developed by PRé Sustainability, the environmental and social impact assessment consultant. Eco-indicator '99 method was applied to perform end-point (damage-based) impact assessment that complies with ISO 14040 standard. This method assesses three damage categories, which are human health, ecosystem quality, and resources affects at the end-point that may occur during product creation activity [14].

III. Result and Discussion

A. Critical Product and Product Flow

PT X focuses on the production of processed cheese product. The processed cheese product focuses on processing natural cheese product (curd cheese) into more varieties of final product in term of their composition (cheese used, texture, additives, etc.) with the variation of type of portion, whether it is individual slices, rectangular blocks, cylinders, or tubes (Safriet 1997). There are four main processes that represent all production line, which are curd preparation, cooking, packaging, and packing process. From the total of six production line, A41 is selected as a value stream target since the highest production demand is found in this type of product during 2017. The cycle time summary can be seen in the Table 2.

TABLE II
Cycle Time Of A41 Production

No.	Process	Cycle time (second)
1.	Unwrapping	87.67
2.	Cutting	47.33
3.	Grinding	210.67
4.	Cooking	515
5.	Filling – packaging	587.12
6.	Cooling – packing	3005
7.	Palletizing	27.34
Total Cycle Time		**4480.13**

Cycle time measurement is divided into seven main processes, which are unwrapping, cutting, grinding, cooking, filling – packaging, cooling – packing, and palletizing. Filling – packaging is the process that has continuous flow. Thus, the calculation of cycle time is merged into one process. This also applies the cooling – packing process. Each process is divided into activities that include operation, transportation, inspection, and delay. Transportation of moving material to the next process, as well as the waiting for WIP (Work-In-Process) activity, are calculated separately from the process. Process delay time is measured based on the Job Order data in each process.

The result shows the total cycle time for A41 is 4480.13 seconds with the lead-time is 4967.46 seconds. The whole process has VA, ENVA, and NVA of 4034.33 seconds, 772.68 seconds, and 160.45 seconds respectively. The non-value-adding activities measured affects the total cycle time of the process, which causes the whole process time becomes longer. The highlight focuses on three processes that causes delay, which are cooking, filling – packaging, and cooling – packing process. Delay occurred in cooking, filling – packaging, and cooling – packing are 13 seconds/batch, 12.45 seconds/batch, and 6.67 seconds/batch respectively. From the cycle time information, the filling – packaging process has the current output speed of 8 products/minute. The ideal output speed determined for the process is 12 products per minute.

B. Critical Sustainability Metrics

Based on questionnaire response of five respondents from the different division, as observed that speed loss, total defect product, and heat loss are selected as critical sustainability metrics. The further analysis focused on minimizing the effect of problems occurred on mentioned metrics.

1) Speed loss

According to the result, eight cause factors contribute the whole speed loss, which are the start-finish loss, cleaning time loss, delay at cooking, time loss due to pump trouble, and delay at filling-packaging, delay at packing, power failure, and time loss due to cooling trouble. Problem due to pump trouble has been solved through the company's corrective actions. Power failure and trouble at cooling tunnel contribute the lowest value of speed loss. Thus, the focus of analysis takes into account the other causes.

Start-finish production loss means the loss that occurs before the first shift started and before the last shift ended. Every production date both starts and finishes at 06:00. The actual time of start-finish time varies, as allowance made is not controlled as punctual. Delay on process was identified in cooking, filling – packaging, and cooling- packing process. Delay in cooking occurred due to idling on removing thick blend product. Thick blend product is the product that does not meet the standard in term of its viscosity that increases before the product from the cooking area are transferred to the next process. Delay on filling – packaging process occurred due to machinery trouble that leads to the idling. Speed controller and motor on the sealer machine did not have match spare part, and it leads to the unstable sealer machine. Sealer machine often stopped, and the sensor of glue on the sealer cannot detect the product that passes through the sealer plate. Another machine trouble occurred is the coding machine that often stagnated and cannot operate properly due to the clumped ink on the sprayer. The delay on cooling – packing process occurred to the idling on conveyor issue. The conveyor often stagnated due to spare part failure and torn packaging that pass and stuck the conveyor belt.

