and Import Probability Distribution

To specify the variability limits, a Probability Distribution was imported for each VA, NVA, and PNVA. Since the variables in this case were all about time and costs, which were continuous variables, symmetrical, positive, have upper and lower limits, and relative to the middle values, a PERT distribution was deemed to be the best fit distribution using @Risk software and Microsoft Excel (2016).

### b. Risk Register

The collected risk assessment data in [Table 2](#) was imported into the risk register using Microsoft Excel (2016) as shown in [Figure 3](#). Throughout the running of the simulation, the risk register calculated the added time and added cost if the sampled risks had high probabilities and impacts.

The risk register in [Figure 3](#) consists of four areas. The first area consists of three columns starting with “Risk” as the first column that were filled from [Table 2](#). The “Probability” percentage of both occurrence and not occurrence of the defined risks were included in the second and the third column, respectively. The probabilities were illustrated through a scale given by the team.

The second area consists of two columns. The first column is “Simulated Occurrence,” which uses both probabilities

(occurring and not occurring) as arguments for the discrete distribution for each risk. When the Monte Carlo simulation is running, the discrete distribution will show the number (1) if the risk probability is occurring and the number (0) if it is not occurring. Depending on these two numbers in the “Simulated Occurrence” column, the second column of this area will use the (IF) function to answer the question of “Occurs?” with “Yes” if the corresponding number is (1) and “No” if the number is (0).

The third area is the “Impact on Time” area. It consists of five columns. The first three columns are (Min, Most likely, and Max), which were entered according to [Table 2](#). Because of the uncertain impact of each risk were defined in three values, the fourth column is using PERT (Beta) distribution as the mean of the impact on time. The reason behind choosing PERT (Beta) distribution is that it allows defining three values considered as limits for the possible outcomes after running Monte Carlo simulation. The fifth column, “Time added to plan,” uses the results of the (Mean) column and multiplied it by the (simulated occurrence) column in order to have the added time (added LT) for each risk if only the “occur?” column shows “yes.” This shows the importance of defining the impact of the defined risks that will hinder delivery on time and cause an increase of the LT, which is against the company aim.

The fourth area is represented by the “Impact on Cost” area. All the columns within this area are similar to the “Impact on Time” area, but here the additional costs that will be added to the original plan were calculated after running the Monte Carlo simulation.

### c. Data Correlation

Spearman’s rank correlation coefficient was used to identify the relationships between inputs (VA, NVA, and risks activities). This will enhance the sampling process during the

**TABLE 2** Risk assessment data collection.

Process	Risk	Probability %	Time impact (seconds)			Cost impact (USD)			PNVA
			Min	Mean	Max	Min	Mean	Max	
Weighing	Error in weighting the ingredients amount	5	50	60	70	10	20	30	Waiting
Packaging I	Wrong measurement of the sachet	2	120	180	240	10	20	30	Defect
	Wrong amount of the coffee mix inside the sachet	2	10	20	30	10	20	30	Defect
	Not fully packaged	15	900	950	1000	12	15	20	Defect
Placing the cover	Misplacing the sticker	8	4	5	6	0	1	2	Defect
Packaging II	Wrong counting the sachets inside the pack	8	10	20	30	0	1	2	Waiting, Defect
Sealing	Unsealed	10	10	20	30	5	8	10	Defect
	Visual mistakes	10	10	20	30	5	8	10	Defect
Stumping the expiry date	Misplacing the stamp	5	10	20	30	1	2	3	Defect
General effects	Electricity shutdown	20	600	750	900	20	30	40	Waiting
	Exposing the raw material to moisture causing its hardening	2	14,400	21,600	28,800	800	1000	1200	Defect
	Hardening of the coffee mix	15	900	950	1000	12	15	20	Defect
	Worker absent	5	1000	1500	2000	30	40	50	Waiting

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running of Monte Carlo simulation to avoid nonsensical results. The used of [Formula 1](#) will identify the correlation coefficient ( $r_s$ ), which, in turn, identifies the strength of the association between the two selected variables, whether it is a negative or positive. Positive correlation indicates that both variables increase and decrease together and the value is ranged between (0) and (1). On the other hand, negative correlation indicates that as one variable increases, the other decreases, and the range is between (-1) and (0) [27].

$$r_s = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \quad (1)$$

where

$r_s$  is the spearman coefficient

$n$  is the number of data points of the two variables

$d_i = rg(x_i) - rg(y_i)$  is the difference between two ranks' values of each observation

$rg(x_i) - rg(y_i)$  is the rank of two variables

The correlation matrix was built using @Risk and Microsoft Excel (2016) as shown in [Figure 4](#). The relationship between the same activity will be equal to (1) while between other activities will be ranged from (-1) to (1) depending on the relationship identified in the correlation coefficient by the team.

