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CIRP Office
9 rue Mayran
75009 Paris - France
Tel : 33 1 45 26 21 80
Fax : 33 1 45 26 92 15
Email: cirp@cirp.net
Website: http://www.cirp.net

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A method for a comprehensive value stream evaluation

Wilfried Sihn (2)[a,b], Matthias Pfeffer[a,b,*]

[a] *Vienna University of Technology, Institute of Management Science, Theresianumgasse 27, 1040 Vienna, Austria*
[b] *Fraunhofer Austria, Theresianumgasse 7, 1040 Vienna, Austria*

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ABSTRACT

The optimization of value streams in manufacture will always present alternative solutions to planners as a result of the interdependencies between all the optimization parameters. In the search for an ideal value stream in terms of cost and benefit, relevant monetary and non-monetary parameters have to be considered. The method introduced describes a mathematical calculation bringing different parameters of a value stream into one equation. After a normalization step, and a systematic prioritization of the parameters, a value is calculated for each alternative solution. This value allows planners to compare alternatives and to find the best-case solution with the current state process.

1. Background and introduction

The escalating changes brought about by introducing new products with an increasing number of product variants force production companies to optimize their processes as a whole. Isolated departmental thinking is replaced by a process-oriented view [1]. Thus, Value Stream Mapping (VSM) has established itself as a procedure for process optimization in industrial plants. It provides a method for analysis and design of production processes which will address these rapid changes [2]. VSM was originally developed as a method for analysis and optimization of industrial processes. It was introduced by Rother/Shook, based on the principles of Lean Thinking [3]. VSM is a simple, effective method of gaining a holistic overview of the value stream within an organization. Based on a current state analysis, flow oriented target value streams are planned and implemented [4]. A value stream includes all activities, i.e. value adding, non-value adding and supporting processes that are necessary to create a product and to make it available for the customers [3]. Since lead time is often considered as a sole performance criterion, difficulties arise with the VSM method in selecting a unique variant of different value streams (target conditions). Subsequent cost calculations can only provide limited conclusions/predictions about a best-case solution.

In the light of these shortcomings, the objective of this paper is to describe a method that evaluates different value streams in terms of costs and benefits. This evaluation considers both the material and the information flow of a company. Firstly, it aims to answer the question, what criteria (targets and indicators) are relevant for the assessment of value streams, and secondly, how these different criteria can be summarized as one comprehensive evaluation model.

2. State of the art and derived requirements for a comprehensive evaluation method

In scientific literature, especially in journal publications, many authors focus on the optimization of the VSM method by standardizing the analysis process or by defining future target conditions. The lead time itself is always paramount; different methods are combined with VSM itself [5], or VSM or other lean methods are introduced as well as ways of measuring lean implementation [6–10]. Evaluating the impact of costs on a value stream is described, e.g. in dependencies of flexibility parameters and product changes [1,6].

The method described combines the lean approach by linking different parameters concerning performance and costs within a value stream. The principles used to establish this method are drawn from literature reviews about scientific publications which deal with the applied concepts and methods as well as from hands-on experiences.

A comprehensive evaluation of different value streams therefore implies the connection of non-monetary (performance) and monetary (e.g. expenses, costs, savings) indicators of the value stream. All the defined indicators must be individually adaptable and prioritizable for the user's requirements. They must also be clearly defined and their correlation to all other indicators has to be depicted transparently.

For the subsequent comparison of future value streams distinct reference values are required to make an explicit statement, regarding the evaluated alternative target conditions. Measurements for the optimization of the existing value stream must be evaluated, as well as their impacts on particular resources or on the whole production processes. Therefore the following requirements are relevant for the evaluation of value streams regarding their performance:

- Description of impacts on the material flow (plant level of operation).

* Corresponding author.

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- Description of impacts on the information flow (production related administration).
- Consideration of lean measures.
- Differentiation between process and individual performance.
- Depiction of performance-oriented indicators.

