

Visualizing Sustainability Performance of Manufacturing Systems using Sustainable Value Stream Mapping (Sus-VSM)

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Abstract

This paper presents the initial results of a comprehensive effort to develop a methodology for sustainable value stream mapping (Sus-VSM) and its application to an industry case study. Suitable metrics and visual symbols were first identified to develop the approach to Sus-VSM. A pilot case study conducted with a local manufacturer of satellite television dishes showed the Sus-VSM approach was able to capture the economical, environmental, and societal sustainability of the line studied. Other and/or additional metrics may be more appropriate if a completely different production line were to be assessed and can be determined through further case studies.

Keywords: sustainable manufacturing, performance evaluation, value stream mapping

1. Introduction

The United States Department of Commerce defines sustainable manufacturing as the creation of manufactured products which use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound [1]. A holistic approach must be taken for the management of products, processes and systems to ensure the economic, environmental and societal sustainability goals are achieved in manufacturing. Lean manufacturing considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, therefore a target for elimination [2].

Lean manufacturing can therefore be considered a pre-requisite to pursuing sustainable manufacturing. Therefore it is important to study how tools used in lean manufacturing can be extended to take account for sustainability considerations. Value Stream Mapping (VSM), which has origins in the Toyota Production System, is an important technique used in lean manufacturing to identify waste. A value stream is defined as all the actions, both value added and non-value added, currently required to bring a product through the main flows essential to every product: the production flow from raw material into the arms of the customer, and the design flow from concept to launch [3]. Conventional VSM methodology does not take into account any environmental or societal metrics both important to evaluating the sustainability of a production line. The ability to visually capture environmental and societal performance through value stream maps will increase its usefulness as a tool companies can use to assess their operations from a sustainable manufacturing perspective. This paper presents the initial result of a comprehensive effort to develop a methodology for sustainable VSM (Sus-VSM) and its applications to an industry case study. Sus-VSM would allow companies to identify those areas that are concerns from environmental and societal perspectives (in addition to economic wastes identified) and then use other methods to further analyze the specified area to implement continuous improvement efforts.

The rest of this paper is structured as follows: in the following section a literature review will describe the current state of work to establish a basis for a methodology for a Sus-VSM. Section 3 will present a methodology describing the proposed Sus-VSM metrics, their significance and visual symbols developed to present them on the Sus-VSM. In section 4, a case study to develop a Sus-VSM using the proposed method will be given. Conclusions and lessons learned from the case study will be discussed in section 5.

2. Literature Review

To enhance the effectiveness of lean implementation and address environmental wastes, the US EPA created a lean and environmental toolkit, in which they define environmental waste as any unnecessary use of resources or a substance released into the air, water, or land that could harm human health and the environment [4]. By tracking and visualizing environmental metrics such as material and water usage along with the typical VSM metrics, multiple companies were able to identify and eliminate environmental wastes. The toolkit also mentions how to add

an EHS (Environmental, Health, and Safety) stamp to identify processes with EHS opportunities. Even though this EPA toolkit has been applied through multiple case studies with companies such as 3M, General Motors, and Lockheed Martin just to name a few; the toolkit does not go into detail about how to include a visual representation of water usage across the entire process line nor does it include any societal metrics.

The US EPA created another toolkit to address energy consumption utilizing the VSM approach [5]. Through this method, the EPA suggests to observe and measure energy consumption during an in-house energy audit. Furthermore, the US EPA suggests encouraging energy efficiency with visual controls such as a energy dashboard to visualize if the energy goals are met. As with the prior US EPA toolkit, this methodology does not mention how to properly track and visualize multiple metrics simultaneously on one VSM. Similar to the US EPA energy toolkit, Kuriger et al [6] proposed a lean sustainable production assessment tool using a real-time dashboard coupled with a continuous improvement dashboard on selected sustainability metrics such as: energy and water consumption, material usage, and CO₂ emissions. This work is built upon prior work in which the idea of an EE-VSM [7] was presented, which considered the energy consumption during the process but not the energy consumed during transportation and specialty storage. Societal metrics are not considered in this methodology nor does it present how to properly visualize multiple metrics simultaneously validated through a case study.