In [Figure 4](#), there are two tables of correlation; each table represents one Excel worksheet. The first table correlates the transportation waste that belongs to weighing process and the waiting waste belongs to mixing process in "Data Calculation"

worksheet. The correlation coefficient was specified using [Formula 1](#) in. The coefficient was equal to 0.7, which makes it high positive relationship between the two variables. It means during the running of Monte Carlo simulation if the transportation time's rank is high, the waiting time's rank will increase. The same idea goes to the other correlations in the second table in [Figure 4](#).

**4.2.2. Qualitative Analysis** Anticipating the risks ranks them according to which risk should be prioritized to be reduced or illuminated first. Ranking the risks depends on [Table 2](#) through the following steps:

1. Ranking the risk probability from 1 to 5, where 1 is for low probability and 5 is for high probability.
2. Ranking the risk impact of different categories. The team identified five categories; personnel safety, public safety, economic, corporate image, and environment impact. Each category got 1 to 5 impact ranking range.
3. Ranking the risks by specifying the risk consequence, which was calculated by multiplying probability and impact as shown in [Table 3](#).
4. Placing the rank of the risk in the heat map in [Figure 5](#) to identify the treatment level for each ranked risk in the risk response plan.

The results of the most critical activities from the heat map were recorded in descending order relying on their risk ranking in [Table 4](#).

**FIGURE 3** Risk register.

Risk	Probability		Simulated Occurrence	Occurs?	Time Impact (sec)					Cost Impact (\$)				
	Occuring	Not Occuring			Min	Most Likely	Max	Mean	Time added to plan (Sec)	Min	Most Likely	Max	Mean	Costs added to plan (\$)
Error in weighting the ing	0.09	0.91	0	No	50	60	70	60	0	10	20	30	20	0
Wrong measurement of t	0.08	0.92	0	No	120	180	240	180	0	10	20	30	20	0
Wrong amount of the coff	0.08	0.92	0	No	10	20	30	20	0	10	20	30	20	0
Not fully packaged	0.15	0.85	0	No	900	950	1000	950	0	12	15	20	15.3333	0
Misplacing the sticker	0.1	0.9	0	No	4	5	6	5	0	0	1	2	1	0
Wrong counting the sache	0.1	0.9	0	No	10	20	30	20	0	0	1	2	1	0
Unsealed	0.1	0.9	0	No	10	20	30	20	0	5	8	10	7.83333	0
Visual mistakes	0.15	0.85	0	No	10	20	30	20	0	5	8	10	7.83333	0
Misplacing the stamp	0.05	0.95	0	No	10	20	30	20	0	1	2	3	2	0
Electricity shutdown	0.3	0.7	0	No	600	750	900	750	0	20	30	40	30	0
Exposing the raw materia	0.2	0.8	0	No	14400	21600	28800	21600	0	800	1000	1200	1000	0
Hardening of the coffee n	0.15	0.85	0	No	900	950	1000	950	0	12	15	20	15.3333	0
Worker absent	0.05	0.95	0	No	1000	1500	2000	1500	0	40	50	60	50	0
								0					0	

From Table 4, it shows that the “hardening of the coffee mix” has the highest risk consequence among other risks with a value equal to 10 in the yellow area. Followed with eight risks placed in the same yellow area. The risky events in the yellow area need a regular review and management updates when building the V-FSM. Even though there are nine risks placed in the yellow area, the “hardening of the coffee mix” and “electricity shutdown” are the highest compared to others, so they need more attention to be managed. The rest risks that were placed in the green area has little to no impact; however, a continuous review is needed to prevent any repeating of these events or increasing of their impact.

### 4.3. Check Phase

Using @Risk software, the Monte Carlo simulation was running for 100 iterations to perform the calculations on the fitted inputs (Tables 1 and 2) with probability distribution and

specify the outputs [total CT, total LT, time added to plan (second), and cost added to plan (USD)]. After running the simulation, each output has 100 values (the same number of iteration) that varied into minimum (Min), mean, and maximum (Max) as shown in Table 5.

Table 5 shows the identified four cells in Excel worksheets as outputs of the simulation results. The total CT and LT graphs are showing the highest bar in the middle of the histogram where the mean value is located. That explains the largest number of sampling process was around the mean value.

In the same table, the minimum values of the time added to plan and cost added to plan results were equal to zero. By looking at the histogram graph for both of them, it shows that the highest bar was placed in the zero value. It means that during the simulation run, few samples were selected around the mean and maximum values, while the rest of the sampled values (which has the largest part of the total samples out of

**FIGURE 4** Input data correlation.

@RISK Corre	Transportatio	Waiting / sec				
Transportatio	1					
Waiting / sec	0.7	1				
@RISK Corre	Wrong meas	Wrong amou	Not fully pac	Unsealed' [se	Visual mistak	Hardening of
Wrong meas	1					
Wrong amou	0.7	1				
Not fully pac	0	0	1			
Unsealed' [se	0	0	0	1		
Visual mistak	0	0	0	0.7	1	
Hardening of	0	0	0.9	0	0	1

