A new methodology to identify supply chains sustainability bottlenecks

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Abstract

The world globalization has been creating a very strong competition amongst companies. To maintain their market position, companies need to guarantee that all their activities are performed with high efficacy and efficiency standards, allowing not only a business profit but also a good company image among their stakeholders. Such reputation is not definitely related only to the service level and the economic performance but also to the way environmental and social aspects are treated within the companies' strategy. This paper explores these concerns and presents a simple and systematic methodology (SustainSC-VSM) for supply chain analyses. SustainSC-VSM is composed of a value stream map and a complementary analysis which is based on the *Sustain-Pro* methodology. SustainSC-VSM will screen and identify the main bottlenecks, regarding sustainable factors (economic, environmental, social) in any supply chain. Moreover, SustainSC-VSM proposes an information factor in order to improve the coordination among the supply chain actors and their sustainable performance. A set of new indicators is applied during the analysis. The analysis of these indicators points out the issues to deal with when the future state Value Stream Map is designed. A case study is presented to highlight the applicability of the developed methodology. The obtained results point out the direction to harmonize business efficiency standards and sustainability in the supply chain.

Key words Supply Chain; Sustainability; Value Stream Mapping; Indicators; *Sustain-Pro*; Lean

1. Introduction

Supply chains have become a strategic aspect that companies have to consider if they want to achieve a good position in the global market. Therefore, in order to strive, supply chains have to embrace sustainability, extending their focus from a specific process to a general positioning, which considers the involvement of all supply chains' stakeholders (community, employees, consumers, etc). Considering these aspects, supply chains and consequently organizations, will achieve a competitive advantage [1]. In this context environmental and social concerns appear as key issues that will allow companies to achieve their sustainability. To achieve this goal companies have frequently adopting lean manufacturing practices [2].

Lean production can be defined as a multi-dimensional approach that encompasses a wide variety of management practices in an integrated system, which includes just-in-time, quality systems, work teams, cellular manufacturing, supplier management, among other [3]. To effectively implement the aforementioned methods into companies' daily routines, several tools have been developed to help practitioners in this task. One of the tools available and frequently used is the Value Stream Mapping (VSM). VSM is a collection of all actions, value added as well as non-value-added, which is required to bring a product (or a group of products) through the main flows, starting with raw material and ending with the customer [4].

While VSM is a tool whose range of scope is mainly facility-level, the Extended Value Stream Map (EVSM) is a tool which focuses on the overall supply chain.

The main purpose of EVSM is to find a new value added map that reduces waste. Womack and Jones [5] identified six features that must be accomplished to build a lean extended value stream: 1) Produce at a closed rate of customer consumption. 2) Very little inventory. 3) Minimize transport links between steps in the production process. 4) Minimize information processing, with pure signal and no noise in the information flows that remain. 5) Minimize the lead time. 6) Changes to smooth flow should involve the least possible or even zero cost.

Although these features support the design of new future state map, it is not always a straightforward procedure and companies sometime are not able to make a step forward. Some authors have presented improved versions of the VSM analysis, which incorporates other features: McDonald [6]; Abdulmalek and Rajgopa [2] used simulation processes and Dotoli [7] used AHP to test the new alternatives proposed by the VSM analysis. All they coincide that combining different techniques with VSM allowed them to identify the most appropriate response. Thus, this paper wants to improve the EVSM implementing indicators to have a basis to work towards the future state of the EVSM.

To effectively fit these tools, it is introduced Sustain-Pro which is a tool that employs an indicator based methodology for designing new sustainable design alternatives [8]. Sustain-Pro methodology follows six step procedure: (1-Data collection; 2- Flow-sheet decomposition; Step 3: Indicators calculation; Step 4: Indicators Sensitivity Analysis; Step 5: Operational Sensitivity Analysis; Step 6: Generation of New Design Alternatives) [9] [10].