Torres and Gatti [8] extended further on the EPA environment and lean toolkit, which they call environmental VSM (E-VSM), and applied the E-VSM methodology to the alcohol and sugar manufacturing industry in Brazil. This methodology investigates water consumption at a detailed level by dividing water losses into latent loss, real loss, intrinsic loss, functional loss, and real functional loss. Such detail could not only be potentially confusing to the user not familiar with such terminology but also difficult to visually identify waste using the E-VSM methodology.

Simons and Mason [9] proposed a method called Sustainable Value Stream Mapping (SVSM) as a means of enhancing sustainability in product manufacturing by analyzing GHG and CO₂ emissions. Societal metrics have been assumed to be indirectly incorporated in this methodology by the assumption that any ensuing economic or environmental benefits will be accompanied by social benefits, therefore incorporating sustainability. Fearne and Norton [10] combined the SVSM created by Simons and Mason with sustainability metrics created by Norton [11] to create a sustainable value stream map (SVCM) technique by placing emphasis on relationships and information flows between food retailers and food manufacturers in the UK. Basic environmental performance indicators (EPI) set by UK Department of Environment, Food, and Rural Affairs (DEFRA) were to be included in the SVCM while other EPI's are to be selected by the user based on the given process and industry. This methodology considered a wide array of sustainability metrics such as energy consumption during the process, transportation, and any storage phases as well as water consumption and material usage. While validating the SVCM methodology through a case study of sourcing and packing of cherry tomatoes over a 12 month period, measuring energy consumption seemed to be a difficult task; therefore the energy consumption metric was measured by the life cycle analysis conducted by Guinee [12]. Even though the EPI's of the case study were chosen from a wide array of sustainability metrics, a methodology of how to measure the different EPI's was not established nor were any societal metrics chosen for the case study. How to properly and cleanly visualize all of the chosen EPI's for the SCVM, also, was not considered.

Paju et al [13] introduced a new methodology termed sustainable manufacturing mapping (SMM) which includes discrete event simulation (DES), life-cycle analysis (LCA), along with VSM. This goal-oriented approach, using more commonly commercial available life-cycle inventories (LCI) data and combining it with DES and VSM, is implied to be highly visual and simple to use. Even with a wide array of sustainability metrics to choose from, it is not clear how to properly visualize the metrics on the VSM in a clear manner.

Many have attempted creating a new Sus-VSM framework but none are comprehensive to be considered a sustainability tool due to not including societal or multiple environmental metrics, neglecting transportation between processes, or presenting a metric visually on the Sus-VSM in a confusing manner.

3. Methodology

Just as traditional VSM is a quick technique to identify opportunities for kaizen efforts, Sus-VSM must incorporate sustainability metrics to visualize sustainability performance and identify opportunities for improvement. To analyze process sustainability with a Sus-VSM, a concise set of metrics must be determined for each area of sustainability (i.e. Economic, Environmental, and Societal). A project team at the University of Kentucky (UK) is involved in a multi-year project with the National Institute of Standards and Technology (NIST) to develop product

and process sustainability metrics. Currently the project team is working towards a comprehensive list of over 50 metrics that can be used to determine the sustainability of the manufacturing process and product. Based on the metrics provided by the UK-NIST project team as well as other metrics considered in the literature mentioned above, a set of metrics were identified to include in the Sus-VSM.

3.1 Environmental Metrics

The environmental metrics chosen to be included in the Sus-VSM are process water, raw material usage, and energy consumption. The following sections will describe the reason for selecting each metric as well as how each will be measured and visualized on the Sus-VSM.