**TABLE 3** Qualitative risk ranking.

Risk	Probability ranking (1-5)	Impact ranking (1-5)					Risk consequence
		Personnel safety	Public safety	Economic	Corporate image	Environment impact	
Error in weighing the ingredients amount	2	-	1	1	2	-	6
Wrong measurement of the sachet	2	-	-	1	2	-	6
Wrong amount of the coffee mix inside the sachet	2	-	-	1	2	-	6
Not fully packaged	2	-	-	-	2	-	4
Misplacing the sticker	2	-	-	-	1	-	2
Wrong counting the sachets inside the pack	2	-	-	1	2	-	6
Unsealed	2	-	-	1	2	-	6
Visual mistakes	2	2	-	1	2	-	6
Misplacing the stamp	2	-	-	-	1	-	2
Electricity shutdown	3	1	-	2	-	-	9
Exposing the raw material to moisture causing its hardening	2	-	-	3	-	-	6
Hardening of the coffee mix	2	-	-	1	4	-	10
Worker absent	2	-	-	2	-	-	4

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the total iterations) were located outside the identified ranges for each input, and because of that, a zero value was given. Showing the variability of CT and LT would give a clearer view of the current situation, and a better plan for the future situation.

Using @Risk software, sensitivity analysis was performed during the Monte Carlo simulation and was presented in a tornado graph. The sensitivity analysis shows the most significant sampled input variables affecting the outputs and the results were displayed as a graph consisting of bars with different lengths. The top is the longest, which represented the largest effective range, input variable, and vice versa.

The tornado graph in Figure 6 shows that the mean CT of mixing process (1929) seconds is the most effective process into the total CT with a medium positive correlation coefficient equals to (0.54). Followed by the mean CT of packaging II process (42) seconds with (0.46) correlation coefficient, which gave medium positive effect into the total CT. Focusing on mitigating the CT of these two processes will bring big

benefit in mitigating the total CT for the future plan. The other processes have low to medium effect, so focusing on them may bring a slight change on the total CT.

Figure 7 shows the tornado graph for the total LT. It obviously shows that the WIP time of receiving the ingredients process which equals to (53) hours was the most effective input to the total LT with correlation coefficient equals to (0.44), which it has a positive medium effect. Followed by sealing WIP time with the mean of (16.45) hours, which has (0.42) correlation coefficient as the second effective input to the total LT. By minimizing these inputs, it will help in reducing the total LT that is the company's main goal.

**FIGURE 5** Probability-impact matrix heat map.

Probability	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
	Impact					

Data taken from Refs. [28, 29]. © Alaa Salahuddin Araibi

**TABLE 4** The risky activities.

Risky event/activities	Risk consequence	Heat map area color
Hardening of the coffee mix	10	Yellow
Electricity shutdown	9	Yellow
Error in weighing the ingredients amount	6	Yellow
Wrong measurement of the sachet	6	Yellow
Wrong amount of the coffee mix inside the sachet	6	Yellow
Wrong counting the sachets inside the pack	6	Yellow
Unsealed	6	Yellow
Visual mistakes	6	Yellow
Exposing the raw material to moisture causing its hardening	6	Yellow
Worker absent	4	Green
Not fully packaged	4	Green
Misplacing the sticker	2	Green
Misplacing the stamp	2	Green

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**TABLE 5** Monte Carlo simulation results.

<b>@RISK Monte Carlo simulation results</b>						
<b>Date:</b> Sunday, December 25, 2022 10:20:39 PM						
Name	Worksheet	Cell	Graph	Min	Mean	Max
Total CT (second)	Data calculation	B22		2108.365	2140.67	2176.286
Total LT (hour)	Data calculation	F24		131.1908	139.807	147.552
Time added to plan (second)	Risk register	L20		0	4807.91	26879.63
Costs added to plan (USD)	Risk register	R20		0	218.2127	1101.387

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Figure 8 shows “Exposing the raw materials to moisture...” risk as the most critical risks in adding time (potential-non-value-added (PNVA)) to the total LT. The risk has a mean of (21,596) seconds and a correlation coefficient equal to (0.7), which is considered as a high positive correlation. The other risks appeared with a low correlation, which has small to no impact to the total LT.