2. Methodology: SustainSC-VSM

The SustainSC-VSM intends to provide a new alternative to detect bottlenecks in the SC combining qualitative and quantitative sustainable-procedures. The developed methodology is based on two pillars: 1) Develop a methodology which does not compromise the future sustainability of the supply chain.2) Lean practices in order to consolidate the company share in the market and perform high efficacy and efficiency standards.

The flow-diagram of the proposed methodology is presented on Figure 1.

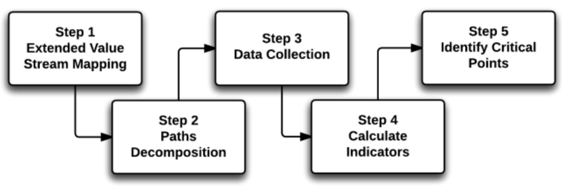

Figure 1: Flow-diagram of the new methodology

2.1 Step 1: Extended Value Stream Mapping: In this step the sequence of entities and operations within the supply chain are represented through the EVSM. To represent the EVSM, it is advisable to follow the following procedure [5].

- Task 1: Define the family product
- Task 2: Define scope of the EVSM
- Task 3: Create a work-team
- Task 4: Define the level of detail
- Task 5: Identify the steps of the EVSM
- Task 6: Map the entities
- Task 7: Map the transport flows
- Task 8: Map the information flows

After this step, the work-team can already visualize the sequence of all activities in the supply chain. All activities with value added and non-value added will be identified accordingly to their sequence and connection.

2.2 Step 2: Paths Decomposition: The supply chain network, represented by EVSM, will be analysed using the graph theory. The entities will be considered as the vertices. These vertices are connected through intermediate streams, called edges. Following the aforementioned procedures the decomposition of the EVSM into open- and closed-paths should be performed in this step. For each path it will be calculated the correspondent flow of components. The flows for open- and closed-paths will be determined following the methodology presented in [8] [9].

2.3 Step 3: Data Collection: In this step, all important data on the supply chain operations needs to be collected. This means the already specified data for EVSM analysis and additional data. It is recommended to the users to assess the demand pattern of the supply chain and to try to delineate the best time interval that frames the most common operations or the critical periods were this methodology should be applied.

2.4 Step 4: Calculate Indicators: In this step, a set of indicators is proposed in order to assess the supply chain paths. The indicators are applied to all paths allowing carrying out a comparative analysis among the paths and prioritizing the retrofits actions that should be taken to improve the initial EVSM. The proposed indicators will cover all the economic, environmental and social sustainable areas plus an information area which will ensure the optimal coordination between entities in order to increase the sustainability performance.

Economic Indicators: These economic indicators aim to assess if the limited resources of the company are applied effectively to create wealth for the company and value for the customer. A good control system should include performance measurements regarding cost, quality, time and flexibility of the supply chain [11].

Economic indicators-cost

Material Value Added –SC (*MVA-SC*): *MVA-SC* gives the value added between the entrance and the exit of a given material (equation 1)

$$MVA\ SC = Fop * (P_{Ex} - P_{En}) \quad (1)$$

Where *Fop* is the flow of the open-path, P_{Ex} is the price of the product when leaving the supply chain and P_{En} is the price of the raw material. Negative values of *MVA-SC* point out the need for improvements. *MVA-SC* was adapted to the supply chains context from a previous work [9].

Energy Cost-SC (*EC*): *EC-SC* provides the value of the energy consumption through the path. *EC-SC* is calculated applying equation 2

$$EC\ SC = \sum_{e=0}^{E} P_{Ut} \times En_e \times AF_e \quad (2)$$

Where P_{Ut} is the price of the utility (fuel, electricity, etc), *En* is the energy consumed in each entity of the path and *AF* is the allocation factor, which gives the allocation of the energy consumed per path. *AF* can be calculated applying equation 3.

$$AF = {}^{MF}\!/_{\sum_p^P MF} \quad (3)$$

Where *MF* is the mass flow and *p* is the path and *P* is the total number of paths passing in that entity. High values of *EC* point out the need of improvements. This indicator was from a previous work [9].