3.1.1 Process Water Metric

Water, oils, and coolants are used in many manufacturing operations of which often large quantities are needed. This is another area for improvement from an environmental sustainability perspective. Hence the reason to incorporate process water as another metric in Sus-VSM. Water, oils, and coolants used in the manufacturing process is the main focus of the water use metric. For instance, if water is added to the product, such as orange juice, this water will be accounted for in the material usage section of the Sus-VSM.

We propose here to track the amount of water needed, used, and lost for each of the process steps (measured on a volumetric basis) to identify potential areas of improvement. The reason for adding this metric to the Sus-VSM is to visually represent the distinction between water needed and used for potential improvements. The amount of water lost is the amount of water which is not used by another process within the process line or recycled within the plant. Water which is only treated and then sent to either local waterways or a municipal waste-water treatment plant (WWTP), or simply lost through spillage or evaporation will be included in the water lost metric. If a given process line has an internal WWTP and recycles the water within the plant or from one process for another, this water will not be included in the water lost metric on the Sus-VSM.

Coolants and Oils can be treated in much the same way with respect to the Sus-VSM. As mentioned previously, this approach can be used to visually present different coolants and oils which are commonly used resources in different manufacturing processes. The quantities of needed, used, and lost apply in the same way to oils and coolants as it did to water. Lost takes on the same definition, but with a minute difference in that instead of heading to the WWTP, oils or coolants discarded or removed from the facility and are not being used for another procedure will be considered as lost.

Process water will be visually captured in a three-box system on the Sus-VSM as shown below in Fig. 1 with the amount needed, used, and lost respectively placed in the left, middle, and right hand boxes. The amount for each is then summed on the right hand side of the Sus-VSM. The three-box system will be placed below each process cell underneath the timeline metric on the Sus-VSM.

Process I			Process II			Process III			Total		
Needed	Used	Lost	Needed	Used	Lost	Needed	Used	Lost	Needed	Used	Lost
1 gall	1 gall	1 gall	3 gall	3 gall	0 gall	10 gall	12 gall	5 gall	14 gall	16 gall	6 gall

Figure 1: Visual Representation of Process Water on Sus-VSM

3.1.2 Raw Material Usage Metric

According to Sygulla et al [14], 50% of costs in manufacturing are derived from the energy consumption and raw material usage to produce the product. By not optimizing the amount of material removed for a given process, an increase in scrap material to be either recycled or taken to a landfill, which demands more energy, is seen. The amount of material used is tied directly to the amount of processing time it takes to create a product, as well as the energy consumption of that process, therefore being directly linked to both economic and environmental performance of a process line. For those reasons raw material usage has been selected as a metric to be included on the Sus-VSM.

Discrete manufacturing steps can be broken down further into two types to be monitored with Sus-VSM, additive and subtractive. Subtractive manufacturing includes such processes as the machining of a gear, or any operations

that involve material removal. As opposed to subtractive manufacturing, additive manufacturing steps can be defined as processes where material is added to the product.

Whether the operation is additive or subtractive, the raw material usage for each operation within a process line is to be recorded per the Sus-VSM. The goal of monitoring the material usage is not only to examine the initial mass of the product and compare it with the final mass at the end of the process line, but also to record the amount of material being added or removed at each operation/process. The rationale being that the initial and final masses of a raw material vs. the final product do not always truly show wasted material; due to a process line possibly containing both additive and subtractive processes, theoretically the initial and final masses could equal one another. Using the approach of recording and displaying the amount of material added or removed during each operation will allow the individual or team to see the magnitude of added or removed material for each process. If the final and initial mass of the product were the only data points given, problems within the process line could be overlooked. Instead, by analyzing the amount of mass added or removed during each operation using the Sus-VSM operations where there are relatively large amounts of added or removed material could be identified. The raw material usage metric acts as an indicator for identification of areas for further improvement.