The method for a value stream evaluation shall demonstrate the impacts of value stream improvements from cost-related point of view. Optimization considering the principles of value stream design must also show positive impacts on costs and savings respectively. Therefore the following requirements must be met to enable evaluation regarding the value stream's economic efficiency:

- Consideration of optimization measures (savings and expenses).
- Description of measure's impacts on investments and incomes.
- Cost-related description of impacts on the whole value stream.
- Consideration of process costs.
- Identification of economic indicators.

3. Defined value stream process as initial situation for the comprehensive evaluation

By applying VSM, different target conditions are developed defining future material and information flows (Fig. 1). The target conditions can be differ by the way the information flows from process to another. In the VSM this could be PULL (Kanban), one piece flow, first-in-first-out, or a combination of these information flows. These different solutions are always based on the same current state value stream. The material flow can be changed by the organizational structure of the different solutions.

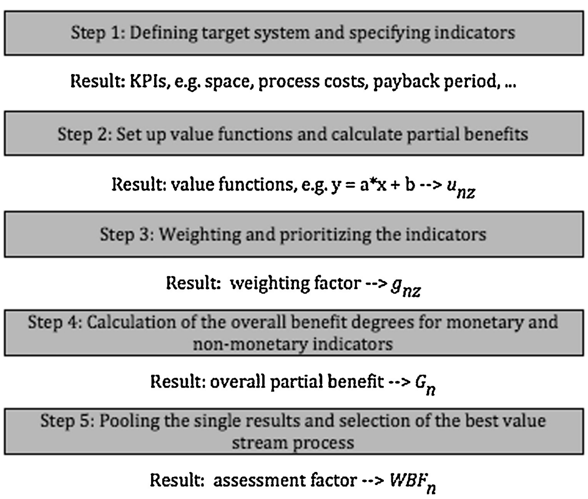

Fig. 1. Five steps of the evaluation method and the specified result.

So, all of these target conditions have different performance indicators (Table 1), different savings, caused by different optimization activities and also the investments required are unequal [3]. It is not possible to find an ideal value stream in terms of costs and performance by comparing all the parameters.

Even by selecting the VSM indicator 'lead time', two possible target conditions could be selected as best-class value stream (target condition 1 and 3, because of the smallest lead time).

Table 1
KPIs of the current state process and the different target conditions.

	Lead time (days)	Flow degree	EPEI (days)	OEE	Space (m^2)	Expenses	Savings	Process costs	Base
Current state	25.7	90	11	100%	5000	–€	–€	1,174,000€	Measured
Target condition 1	10	37	11	100%	4500	990,000€	280,000€	832,485€	Estimated
Target condition 2	12	42	11	100%	4750	362,000€	110,000€	979,379€	Estimated
Target condition 3	10	37	11	100%	3750	1,020,000€	400,000€	824,085€	Estimated

For description of the selected KPIs see text.

4. Key elements of the comprehensive evaluation

The objective of this approach is the evaluation of alternative target conditions, which take place in five evaluation steps (Fig. 2). In the assessment step 1, monetary and non-monetary indicators, based on specified parameters, have to be determined. The set-up of the value functions and the calculation of the partial benefit values for all future value stream alternatives are carried out in step 2. The value functions are mathematical relationships between the start and end value (worst/best case), to convert the measured parameter evaluation from step 1 in a normalized value (=partial benefit). Therefore, it is necessary to define minimum and maximum scenarios. By weighting the evaluation criteria in step 3, the defined indicators will be prioritized. The calculation of the degree of performance is done in step 4 by adding up the weighted partial benefits of all monetary and all non-monetary indicators for each future state variant. The calculation of a value stream assessment factor (WBF), based on the defined ideal state (=highest monetary and non-monetary benefit) is made in the last evaluation step, as well as the coupling of the two overall benefits in terms of indifference curves. This visualization of the results shows the position of the different future state alternatives, both in relation to each other and in relation to the current state process and also in relation to the best in class process (ideal state) (Fig. 1).