Total Inventory Level Cost (*TILC*): *TILC* gives information about the most critical paths in terms of inventory costs. This indicator presents high values when the inventory for a given stock keeping units (*SKU*) is in excess of inventory (equation 4).

$$TILC = \sum_{e=0}^{E} Inv_e * HC_e * Afe \quad (4)$$

Where *Inv* is the inventory of entity *e*, *HC* is the holding cost of a given *SKU* in an entity *e.* The higher the indicator value, the higher is the inventory cost in a specific path.

Entity Inventory Level Cost (*EILC*): *EILC* gives information about the most critical entity in terms of inventory cost, within the identified critical path in terms of *TILC* (equation 5).

$$EILC = \frac{Inv_e \times HC_e * Afe}{\sum_{e=0}^{E} Inv_e * HC_e * Afe} \quad (5)$$

The closest value of *EILC* to 1 represents the bottleneck of the path in terms of inventory costs.

Backorder Cost (BC): BC indicator is the total value of lost sales as a result of not meeting the customer demand in a given path (equation 6).

$$BC = (Dem_c - F_{OP}) \times (1 + i) \times P_{Ex}) \quad (6)$$

Where Dem_c is the demand of component *c* and *I* (penalty rate) is the increment in percentage over

P_{Ex}. High values of *BC* point out to the need of improvements, since many backorders are being observed.

Economic Indicator –Time

Lead Time Factor (*LTF*): LTF gives the total lead time in each path (equation 7). This indicator allows the determination of the most critical paths in terms of lead time to the final customers.

$$LTF = \sum_{e}^{E} LT \quad (7)$$

LT represents the lead time of the entity *e*. High values of *LTF* point out the need of improvements. This indicator was adapted to the SC context from a previous work [10].

Operational Lead Time Factor (*OLTF*)*: OLTF* gives information about the most critical entity in terms of lead time, within the identified critical path in terms of *LTF* (equation 8).

$$OLTF = \frac{LT_e}{\sum_{e}^{E} LT} \quad (8)$$

High values of *OLTF* point out the bottleneck in terms of entity lead time. This indicator was adapted to the SC context from a previous work [10].

Inventory Turnover (*IT*): IT indicates the inventory which takes longer to empty in a given path. IT indicator is only applied to entities with inventory (equation 9).

$$IT = max\left(\frac{Inv_e}{Dem_e}\right) \quad (9)$$

Where *Inv* is the largest inventory of the entity *e*, *Dem* is the demand of the downstream process. The *IT* indicator was adapted to the SC context from a previous work [5].

Economic- Quality

Service Level Quantity Factor (*SLQF*)*: SLQF* indicator gives information about the accomplishment of the delivered quantity when compared to the placed orders (equation 10).

$$SLQF = \frac{Dem_c - Fop}{Dem_c} \quad (10)$$

Values different from 0 of SLQF highlight that the service level in terms of quantities delivered are not being accomplished and consequently that path is not satisfying the customer.

Service Level Time Factor (*SLTF*): *SLTF* indicator gives information about the accomplishment of the delivered time when compared to the schedule (equation 11).

$$SLTF = \frac{F_{OP-OnTime}}{F_{OP}} \quad (11)$$

Where *OnTime* is the flowrate of the open-path delivered according to the scheduled time. Values different from 0 of *SLTF* stress the need of a better service level in terms of time delivery

Ok-Parts (OP): OP indicator displays the percentage of flow which goes from the raw material to the customer arms and reaches a suitable quality (equation 12).

$$OP = \prod_{e=0}^{E}\left(1 - \frac{Def_e * Af e}{Fop}\right) * 100 \quad (12)$$

The *Def* is the defective flow rate of the entity *e*. The farther the percentage is to 100, the lower is the quality performance of the path.

Overall throughput effectiveness (*OTE-SC*): *OTE-SC* metric proposed in this work is developed based on the idea of comparing actual productivity to maximum attainable productivity for a given path (equation 13).

$$SC - OTE = \frac{\text{Fop}}{TFop} * 100 \tag{13}$$

TFop stands up for the theoretical flow of an open-path working at full yield. Low values of *OTE-SC* display a poor production performance.