Solid material will be monitored on a mass basis. The Sus-VSM will record this metric by utilizing a dotted-line for the initial mass while the material added and removed during the process will be recorded above and below the dotted-line, respectively. For a given process, such as grinding, the amount removed will be placed below the dotted line and vice versa for an additive process, as seen in Fig. 2 below. For a process which does not add nor remove material from the product, the recorded raw material usage will be represented by the dotted line. The added and removed mass will then be summed and displayed on the right hand as seen in Fig. 2 below.

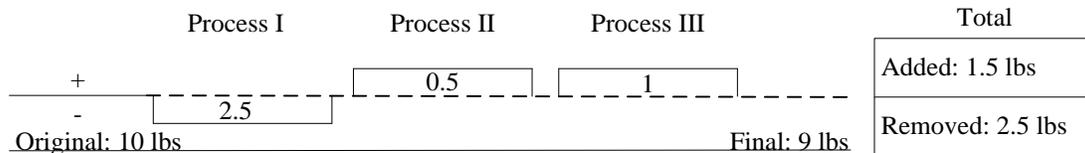


Figure 2: Visual Representation of Raw Material Usage on Sus-VSM

3.1.3 Energy Consumption Metric

Energy consumption has a direct relationship to environmental sustainability due to the use of non-renewable resources as well as Green House Gas emissions. Therefore, energy consumption is an important metric that must be included in the Sus-VSM. The energy consumption metric identifies the amount of energy consumed by a process, not the energy losses of the machines due to heat, inefficiencies, etc. (energy loss is beyond the scope of the Sus-VSM). Once energy consumption data is measured for each process, the Sus-VSM will act as a map to identify which processes have higher energy consumption and then can be further investigated through a more detailed analysis to identify energy inefficiencies or losses.

Along with process energy consumption, we look at the energy consumption associated with actions occurring between operations such as transportation and specialty storage. Transportation energy will include transportation within the plant, as well as transportation during an operation farm-out. This would also include any energy needed for a heating or cooling chamber to keep a product at a certain temperature for the next operation. However, the indirect energy consumption which includes lighting, heating and cooling the building, or any other energy consumed which is not dependent on the number of products produced is not be measured or recorded for Sus-VSM purposes.

With consideration of both the process energy consumption and the energy consumption in between each process, a visual must be created to effectively display both areas clearly. As seen in Fig. 3 below, the energy consumed during transportation and/or specialty storage will be placed on the line between the circles, while the energy consumed during the process will be placed inside the circles on the Sus-VSM. A common energy unit must be used on the Sus-VSM due to energy measurements of various manufacturing equipment. For example, if specialty storage is used in between a process but the units for measuring the energy consumption is thousand cubic feet (MCF) of natural gas, while the units for measuring the energy consumption for a forklift and a manufacturing process are

gallons of diesel fuel consumed and kWh, respectively. One then can easily convert each of the above units into a common unit, such as BTU, by using the energy density of diesel fuel and natural gas.

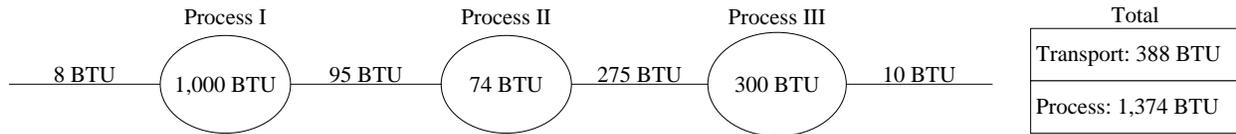


Figure 3: Visual Representation of Energy Consumption on Sus-VSM

3.2 Societal Metrics

Pirages [15] defines sustainable growth as economic growth that can be supported by the physical and social environment for the foreseeable future. Therefore, sustainability requires examining impact on the social environment by considering all stakeholders involved. Given the scope of the activities assessed using the Sus-VSM, the influenced stakeholder group has been chosen as the employees. To evaluate this aspect, risks to the employee’s health and safety must be measured and monitored on a regular basis whether those risks are everyday hazards present to the employee or potential hazards to the employee of a given process. The societal metrics purposed here are further broken down into two categories: Physical Work and Work Environment. These societal metrics aim to assess the working conditions and safety of the employees, and act as an indicator of a possible need for further investigation.