Cleaning time reduced-speed also contribute to the speed loss. In this company, there is a regulation to manage cleaning every 48 hours. The cleaning covers wet cleaning throughout preparation area (includes cutting and grinding area), cooking area, and filling – packaging area. The current speed of cleaning is 2.8 hours/cleaning while last year the performance gained is 2.14 hours/cleaning. This can affect the production start-up time, up to 0.66 hours of reduced speed in each cleaning. The figure below shows the Pareto chart of speed loss.

2) Total Defect Product

Identification on total defect product also highlighted the defect generated from three processes, which are cooking, filling – packaging, and cooling – packing. The defect on these processes are calculated as 1.12 kg/batch, 3.48 kg/batch, and 0.25 kg/batch respectively. Defect product on Filling – packaging process occurred due to machine idling and operator's un-optimal speed. These causes will affect the viscosity of the product blend to be out of standard. Defect product on cooking process occurred due to the amount of product that had high viscosity before it was transferred to the filling area. The un-standard viscosity of the product is mainly caused by the high moisture content in the product. Defect on packing process occurred due to the stuck conveyor that causes the product is damaged (in form and packaging). The chart of defect product summary is shown in the Fig. 3.

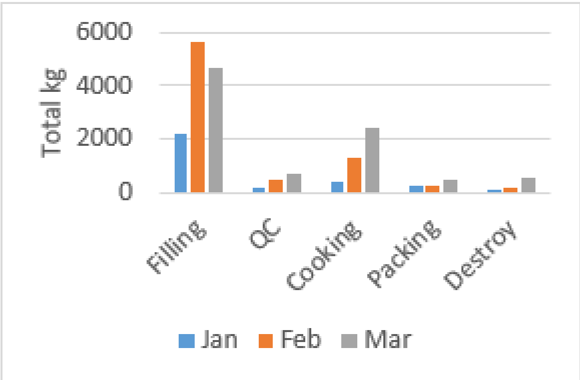

Fig. 3 Data of total defect product

3) Heat loss

Heat loss is taken into account as energy utilized during cooking and cleaning process. Heat loss is to measure the rate of heat transfer from the steam supply system through existing piping insulation. The calculation of heat loss through piping follows the principle of heat transfer through cylinder shells which consider thermal resistance all the way from the center of the whole cylinder to the outdoors. The thermal resistance network consists of conduction and convection in series [15]. The rate of heat transfer under steady conditions as expressed with formula as follow:

$$Q = \frac{T_a - T_u}{R_{total}} \quad (3)$$

Q = Heat transfer rate (W)
T_a = Steam temperature (°C)
T_u = Room temperature (°C)
R_{total} = Total thermal resistance (°C/W)

The construction of the piping system in this company consists of three layers, which are the inner pipe surface, followed by the Rockwool-based insulator, and then the outer surface layer which is made from aluminum. The loss is calculated by determining the flow of heat transfer all the way from inside the pipe to the environment through 3 layers of different material. Each material has the different thermal conductivity which implicates to the ability of heat transfer occurred. The Fig. 4. below shows the schematic insulation system.

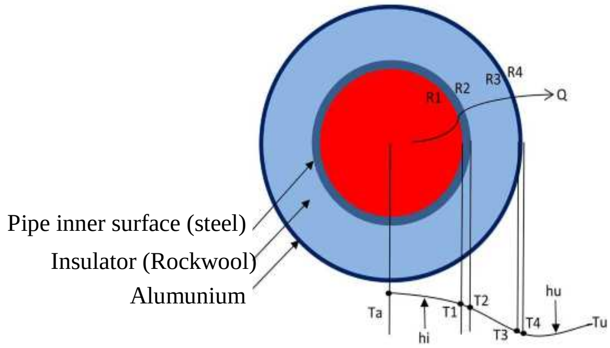

Fig. 4 Insulation system

Heat transfer rate was calculated using information regarding insulation surface temperature, the thermal conductivity of each material, and steam mass flow. Amount of actual energy generated from heat loss during cooking and cleaning process was determined by using total cycle time of each process through the specified period. Table 3 below is the summary of the current condition of insulation heat loss on both cooking and cleaning process.

TABLE III
CURRENT INSULATION HEAT LOSS OF A41 PRODUCTION

Indicator	Value	Unit
Rate of heat loss	730.273	J/s
Loss on cooking	2 488 945.285	MJ
Loss on cleaning	12 268.585	MJ

C. Root Cause of Failure

Focus on determining the root cause of failure was conducted in speed loss and total defect product metric. Five main problems need to be considered, which are shown in the Table 4.