Economic Indicator- Flexibility

Flexibility Volume Factor (*FVF*)*: FVF* indicates if a company has capacity to adapt its production to demand changes in terms of volume (equation 14).

$$FVF = \min(\frac{Cap_e - Dem_e}{Cap_e}) \tag{14}$$

Where Cap_e is the process capacity of the entity *e* of a given path. The lower the value of the *FVF*, the lower is the capacity of the company to adapt its production to demand fluctuations.

Flexibility Time Factor (*FTF*): FTF displays a company ability to adapt its production to meet the demand changes of the customer in terms of time (equation 15).

$$FTF = \frac{(DDD - EDD)}{(DDD)} \tag{15}$$

Where *DDD* is the due date for delivery, *EDD* is the earliest due date which the delivery can be submitted. The lower the value of *FTF*, the lower is the capacity to deliver their products in front of a change of deadlines. The indicator was adapted to the SC context from a previous work [11].

Environmental Indicators: Some companies influenced by stakeholder's pressure have adopted environmental indicators as a support tool to enhance friendly environmental policies. Many quantitative performance metrics has been developed to determine the impact of the supply chain in the environment such as GHG emissions, waste generation, material recycle or energy use [12].

Carbon emission (*CE*): *CE* indicator that quantifies the CO_2 emissions of each open path of the supply chain into the atmosphere (Equation 16).

$$CE = \sum_{e=0}^{E} AF_e \times CDE_e \tag{16}$$

Where and *CDE* is the carbon footprint emitted by each entity. High values of *CE* point out to the need of improvement.

Waste Factor (*WF*): *WF* provides information about the disposal of material that is produced in the supply chain per each path (equation 17).

$$WF = \frac{\sum_{e=0}^{E} W_e * AF_e}{Fop} \tag{17}$$

Where *We* is the waste of material in the entity *e*. High values of *WF* display an overexploitation of environmental resources.

Sustainable Energy (*SE*) *SE* indicator displays the company commitment to use friendly-environmental resources to manufacture and transport the product (equation 18).

$$SE = \frac{\sum_{e=0}^{E} Gen_e * Af_e}{\sum_{e=0}^{E} En_e * Af_e} * 100 \tag{18}$$

Where *Gen* is the consumption of green energy of the entity *e*. Low values of *SE* reveal a low degree of environmental sustainability.

Social Indicators: Simões [13] identifies 4 elements that stakeholders believe worthy of protection: labour practices, human rights, product responsibility and society. The proposed indicators cover all the aforementioned topics.

Labour Equity (*LE*): *LE* indicator describes the distribution of employee compensation including all benefits (equation 19).

$$LE = \min(\frac{Ls_e}{Hs_e}) \quad (19)$$

Where *Ls* represents the lowest salary of a given entity *e* and *Hs* is the highest salary. The closer the LE ratio is to one, the greater is the equity distribution. This indicator was presented [14].

Fatal Accident Rate (*FAR*): *FAR* is a statistical method that reports the number of incidents of an activity based on the total amount of employees working their entire lifetime. This Indicator can be calculated applying equation 20.

$$FAR = \frac{\sum_{e=0}^{E} Ninc_e * 10^8}{\sum_{e=0}^{E} NE_e * Wh_e} \quad (20)$$

Where *Ninc* is the number of incidents in the entity *e*, *NE* the number of employees and *Wh* the working hours per year. High values reveal need of improvement in the company's procedures or a change in the operations.

Corruption (*C*): C indicator accounts the number of law sues in a given path (equation 21).

$$C = \sum_{e=0}^{E} Nls_e \quad (21)$$

Where *Nls* means number of law sues of each entity. Values not equal to 0 reveal corruption.

Information Indicators: This new proposed field assess the effectiveness of coordination among the members of the supply chain and the potential breakthroughs that can be implemented in the information sharing policies.