3.2.1 Physical Work Metric

This metric is introduced to capture and present the physical ergonomics of the workplace. The Rapid Entire Body Assessment (REBA) [16], Rapid Upper Limb Assessment (RULA) [17], and the National Institute for Occupational Safety and Health (NIOSH)[18] lifting equation were all investigated for possible use to assess Physical Work. To be useable in a Sus-VSM, it is necessary that whatever the method chosen will provide the best assessment with the least needed information in a reasonable time frame. All the methods mentioned fall short with respect to one or more of the aspects and were therefore not considered. The Physical Load Index (PLI), introduced by Hollman et al [19] as a simple measure that is suitable as a gauge for physical work assessment. The PLI, which ranges from 0-56, is assessed using a questionnaire which takes into account the frequency of occurrence (from never to very often) of different body positions and the handling of various loads. The body positions include those of one’s trunk, arms, and legs as well as loads lifted at a given body positions. The measurements are used in an equation proposed by Hollman et al to come up with the PLI. In the Sus-VSM the PLI is to be recorded at each process as well in between processes to capture the physical hazards present to each employee. The PLI can be seen as an easily measured indicator or risk for further investigation which might include utilizing the REBA, RULA, or NIOSH tools.

3.2.2 Work Environment Metric

The second societal metric to be included on the Sus-VSM is the work environment. The work environment metrics, which includes four risk categories and the noise level, assess potential hazards to the employee(s) due to the environment in which they have to work. Different manufacturing processes can have different potential hazards. Therefore, four potential risk categories have been identified to evaluate work environment: Electrical Systems (E), Hazardous Chemicals/Materials Used (H), Pressurized Systems (P), and High-Speed Components (S). A rating system of 1-5, as seen in Table 1, is then given for each of the potential risk categories for a given process based on the likelihood and impact of such risk. From this metric, an organization could put in place proper controls to ensure the safety of the employees as well as to reduce the potential risk. By identifying which process is in need of further investigation, this societal metric goes beyond what is presented by the EPA EHS stamp, which only identifies whether or not to involve the EHS staff in the improvement evaluation period. The work environment metric will be represented by a circle, as seen in Fig. 4, above each respective process cell box.

Table 1: Work Environment Risk Rating Description

Potential Operator Risk	Description
--	Potential risk does not exist (DNE).
1	Risk is present but has low impact and probability of occurring.
2	Risk is present but has low impact and high probability or high impact and low probability of occurring.
3	Risk is present but has medium impact and medium probability of occurring.
4	Risk is present but has either medium impact and high probability of occurring or high impact and medium probability of occurring.
5	Risk is present but has high impact and high probability of occurring.

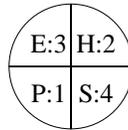


Figure 4: Symbol to Capture Status of Work Environment Metric

For example, if a potential risk is present to the operator due to pressurized systems being in place but has a low impact (meaning the occurrence of an injury would be minor) and the probability of occurrence is low, then the potential work environmental risk rating for the pressurized system metric of that specific process is ‘1’. The remainder of the work environment circle can be filled out accordingly for each process step represented on the Sus-VSM.