TABLE IV
SUMMARY OF ROOT CAUSE ANALYSIS

Problem Identified	Root cause of failure
Delay and defect due to high viscosity issue	Instability condition on curd cheese (RC_1)
Delay and defect due to the minor stoppage on filling - packaging	Different speed specification between speed controller and motor (RC_2)
	Lack of operator that understands machinery inspection (RC_3)
	New operator exists (RC_4)
	Ink clumped on the coding machine (RC_5)
	Proper spray holder is not installed (RC_6)
Delay and defect on cooling - packing	Product with torn packaging is not removed (RC_7)
	Conveyor belt loses (RC_8)
Start-finish production delay	Operator disciplinary (RC_9)
	Control on production is not optimum (RC_{10})
Cleaning process reduced-speed	Operator disciplinary (RC_9)
	Jet spray machine is out of order (RC_{11})
	Preparation of chemical material is not done as scheduled (RC_{12})

RPN was calculated by multiplying the questionnaire response of severity, occurrence, and detectability. The Fig. 5. below shows the distribution of RPN values.

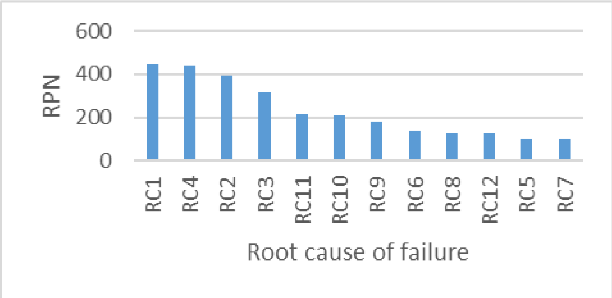

Fig. 5 The distribution of risk priority number (RPN)

Improvement of economic category focused on reducing speed loss and defect on two processes, which are filling – packaging and cooling packing, and reducing speed loss on cleaning. Table 5 shows the suggestion of failure.

TABLE V
FUTURE SUGGESTION OF FAILURE ROOT CAUSE

Root cause	Suggestion
Different speed specification between speed controller and motor (RC_2)	Change spare part with consideration of machine specification
Lack of operator that understands machinery inspection (RC_3)	Conduct intensive autonomous maintenance training to give a deep understanding of machinery inspection
New operator exists (RC_4)	Conduct intensive On-Job Training on new-hired operators and increase production control
Ink clumped on the coding machine (RC_5)	Perform coding machine cleaning during the cleaning process
Proper spray holder is not installed (RC_6)	Install proper spray holder
Product with torn packaging is not removed (RC_7)	Increase production control to packaging operator regarding the damaging impact of torn packaging
Conveyor belt loses (RC_8)	Conduct preventive maintenance on the conveyor as scheduled
Operator disciplinary (RC_9)	Manage reward for best achievement in each process division
Jet spray machine is out of order (RC_{11})	Repair the jet spray to reduce 30 minutes of cleaning time
Preparation of chemical material is not done as scheduled (RC_{12})	Conduct chemical material preparation before the cleaning process starts

The summary of the improvement proposed can be seen in the Table 6 as follow.

TABLE VI
FUTURE-STATE IMPROVEMENT OF ECONOMICAL CATEGORY

Indicator	Value	Unit
Production lead time	4759.17	seconds
Cleaning lead time	2.14	hour
Total defect product	2.82	kg/batch

D. *Life Cycle Assessment*

In this stage, further environmental performance analysis was conducted using the gate-to-gate approach of the life cycle assessment. The analysis consists of several main steps that begin with determining goal and scopes, analyzing life cycle inventory, assessing environmental impacts, analyzing for future improvement. The analysis considered the inventory input from electricity usage, the steam loss generated, process water usage, chemical material usage, and packaging material. All the input has the possibility of causing environmental impact with three-damage category, which are damage to human health, ecosystem quality, and resources. The inventory was added as the input of environmental assessment, and the output of assessment was calculated using Simapro v. 8.0 software. The output is presented as a single score with Point (Pt) as the unit to represent the environmental impact. It is shown in Table 7.