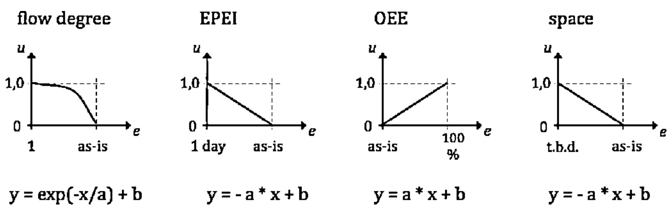

Fig. 2. Value functions for the selected non-monetary indicators.

The five steps of the evaluation method are shown in a practical approach, carried out in a production plant for medical equipment.

4.1. Evaluation step 1: Defining target system and specifying indicators

In the first step the target system has to be set. All relevant key performance indicators (KPIs) for the process have to be described (non-monetary and monetary indicators) and defined mathematically. In this example, a KPI set of a process indicator (lead time), a flexibility indicator (EPEI – Every Part Every Interval, which describes the overall time in which all product variants can be produced on one defined resource), a machine indicator (OEE – Overall Equipment Effectiveness, evaluates the effectiveness of a manufacturing operation) and an indicator of the physical layout (m^2) were chosen [2,5]. The mathematical descriptions of the selected non-monetary KPIs are shown in Table 2. Nevertheless, some of these indicators need additional simulation to estimate the values. These simulations can be done either in a practical way, or with a simulation model [4,7].

The chosen monetary indicators are all estimated expenses for the alternative target conditions, the process costs for the changed information flow and the payback period for breaking even after necessary expenses. The mathematical definitions also have to be defined for the monetary indicators [11].

All shown indicators, either monetary or non-monetary, can be adapted individually.

Table 2
Mathematical descriptions of the selected non-monetary indicators.

Flow degree		EPEI	
$FG = \frac{ZDL_m}{ZDF_m} = \frac{BZ+RZ+TZ+LZ}{BZ+RZ}$		$EPEI = \frac{\sum BZ + \sum RZ}{RES \times V \times AZ}$	
Measurement unit: none		Measurement unit: time (days)	
FG	Flow degree	BZ	Operating time
ZDL_m	Average lead time	RZ	Change over time
ZDF_m	Average process time	AZ	Working hours per day
BZ	Operating time	RES	Number of resources
RZ	Change over time	V	Technical availability or OEE
TZ	Transportation time		
LZ	Idle time		
OEE		**Space**	
$OEE = \eta_{Nutzung} \times \eta_{Leistung} \times \eta_{Qualitat}$		$Fläche_{Gesamt} = Fläche_p + Fläche_L + Fläche_S$	
Measurement unit %		Measurement unit: m^2	
$\eta_{Qualität}$	Degree of quality	$Fläche_{Gesamt}$	Space
$\eta_{Leistung}$	Degree of performance	$Fläche_P$	Space for production
$\eta_{Nutzung}$	Degree of utilization	$Fläche_L$	Space for warehouse and logistics
		$Fläche_S$	Additional spaces

4.2. Evaluation step 2: Set up value functions and calculate partial benefits

In evaluation step 2 a normalized value for each defined indicator will be calculated. This mathematical transfer process (from a unit based indicator (e.g. €, m^2, %, time) to a non-dimensional value) for each KPI ensures the further calculation and comparison of all different value stream maps. With these normalized values (=partial benefits) any other indicators could be included into this evaluation method. These values are determined between 0 (worst case) and 1 (best case).

To calculate the partial benefits, a value function must be pre-defined for all specified indicators from evaluation step 1 (see also Fig. 2). The definitions of these value functions are based on the relationship between the direction of the optimization and the possibility to reach the 'ideal state'. The algebraic sign is defined by the direction of the optimization (minimization indicators: negative, maximization indicators: positive). The exponential function is chosen, if the ideal state is nearly impossible to reach for the company, e.g. a flow degree of 1, which is a theoretical value.

Once a general value function is defined, the specific parameters (a, b) have to be calculated. This will be done using a mathematical approach, by setting the function to 0 with the worst value for the specified indicator and to 1 with the best case. For instance, the OEE in its worst case can be the current state (e.g. 80%), in its best case a maximum of 100%.