Noise levels in a manufacturing environment pose another area of concern for the operators. While any noise above 80 dBA puts the operator at risk [20], but the duration of the exposure to that noise level greatly determines the effects on the operator. These levels of exposure also need to be recorded on the Sus-VSM to allowing the user to examine another aspect of the employees’ health and safety. Equation (1) below indicates how to measure the noise dose (D), with the total daily noise dose equaling the sum of partial doses. The noise dose for an operator will range from >0 to 100% [20].

$$D = \frac{\text{Time actually spent at sound level}}{\text{Maximum permissible time at sound level}} \times 100\% \quad (1)$$

From the noise dose calculated above, one can measure the Time Weighted Average (TWA) in order to record the noise exposure, in dBa, as seen in Equation (2) below. The TWA can be thought of as the equivalent sound level that would produce a noise dose equal to being exposed to that sound level over a continuous 8 hour period (a full work shift) [20].

$$TWA = 16.61 \log_{10} \frac{D}{100} + 90 \quad (2)$$

Using TWA calculated in Equation (2) above, the noise is to be measured at each process and recorded within the process box on the Sus-VSM along with the cycle time, changeover time, uptime, and PLI.

4. Case Study

To validate the purposed Sus-VSM methodology, a pilot case study was conducted with a local manufacturer of satellite television dishes. Figure 5 below shows the steps involved in the manufacturing process which produces roughly 20,000 satellite dishes per month. Steel arrives at the plant in coils which is then stamped per design specifications into a final shape. The dish is then washed in a five-stage wash system to remove any oils or impurities from previous process steps. It is then dried in a dry-off oven, which is considered as specialty storage, before powder paint is applied. Following the application of the powder paint, a cure oven is used to melt and adhere the powder paint on the dish. The wash, paint, and cure oven processes all use the same conveyor system. Once the dish is pulled from the conveyor system after the cure oven process, appropriate emblems are then pad printed onto the dish. The dish is then transported to another location to be kitted with other accessories before it is shipped to the

customer. The dish is transported via forklift and truck between operations and warehouse location, respectively. The following will describe how the data was collected for each metric at each operation.

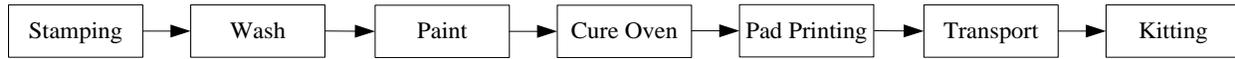


Figure 5: Satellite Dish Manufacturing Process Flow

4.1 Data Collection

Measuring the cycle times for the different processes in the case study was done either by time studies (watching a part start a process and run through to the end) or calculated if the process could not be monitored. For the stamping, pad printing, and kitting processes, cycle times were measured by taking the average time it took a part to go through the process. Cycle times for the wash, paint, and cure oven processes could not be measured in the conventional way due to being closed-off systems. Therefore, cycle times were calculated by dividing the length of the individual process by the speed of the conveyor system. Inventories were physically counted after the stamping, cure oven, pad printing, and kitting process. Based on this, the lead time was calculated by dividing the amount of dishes in inventory by an average daily demand. The inventory prior to stamping was calculated based on the total mass of the steel divided by the mass of a steel blank needed to produce one dish. With regards to the three processes on the conveyor system - wash, paint, and cure oven – the inventory was calculated by using the length between processes, the conveyor speed, and the spacing between each dish. All information regarding the raw material lead time, frequency of raw material and finished product shipments, the flow of information within the manufacturing facility and to the customers and suppliers, was provided by the manufacturer.

For the PLI data collection, employees involved with each process and the employees involved with transporting the goods within the manufacturing facility were asked to fill out the questionnaire presented by Hollman et al, [19]. The average and maximum PLI scores were selected to be displayed for each operation on the Sus-VSM. Noise data collection was completed prior to the Sus-VSM task by a third-party. The necessary information for the work environment circle for each process was provided by the Quality Manager.

Per the raw material usage metric, the original and final masses were obtained by using the blank steel mass and weighing the dish after pad printing, respectively. Weighing of the dish also occurred after the stamping and cure oven processes to see the difference from the mass at the beginning of the process. The mass added during the painting process per dish was given by the manufacturer.