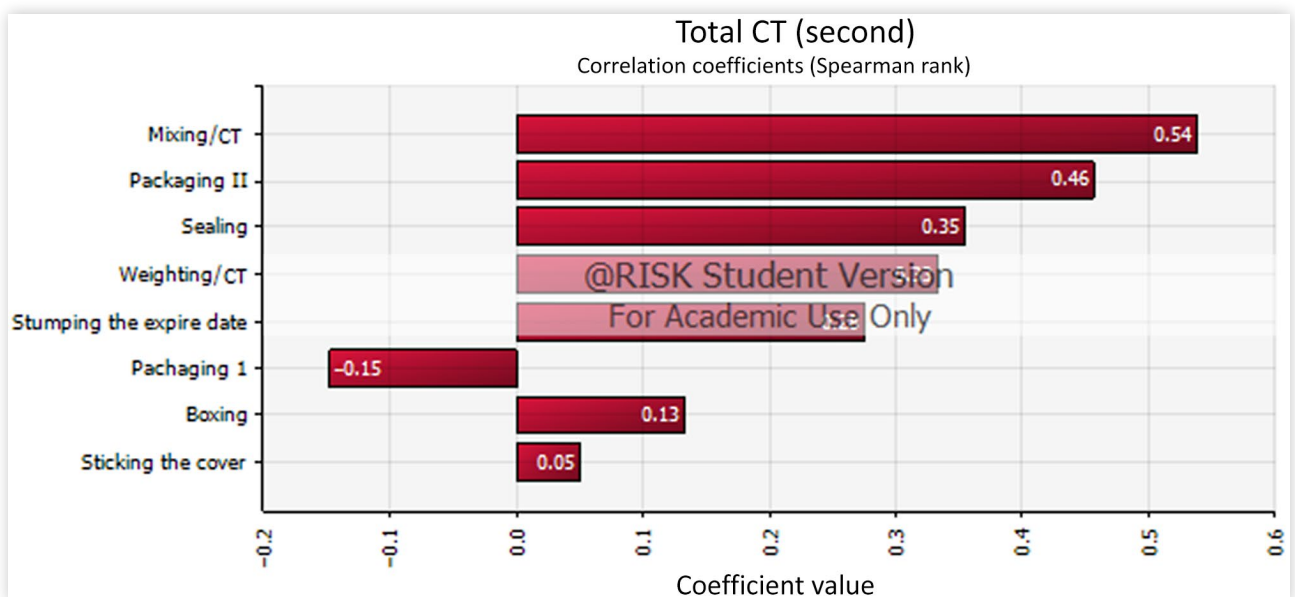
The tornado graph in Figure 9 is showing the added costs as an impact of the risks occurrence. It shows that “Exposing the raw material...” risk was on the top of the bars with (0.7) of correlation coefficient. The impact on the cost was equal to (699 USD). While the second risk was, the “electricity shutdown” with (15 USD) added cost as an impact. The third

risk from the top was “worker absent” risk with (12 USD) as an impact. Preventing the occurrence of these risks can prevent the unwanted impacts on the total LT and total cost.

Monte Carlo simulation results for inputs and outputs were used to draw the V-CSM along with the traditional VSM in Figure 10. The V-CSM was created using Creately [30] website through using the online VSM templates and diagram tool.

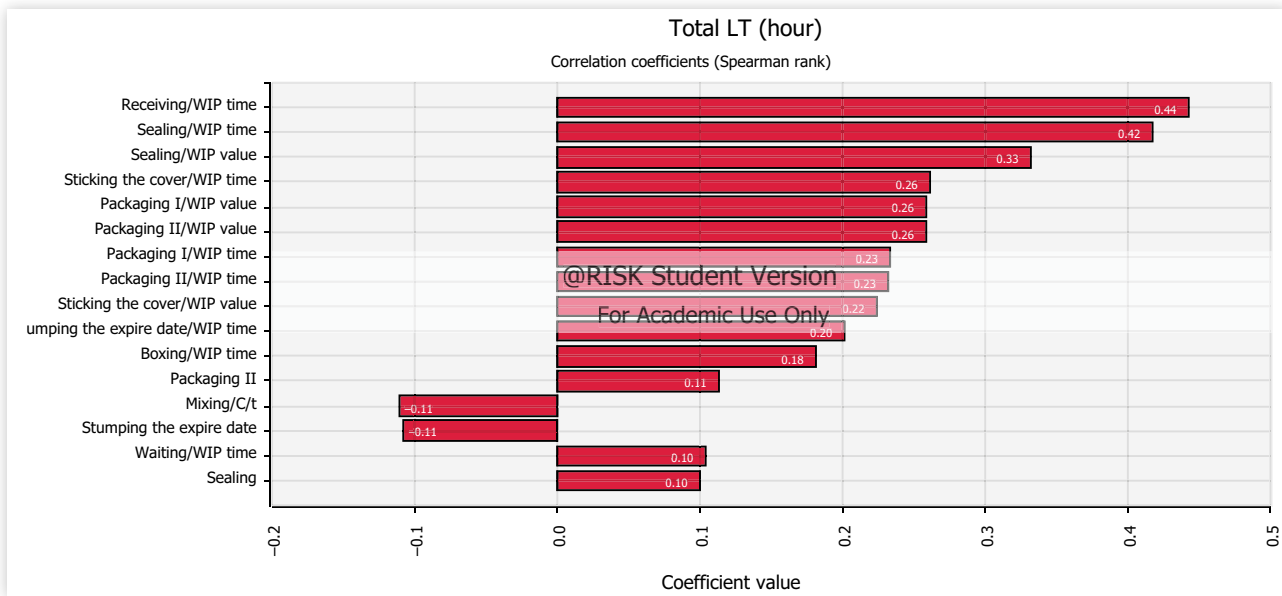
The V-CSM in Figure 10 shows how the data inputs and outputs are varying, which reflects the true image of the variable manufacturing environment depending on the situation in which the production line is in, such as the risks that were highlighted, hence affecting operating parameters such

**FIGURE 6** Tornado graph for total CT.



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**FIGURE 7** Tornado graph for total LT.