Variability of Lead Time (*VLT*): *VLT* aims to provide a tool to monitor the relative variability of the lead time (equation 22).

$$VLT = \frac{\sigma_{LTF}}{LTF} \quad (22)$$

High values of *VLT* reveal a need for improvement in the stability of the information flow across the given path.

Bullwhip Effect (*BE*) : *BE* indicator provides information about the demand variation in the more upstream process of a given path. *BE* indicator can be calculated applying equation 23.

$$BE = \frac{\sigma_{Fop}}{\sigma_{Dem}} \quad (23)$$

Where σ_{Fop} and σ_{Dem} represent the variance of the orders of the first entity of a path and the demand of the flow in a given path. High values of BE highlight the need of enhancement.

2.5 Step 5: Identify Critical Points : The indicators above described are applied to each path and based on their values it is possible to identify the most critical supply chain areas. The bottlenecks of the supply chain should be firstly analysed and efforts to improve them should be done.

3. Case Study

The studied product is a heat exchanger.

3.1 Step 1: Extended Value Stream Mapping: The figure 2 presents the EVSM

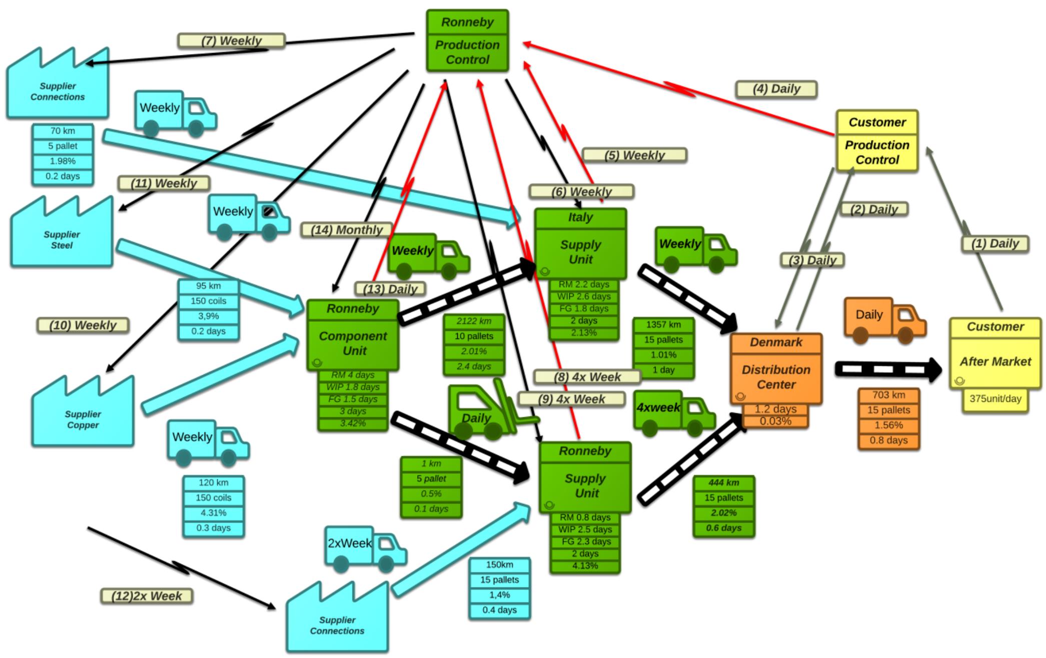

Figure 2: EVSM representation of the after-market

3.2 Step 2: Path-flow decomposition: The network decomposition was applied and a total of 9 open-paths were obtained. Due to the lack of space the paths are not presented, however the critical paths will be described though the text to enable the indicators interpretation.

3.3 Step 3: Data collection: The data was mainly obtained from [15][16].Due to the lack of information some assumptions were made.