Since the information on the Sus-VSM must be on a per dish basis, the energy consumption and process water metrics must be calculated and displayed on a per dish basis as well. Equation (3) below served as a basis for this calculation.

$$\text{Amount per dish} = \frac{\text{Total energy or water flow during process over a given time}}{\text{Total number of dishes in system during process during that time}} \quad (3)$$

Given the water flow (gallons/s) or energy flow (power rating), cycle time (s), and number of parts in the process system at any given time (n), one can then calculate the water used or energy consumed per dish by using Equation (4) below.

$$\text{Amount per dish} = \frac{\text{Flow Rate} \times \text{Cycle Time}}{(2n-1)} \quad (4)$$

For the wash process, discharge pressure gauge readings were taken and compared to their respective pump curve and design specification. From this information and using Equation (4) above, the needed and used process water information for the five-stage wash process was calculated. Due to recycling occurring within the five-stage wash process, the fresh water intake was considered to be equivalent to the amount of water lost during the process. The stamping process water was then calculated using the oil-to-water mix ratio needed to perform an eight-hour work shift, and then divided by the number of dishes produced over those eight hours. It was assumed this number was also the amount needed for the process.

Using Equation (4) above, the energy consumption was calculated for the stamping, wash, cure oven, and pad printing processes as well as the dry-off oven step prior to the paint processes. Some of the above processes had

pumps, fans, and natural gas burners, all of which consume energy. The aggregate energy (BTU) and energy flow (BTU/s) were calculated where relevant. Given the power rating (BTU/s), speed (feet/s), distance travelled for the forklifts and truck (feet), and number of dishes per batch, the inter-process energy consumption was calculated using Equation (5) below.

$$\text{Energy consumed per dish} = \frac{\text{Power Rating} * \text{Distance Travelled}}{\text{Speed} * \text{Number of Dishes in Batch}} \quad (5)$$

Figure 6 shows the Sus-VSM developed for the satellite dish manufacturing line. As can be observed, the value added time is approximately 32 minutes, whereas the total lead time is over 12 days; indicating the existence of considerable non-value added activities. What is more interesting is the sustainability performance of the production line that is revealed through the Sus-VSM. One of the most important revelations to the satellite dish manufacturer was the high energy consumption (60% of total) for the wash process. The 64 gallons lost per dish also points to opportunity to improve environmental sustainability of this line. The PLI scores, one of the metrics used to assess societal sustainability, were not alarming in general; it was highest for the kitting process due to the repetitive nature operations involved. No areas of major concern were observed with regards to the risk circle or noise level, the other societal sustainability metrics included in the Sus-VSM. Overall, the manufacturer found the Sus-VSM to be very helpful to visually capture the sustainability performance of the production line. The consensus was that the metrics and visual symbols used captured the most important criteria related to environmental and societal sustainability performance (in addition to economic performance) for subsequent in-depth analysis using other, more comprehensive techniques.

5. Conclusions

This paper presented the methodology developed to prepare a sustainable VSM (Sus-VSM) which includes various metrics to evaluate not only the economic performance but also the environmental and societal sustainability performance of a manufacturing line. Metrics were selected to assess process water consumption, raw material usage, energy consumption, potential hazards concerning the work environment and the physical work done by the employees. Necessary visual symbols were then created for each proposed metric on the Sus-VSM to easily visualize potential areas for continuous improvement.

The pilot case study, conducted with a local manufacturer of television satellite dishes, helped validate many aspects of the Sus-VSM methodology. Several shortcomings of the initial Sus-VSM methodology came to light during the pilot case study. One was the confusion regarding the needed and lost process water metrics. After further discussion, the required and net amount of process water used were thought to be a more conventional and easier metric to define and measure. The metrics selected for the Sus-VSM turned out to be sufficient to capture the environmental and societal sustainability of the line studied. However, if a completely different production line (i.e. chemical process) were to be assessed, other metrics may need to be considered. Therefore, future case studies are needed to further refine and validate the data collection procedure and any additional changes made to the initial Sus-VSM methodology.