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as the total CT. The information part in the V-CSM were shown in a curve with three values; minimum value is on the bottom of the curve, mean value is in the middle, and maximum value on the top of the curve. Risks impact on time were added as a PNVA activates, so that their impact can be seen obviously during the preparation for the V-FSM.

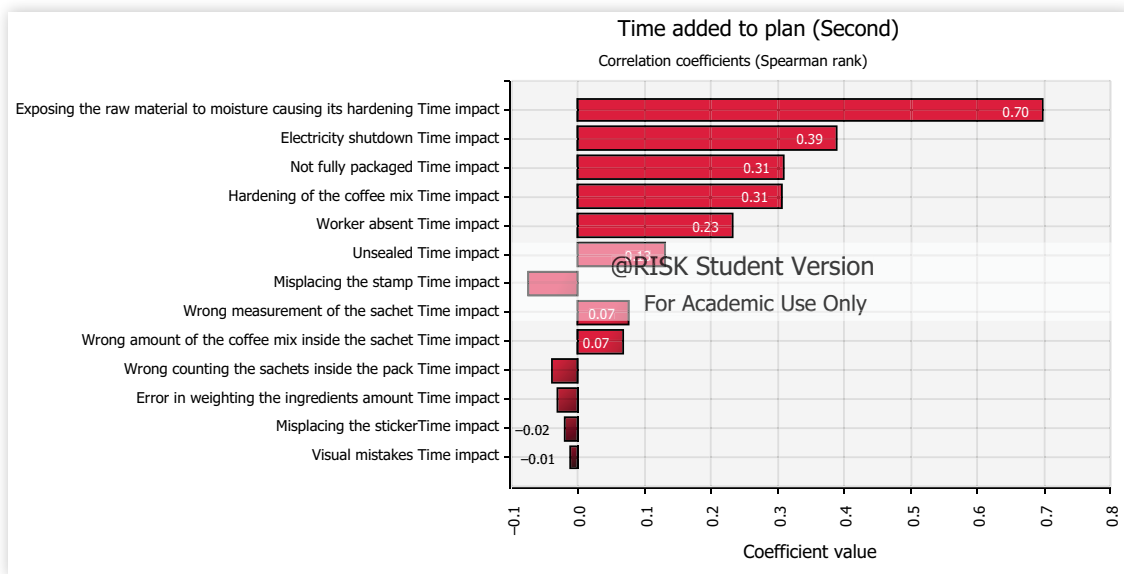
The V-CSM shows that the variability affects arrival and departure rates of materials from one process to the next, causing delays and longer LT, which is against the company goal. Defining and showing the variability through the V-VSM leads to predictability in the number of conforming products, so that the company can meet customer deadlines.

### 4.4. Act Phase

The outcomes of the check phase can be repeated considering a number of scenarios. The differences between these scenarios are described as follows:

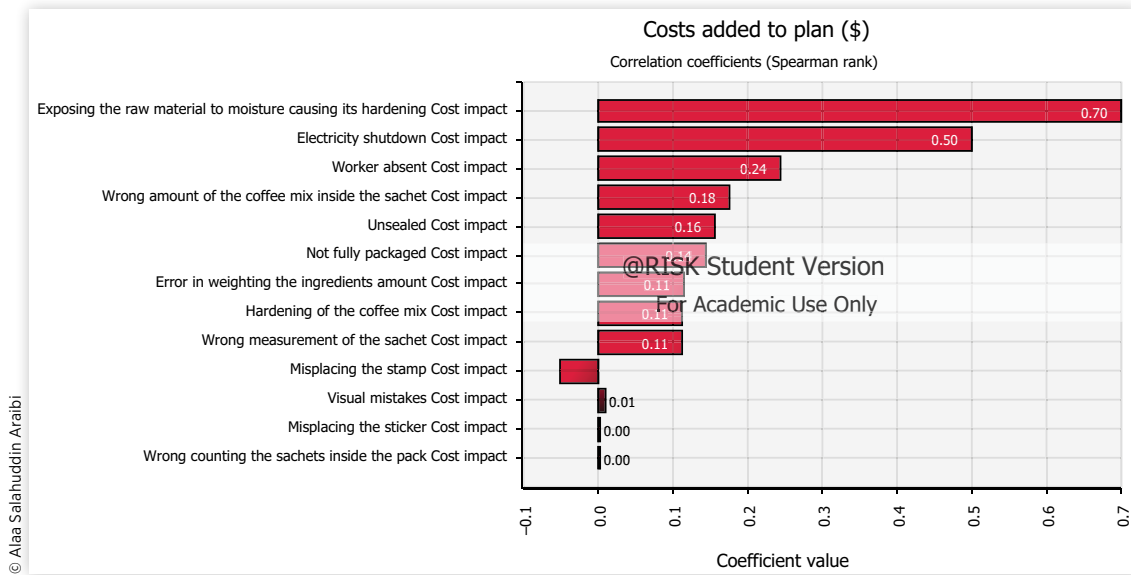
1. Changing the range of some or all the inputs according to the recollection of the data or depending on some cases, which had happened in the past, so each case could be a new scenario.
2. Changing the probability/impact of some or all the identified risks or adding new risks that might occur.