3.4 Step 4: Calculate Indicators: The table 1 presents of the indicators introduced in the section 2.4.

Table 1: Indicator Values

Indicator	Bottleneck	Value (units)
EC	OP9	493.554,16 €
TILC	OP1	24.751,29 €
EILC	Ronneby C.O.	0,7405
BC	OP7	264.444,44 €
LTF	OP9	25,7 days
OLTF	Italy-U.S.	0,498
IT	OP9	4,5 days
FVF	OP 1/3/5/7	0,016
FTF	OP5	0,067
SLQF	OP3	0,03
SLTF	OP4	0,025
OK-P	OP3	88,16%
OTE	OP1	85,71%
VLT	OP5	0,3667
BE	OP7	1,3
CE	OP9	8780,47 t
WF	OP9	0,2173
SE	OP6/8/9	0 %
LE	OP7/8	0,2705
C	OP3	3 ls
FAR	OP7	537 inc/w*h

3.5 Step 5: Critical Points: In this section, some bottlenecks are identified and changes suggested:

Energy Cost (EC-SC): Open path 9 (Italian S.U.→ Indianapolis Distribution Center → U.S. market) appears as the most critical path in terms of energy consumption. This indicator points out the possibility of opening or use an existing factory in U.S. to produce the components that are at the moment produced in Italy. This solution would reduce the transportation costs and consequently will reduce the energy consumption.

Total Inventory Level Factor (TILF) and Entity Inventory Level Cost (EILC): Open Path 1 (Steel Supplier → Ronneby C.O. → Ronneby S.U.) is the most expensive path in terms of inventory. As it can be observed in the EILC indicator, the Ronneby C.O. factory has the largest allocation of inventory cost in the path. It would be advisable to consider a change from the current MTS policy to MTO in order to reduce unnecessary inventory.

Lead Time Factor (LTF) and Operational Lead Time Factor (OLTF): The most critical path in terms of LTF is OP 9. Analysing the OLTF of the OP 9 is possible to see that the transportation time from the Italian factory to the Indianapolis distribution center is the main supply chain bottleneck in terms of lead time. As mentioned in the EC-SC indicator, it would be advisable to study the possibility to use the facilities that Alfa Laval has in U.S. to produce the components that are at the moment produced in Italy. This solution would reduce the transportation time.

Variability Lead Time (VLT): Open-path 5 (Connection Supplier→Ronneby S.U.) has the largest relative variance in the supply chain. This uncertainty undermines the production performance of the Ronneby S.U. It would be advisable to establish well-defined standards to prevent the SC from this time fluctuations.

Bullwhip Effect (BE): Open-path 7 (Ronneby S.U.→ Danish distribution center → after-market) is the most critical path in terms of material distortion. After-market is an unsteady market so a lot of unforeseen variations triggers rush orders causing malfunction in the supply chain. It is suggested to implement a vendor-managed inventory (currently the costumer production control sends orders to the Ronneby production control, (see EVSM, figure 2).

Carbon Emission (CE): Open path 9 (has the largest carbon footprint in the supply chain. The transportation flow from Italy S.U. has a significantly impact in the environment, thereby it is strongly recommended to adopt the aforementioned solution for OP 9.

Corruption (C): Open-path 3 (Copper Supplier→ Ronneby C.O. → Ronneby S.U.) holds the worst performance regarding corruption. All the entities of this path account a law sue for breaking the law and the business ethic code of the supply chain. This represents, without any doubt, a non-sustainable social performance which would probably damage the whole supply chain. An internal audit program would help to revise the current standards in order to significantly decrease these figures.

4. Conclusions and Future Work:

A new methodology was created to provide a tool to identify the supply chain bottlenecks, screen waste and analyse the company's sustainability performance in a systematic procedure. Three different operational techniques or methodologies related to the lean and sustainability principals were adopted and further developed: Value Stream Map, *Sustain-Pro*, performance indicators. This paper also explored the coordination among the supply chain actors with the purpose of improving the sustainability performance. A real case-study was used to test the methodology and important results were obtained. As future work SustainSC-VSM needs to be tested again with real data to validate the results. Companies that may adopt SustainSC-VSM must understand that SustainSC-VSM is a generic methodology for all supply chain and much customization is needed to meet the requirements of a specific field.

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