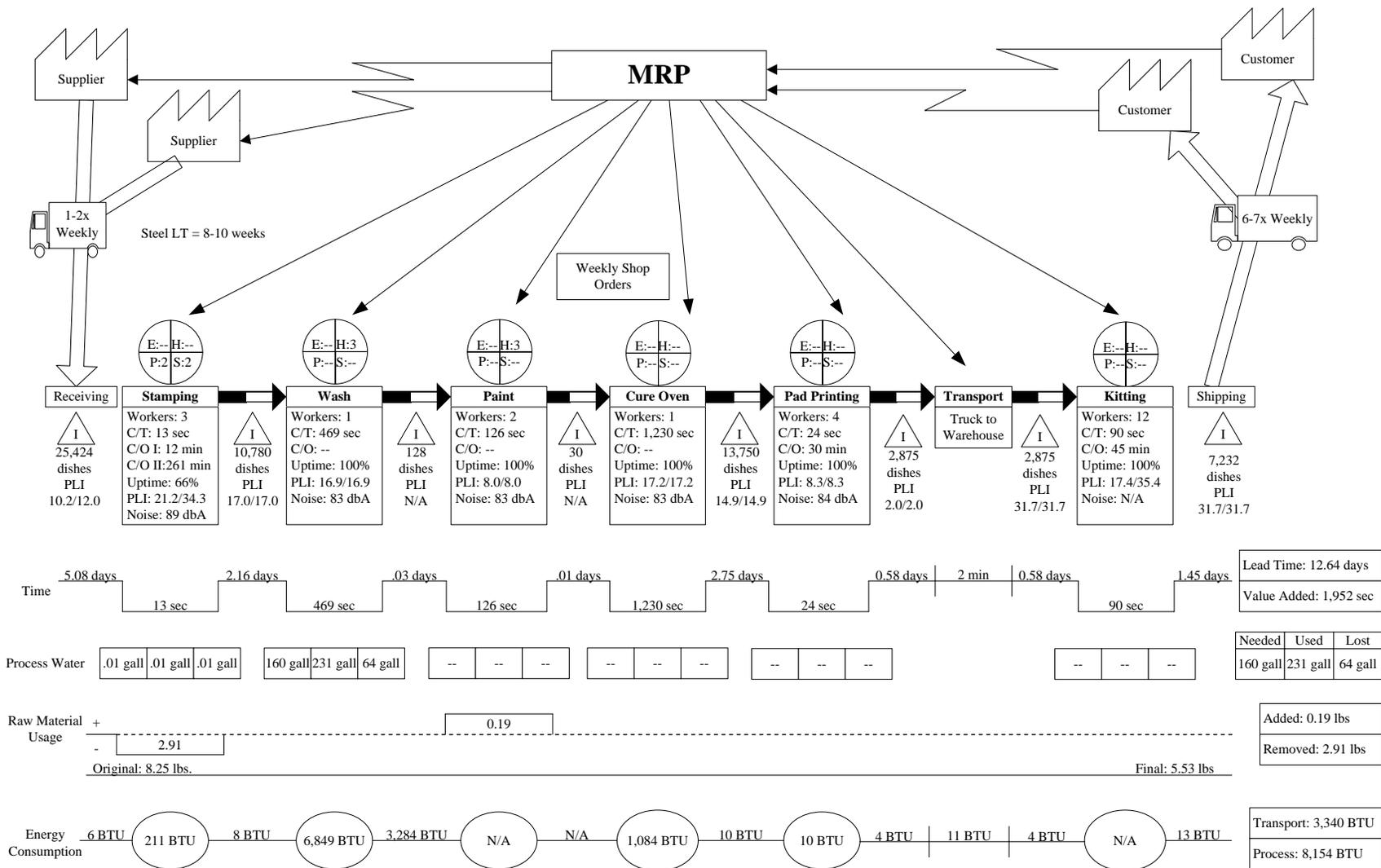


Figure 6: Satellite Dish Sus-VSM

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