**FIGURE 8** Tornado graph for time added to plan.



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**FIGURE 9** Tornado graph for costs added to plan.



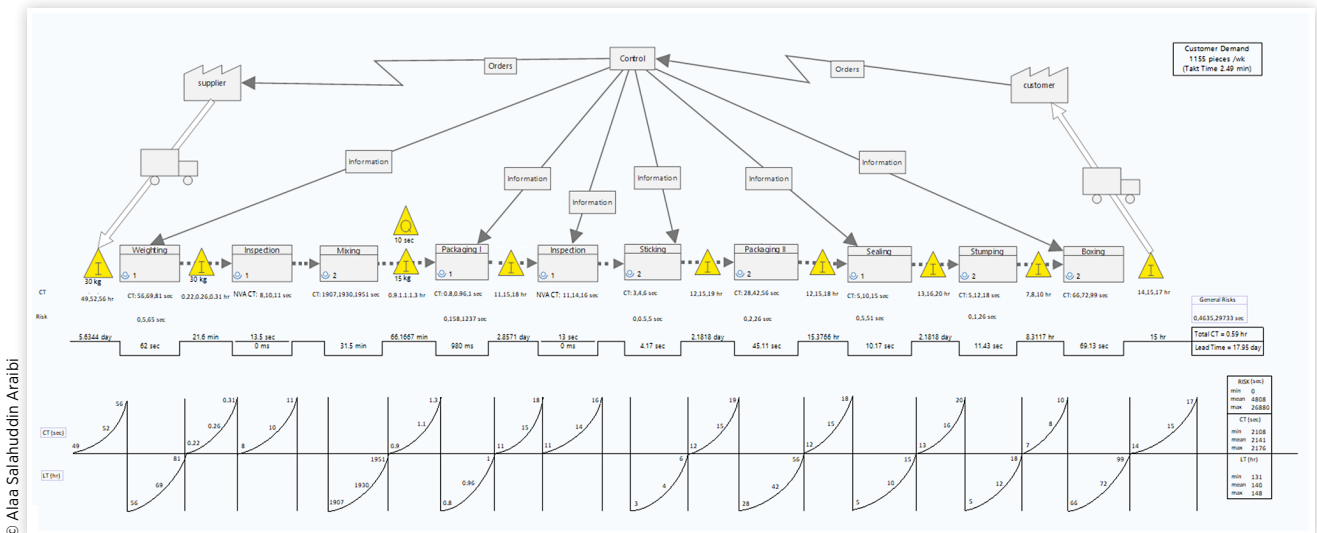
3. Trying different scenarios to see how the impact of the key inputs will be sensitive toward the output. By this, it will be easy to identify the critical inputs for more output improvement.

The variability in the V-CSM outputs meant that the input variables were ranging. There were also risks that appeared to occasionally impact the time and cost. Getting rid of these risks would reduce the variability to the extent that it would not affect the identified objectives. Although there were possibilities for the values to range between the identified upper and lower limits, the target value for each variable would

always be around the mean. The question here was how the variability could be reduced as much as possible in order to build the V-FSM to be close to the target. The answer was by mitigating and/or eliminating the identified risks. Even though all the identified risks would be eliminated, there would be no guaranty that no risks would occur in the future. That is why the variability was included in the V-FSM in the anticipation of the impact from any of the risks.

The team discussed the probability and impact of each risk to give a solution strategy to be implemented. The given solutions were set depending on their priority in ranking using risk ranking matrix and the sensitivity analysis results by using Monte Carlo simulation.

**FIGURE 10** The V-CSM and the traditional CSM.



**TABLE 6** Scenarios results summary.

Outcomes	Traditional CSM	V-CSM		% Changes from the traditional CSM
		Scenario 1		
CT (second)	2092.99	Min	2108.365	The minimum increment is equal to +0.7% than the traditional CT
		Mean	2140.67	+2.2% is the increment than the traditional CT
		Max	2176.286	+3.8% is the increment between the maximum limit and the traditional CT, which is equal to 83 seconds added to the traditional
LT (hour)	143.6	Min	131.1908	−9% hour is the reduction than the traditional LT
		Mean	139.807	−2% hour is the reduction than the traditional LT
		Max	147.552	+2% is the increment of hour compared to the traditional LT
Added delay (second)	-	Min	0	There is no impact to the minimum value of the risks occurrence
		Mean	4807.91	Another 80 minutes will be added to the total LT if no action will be taken to reduce the most critical risks
		Max	26,879.63	7.5 hour will be added to the total LT if no action will be taken to reduce the most critical risks
Added cost (USD)	-	Min	0	There is no impact to the minimum value of the risks occurrence
		Mean	218.2127	Added cost as an impact to the occurrence of the critical risks around the mean of their time
		Max	1101.387	More cost added as an impact to the occurrence of the critical risks around the max of their time