TABLE VII
SINGLE SCORE OF CURRENT DAMAGE CATEGORIES

Process	Damage Category (Pt)			
	Human Health	Ecosystem Quality	Resources	Total
Unwrapping	37.5	0.17	1.65	39.4
Grinding	1210	5.45	52.9	1260
Cooking	48900	840	11400	60700
Cooling-packing	5920	26.8	259	6200
Palletizing	1130	5.09	49.4	1180
Cleaning	55.1	3.93	51.3	108

E. *Improvement of LCA Scenario*

Improvement of life cycle assessment focused on reducing environmental impacts on heat loss generated due to insulation system. The insulation condition that is currently being used by the company to flow steam on A41 production is Rockwool material with 42 mm of thickness. Rockwool is the typical material that is used on steam with intermediate temperature (15°C-315°C). The loss from the pipework system is possible to be reduced by choosing the appropriate material and thickness [16]. Selecting Rockwool as insulator material in this company has met the literature suggestion since the average of steam temperature used is 150.6ºC. Rockwool has relatively same good workability with more economical cost compared to other insulation material [17]. The outer side of the insulator is covered by aluminum material with 1 mm of thickness. Aluminum is used on the cold side of insulation as water vapor barrier to avoid losing a certain amount of water vapor.

Focus on reducing loss is then suggested on selecting appropriate insulator thickness. The current condition of insulator thickness does not meet the requirement proposed by [16]. With the outside diameter of the steel pipe 60.3 mm, the thermal conductivity of insulator 0.05 W/m°C, and hot face temperature 150.6ºC, the suggested thickness of the insulator is 49 mm. Adding more thickness to the required one will surely give benefit both in an economic and environmental perspective. Based on the calculation, the heat loss can be reduced as 6.49%, and the environmental impact on cooking and cleaning can be reduced by applying 49 mm of insulator thickness. Table 8 shows the environmental impact improvement addressing the application of suggested thickness.

TABLE VIII
FUTURE-STATE OF LCA SCENARIO

Future state parameter	Value	Unit
Heat loss rate	682.897	J/s
Heat loss on cleaning	11 472.666	MJ
Heat loss on cooking	2 327 476.139	MJ
Environmental impact on cleaning	102	Pt
Environmental impact on cooking	59 500	Pt

F. Advantages and Disadvantages

The advantage of this research is to allow lean improvement process to focus on sustainability category improvement actions and to monitor the environmental impacts during lean improvement initiatives. The disadvantage of this research are the focus analysis of triple bottom line that only considers the critical sustainability metrics, the environmental impact assessment that does not consider heat loss from other causes, and the inventory assessment that only collects last three-month performance data.

IV. CONCLUSION

Sustainable Value Stream Mapping (Sus-VSM), with the integration of Life Cycle Assessment (LCA), evaluated manufacturing performance through sustainability, following triple bottom line perspective. Critical sustainability metrics selected using the Borda Count Method (BCM) were speed loss, total defect product, and heat loss. Speed loss focused on evaluating delay time on the following process: cooking, filling – packaging, cooling – packing, and reduced-speed on the cleaning process. Life cycle assessment was used to evaluate the environmental impact of processes. In this research. Evaluation of environmental impact focused on minimizing impacts that were caused by heat loss on pipe insulation system.

Current total lead time of production are 4967.46 seconds with total defect product on cooking, filling – packaging, and cooling – packing are 4.85 kg/batch. Reduce speed on cleaning was calculated as 0.66 hours/cleaning. Evaluation of minimizing speed loss and defect product was proposed with the future state of production lead time as 4759.17 seconds, reduced-speed of cleaning 0 hours/cleaning, and defect product 2.82 kg/batch.

Total heat loss on cooking and cleaning process was calculated to be 2 488 945.285 MJ and 12 268.585 MJ respectively. Analysis of environmental impact using Simapro v. 8.0 software shows that impact for cleaning and cooking were 108 Pt and 60 700 Pt. Environmental impact on cleaning and cooking can be reduced by implementing insulation thickness 49 mm to meet literature standard based on UK Government’s Energy Efficiency Best Practice Programme. Future environmental impact assessed can be reduced to 102 Pt on cleaning and 59 500 Pt on cooking.

Based on the disadvantages mentioned, it is suggested to do further analysis on not only critical sustainability metrics. The heat loss calculation is more comprehensively considered as other causes. Life cycle assessment is required for measurement on a year basis to to decide further scenario that represents annual performance.

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