These best/worst-case definitions for all indicators are reference figures, which are needed to calculate the parameters of the value function as described.

To calculate the partial benefit for each single non-monetary indicator for the future value stream alternatives (u_{nz}), the generated digit from each target condition has to be set into the value function.

Each partial benefit is now defined as a function of the following parameters:

$$u_{nz} = f(f_{z(x,y)}; a_{nz}; b_{nz}; i_z; e_{nz})$$

where u_{nz} is the partial benefit of target condition n for indicator z, n is the alternative target condition, z indicator, $f_z(x, y)$ is the value function for indicator z, i_z is the as-is-value from current state process, e_{nz} is the result of target condition n of indicator z, and a_{nz}/b_{nz} are the variables of the value functions for indicator z.

The same procedure has to be carried out for the monetary indicators.

Now, it is possible to calculate all partial benefits for each single monetary indicator for each future value stream alternative.

4.3. Evaluation step 3: Weighting and prioritizing the indicators

In a pair wise comparison of the monetary and non-monetary indicators a weighting factor (g_{nz}) for each indicator is calculated. By asking the question, which of the chosen indicators is more important than the other, the defined KPIs can be prioritized. This prioritization is valid for all different alternative value streams.

Table 3 shows the example of the non-monetary indicators, with the calculated weighting factors (g_{nz}). The prioritization should be done as a team decision, because of the impact on the calculation of the overall benefits.

Table 3
Prioritization of the non-monetary indicators and the calculation of the specific weighting factor for each KPI.

	flow degree	EPEI	OEE	Space	Sum	Rank	weighting factor (g)
flow degree		1	1	2	4	1	33%
EPEI	1		1	2	4	1	33%
OEE	1	1		1	3	3	25%
Space	0	0	1		1	4	8%
					12		100%

4.4. Evaluation step 4: Calculation of the overall benefit degrees for monetary and non-monetary indicators

In this step the overall benefit in the case of performance and in the case of the economic indicator will be calculated. This is done by summarizing the products of the partial benefits (step 2) and the weighting factors (step 3) for the monetary and the non-monetary indicators. An example is shown in Table 4. The general equation of the overall benefit for monetary and non-monetary calculation is described as follows:

$$G_n = \sum (u_{nz} \times g_{nz})$$

where G_n is the overall benefit for value stream n, n is the value stream (either current or target conditions), z is the indicator, u_{nz} is the partial benefit of value stream n for indicator z, Z is the amount of indicators, and g_{nz} is the weighting factor of value stream n for indicator z.

Table 4
Calculation of the overall benefit of the selected non-monetary indicators for all different target conditions (examples).

	Flow degree			...	Space			Overall benefit non-monetary Gn_non-monetary
	e_{nz}	u_{nz}	g_{nz}		e_{nz}	u_{nz}	g_{nz}	
Current state	90	0	33%	...	100%	0	8%	0.250
Target condition 1	37	0.601	33%	...	90%	0.33	8%	0.478
Target condition 2	42	0.544	33%	...	95%	0.16	8%	0.445
Target condition 3	37	0.601	33%	...	75%	0.83	8%	0.520

The overall benefit G_n is defined as the overall benefit for monetary ($G_{n\_monetary}$) and non-monetary indicators ($G_{n\_non-monetary}$).

4.5. Evaluation step 5: Pooling the single results and selection of the best value stream process

The final evaluation steps bring the single overall benefit values for each value stream process within a holistic mathematical approach. This is required in order to compare all processes with each other. The calculated values of each value stream are combined in two ways:

1. Combining within indifference curves.
2. Combining in a stream assessment factor (*WBF*).

Combining the results in indifference curves

Laux describes the indifference curve as a geometrical point of value combinations in matters of the selected indicators in which the decider is indifferent [12]. This means that all combinations of the normalized overall benefits, monetary and non-monetary, which are on the same indifferent curve, have the same cost–benefit ratio.