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In this case, only one scenario through Monte Carlo simulation was made, and it was compared to the traditional VSM in [Table 6](#). This table can help in the decision-making process, where one can select a scenario by the team to build the V-FSM. Within the first scenario, each variable has three values (minimum, mean, and maximum). Building the V-FSM can consider a set of the minimum values of all variables, same for the mean values, and the maximum values, so each set can be a scenario of V-FSM. However, the team was considering reducing the LT as possible as they can, and for that, the team choose the minimum limits to work on and build the V-FSM as shown in [Figure 11](#).

The team calculated the takt time (TT), and it was equal to 149 seconds. Thus, the V-FSM was focused on using the minimum values of the processes CT to meet the TT.

Checking [Table 1](#), the “mixing” process CT was 12 times the period of TT. As well as, the sensitivity analysis in [Figure 6](#) shows the total CT is sensitive toward “mixing” process CT. However, the company is still managing to meet customer demand within deadlines, and the reason is the difference between actual CT and average CT (per unit). The average CT in the “mixing” process depends on the number of products that are treated at the same time. The “mixing” process is performed once per production cycle for mixing all the ingredients of 30 kilogram of coffee to produce a total number of 1155 sachets. For that, the average CT for “mixing” process is (1.6) seconds per sachet. Therefore, the “mixing” CT is not a problem to meet the TT.

The team found it hard to achieve one continuous flow of a production line without any WIP between the processes. Therefore, two cells were created; the first cell includes of (weighing, mixing, and packaging I) with a CT of (59) second/sachet, while the second cell contain all the rest of the processes with a CT of (97) seconds/sachet. Comparing the cells CT to the TT, there is an empty space, which makes the application

of this V-FSM considered safe since the FSM is a futuristic, predictive map. This will bring flexibility in applying the V-FSM especially in the first stages of application. As well as, to solve the problem of having any new risk through the application. One employee is needed in each cell as shown in [Figure 11](#).

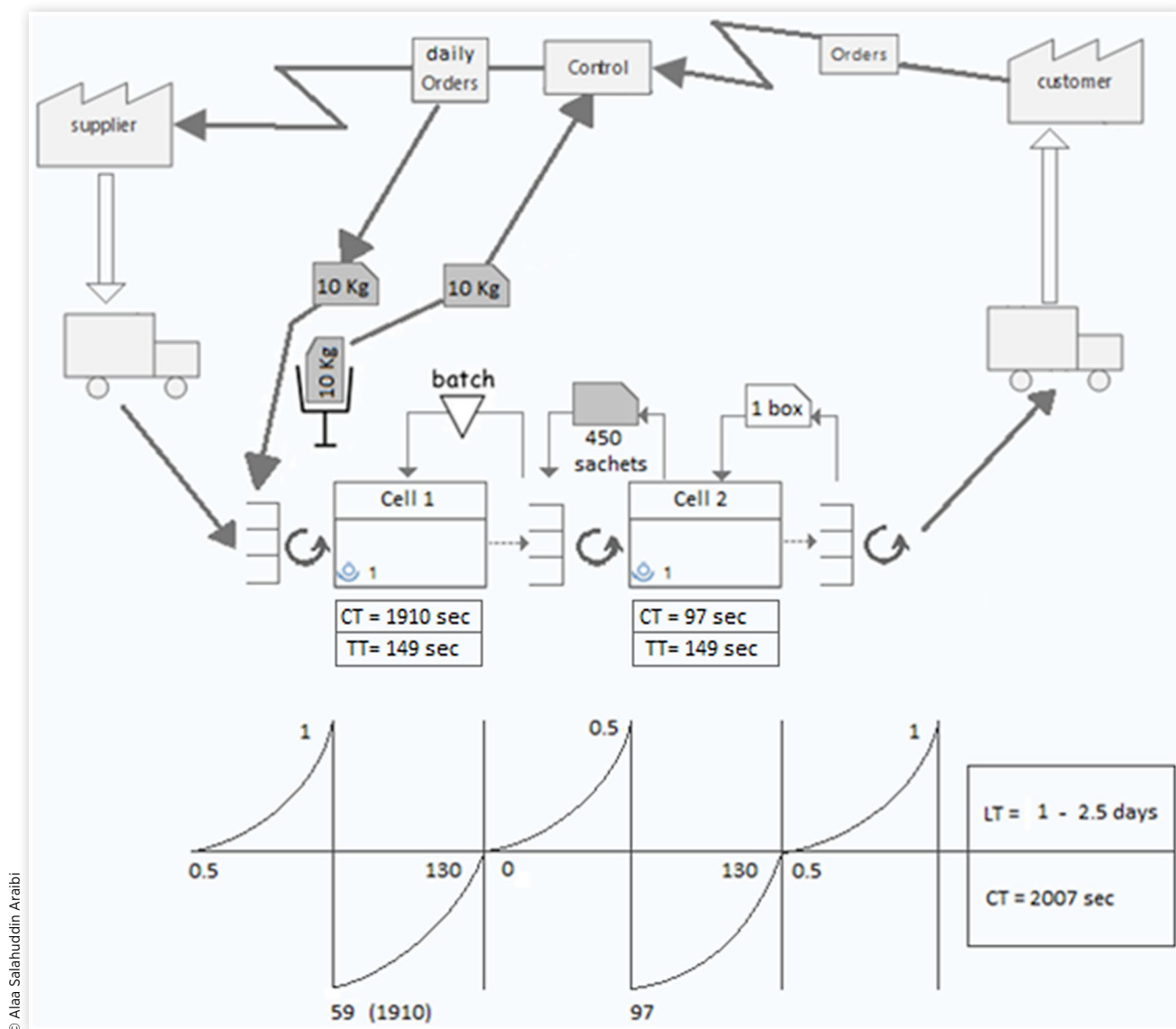
Three supermarkets were applied in the V-FSM. The first one is for the finish goods, where the customer can pull directly from it. The second supermarket was for the first cell using withdrawals as a pull system from the second cell, which will be the controller of the first cell. The third supermarket is for the ingredients coming from the supplier.