For the calculation of the indifference curve, the transformed circle equation is used. The centre is always at the best ratio at point (1:1). This point is defined as an ideal, theoretical process for the chosen value stream.

Each point within the graph shows a single value stream. The closer this point is to the ideal process (1:1), the better the cost–benefit ratio. In this example all developed future states are better than the current state; the best ratio is given with value stream alternative 2 (Fig. 3).

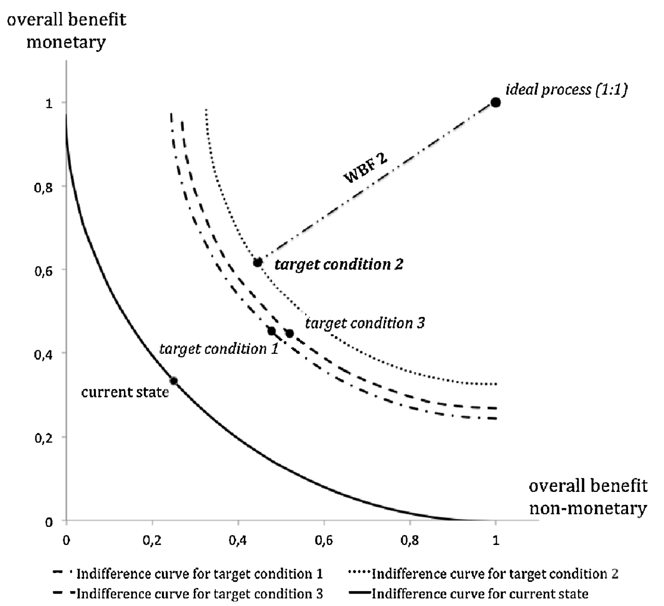

Fig. 3. Indifference curves for different overall benefits of monetary/non-monetary indicators.

Combining the results in a value stream assessment factor

The last step of the comprehensive evaluation is to calculate one single parameter to compare all defined target conditions with each other and with the current value stream, based on the transformed circle equation.

$$WBF_n = \sqrt{((G_{n\_monetary} - 1)^2 + (G_{n\_non-monetary} - 1)^2)}$$

where WBF_n is the value stream assessment factor for target condition n, $G_{n\_non\text{-}monetary}$ is the overall benefit for all selected non-monetary indicators for target condition n and $G_{n\_monetary}$ is the overall benefit for all selected monetary indicators for target condition n.

Through this assessment factor, a comparable figure is generated to find the best solution by having different indicators with different units.

The lower the WBF is, the better the chosen target condition in terms of the defined indicators is. In this example target condition 2 has the lowest WBF (Table 5). All future optimizations should lead to a smaller value stream assessment factor. Corresponding to this, every optimization activity should lead to a higher WBF.

Table 5
Assessment factors (*WBFs*) for all alternative target conditions.

	Overall benefit non-mentary	Overall benefit monetary	Assessment factor WBF
Current state	0.250	0.333	1.003
Target condition 1	0.478	0.453	0.756
Target condition 2	0.445	0.617	0.675
Target condition 3	0.520	0.448	0.732

5. Summary and outlook

The method for a comprehensive value stream evaluation combines different indicators of performance and costs. By linking both sides within one mathematical equation a single, comparable value for each defined value stream can be found. With this result it is possible to compare all defined target conditions with each other and the current state processes. In addition to this, it is also possible to compare all different target conditions to an ideal process. The chosen indicators can be monetary or non-monetary, independent of their measurement unit. This is possible by normalizing every single indicator for each value stream alternative. With this result, a best-in-case value stream can be defined and the planning and optimization processes of the VSM method are extended by a mathematical approach.

The practical advantage of using this new approach is to optimize the planning and optimization process within a company.

Further research in terms of changing product variants and the impact on the value streams is currently taking place. In addition to this work, the requirements of leadership management and the change in the effects on the organizational structure are also examined in further scientific work. The change of the organizational structure should also be integrated in the evaluation method.

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