[Table 7](#) shows the improvements done so far from using the V-VSM when comparing the current and the future states. The total LT was decreased 85% and the total CT was decreased 2% by comparing the minimum values in both V-CSM and V-FSM. As well as, the risks’ probability and impact were controlled in the risk response plan. The LT was defined in a range of (8–20) hour, where the goal is to work within (8) hour; however, the range was given just to control the impact of any new undefined risk during the application of the V-FSM.

## 4.5. Conclusion

The VSM shows an image of the manufacturing system in a particular time. For that reason, it tends to vary depending on the state in which the manufacturing work is in. If the variation in the manufacturing system is deserted throughout the preparation of the current state map, the future state map will be incorrect. It can affect the functional constraints for instance machine cycle times, as well as measurements of performance such as TT of the manufacturing system. In consequence, this article developed a novel advance VSM with a complementary tool using RM processes named

**FIGURE 11** V-FSM (using the minimum values of each variable).



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**TABLE 7** Total results comparison.

Outcomes	Traditional CSM		V-CSM Scenario 1	V-FSM Scenario 1
CT (second)	2092.99	Min	2108.365	2007
		Mean	2140.67	
		Max	2176.286	
LT (hour)	143.6	Min	131.1908	8-20
		Mean	139.807	
		Max	147.552	
Added delay (second)	-	Min	0	0
		Mean	4807.91	
		Max	26,879.63	
Added cost (USD)	-	Min	0	0
		Mean	218.2127	
		Max	1101.387	

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V-VSM. The proposed model specifies the ranges of variability in the production processes as well as the possible risks by generating scenarios of CSM using Monte Carlo simulation. The significance of the V-VSM model can be summarized as following:

1. High accuracy in reflecting the dynamic state through the collection, calculation, and presentation of data considering their variabilities unlike the traditional VSM, which can be beneficial for only static processes.
2. Reflect the real situation through offering multi-scenarios of V-CSM unlike a snapshot of one situation given by the traditional VSM.
3. Support the decision-making process through offering the stakeholders multi-scenarios of V-FSM, which gives them the permissibility in choosing the most preferable plan for implementation.
4. Reach stakeholder satisfaction through considering their opinions and knowledge from the collection and analysis of input data until the development of V-CSM and V-FSM, which increases the probability of getting satisfactory results.
5. Flexibility on using the V-VSM model in different sectors such as automotive, food, and the like.
6. Avoiding potential non-value-added (PNVA) activities and potential wastes through the definition of current and potential uncertainties and risks events through giving the stakeholders a futuristic look of the riskiest activities and their impacts on time (total LT) and cost.
7. High quality in dealing with data through the correlation of all data inputs, where the sampling process during the Monte Carlo simulation is not random.

A coffee production line was applied as a case study to validate the performance of the V-VSM model. The results were shown through the drawing of the V-CSM and V-FSM, where all the data were varied to fit the dynamic environment. Risks were defined through their impact on the LT as a potential wastes, and were managed to be eliminated. The total LT was decreased 85% and the total CT was decreased 2% by comparing both V-CSM and V-FSM.

The following suggestions are recommended for further work related to this study:

1. The study focused on the process variability, thereby, customer demand variability can be considered in the future work.
2. Tools and techniques such as quality function deployment (QFD) or failure mode and effect analysis (FMEA) can be used for further analysis of the developed model.
3. The developed model was tested in the food sector with one scenario for each V-CSM and V-FSM; therefore, more scenarios can be generated and tested within this sector or another sector is suggested.

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