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A Systematic Methodology to Reduce Losses in Production with the Balanced Scorecard Approach

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Abstract Efficiency in the industrial production has been one of the most discussed topics over the last years. Due to the direct link between efficiency and reduction of losses, several concepts have been introduced focusing on these losses. Furthermore, the suggested optimization approach is based on the factors of production theory and combines these input factors with the stated and newly identified losses. This paper offers a methodology to reduce these losses by using the balanced scorecard methodology. A case study in the polymer industry is given showing how to identify and measure losses in a production system.

Keywords Production, Losses, Lean Management, Balanced Scorecard Approach, Scorecard, Case Study, Process Industry

1. Introduction

Nowadays industry is facing rising material and energy prices, which creates the urgent need to avoid any losses in the production process. Especially companies in the basic and process industry face this challenge. This paper shows how industrial companies can methodically increase their production performance. The presented method is based on the balanced scorecard approach and supports the change process towards an efficient production. The paper starts by defining a production system, explaining the smallest elements of the system, and also briefly discussing the interaction between the system and its environment. The next part describes the concepts of the factors of production theory and their different definitions. Loss approaches in several management concepts are an essential input to build up the scorecard. Those fundamental literature findings are used to define the new methodical approach of the loss scorecard. A case study shows how this method works. The general system of an extrusion process is defined. Losses occurring in the system are defined. On that basis, a strategy map as a starting point for indicator definition is shown. The last part of this paper presents the results of a comparison of two systems in the polymer industry.

1.1. Efficient Production

First of all, it is necessary to define the term production. The literature describes the term industrial production as the transformation process of material and non-material input goods to higher output goods[1]. Due to the complex structures of modern production facilities, these can be considered as systems. GÜNTER and ROPOHL define a system as a model of integrity with a relationship between attributes (inputs, outputs, states, etc.). A milieu or a super system surrounds this structure[2]. The production system interacts with its natural, technological, political, legal, economic, and social-cultural environment. The smallest part of a production system is the independently working operating system. REFA defines an operating system as a system that fulfills work tasks as a cooperation of people and resources (machinery, materials). Seven additional design objects are relevant for this interaction. These include people, resources, work assignment, workflow, input and output as well as environmental factors [3]. Figure 1 shows the structure of a production system with its smallest element and the design objects. The interaction of these factors has to be as efficient as possible. Efficiency can be divided into technical efficiency and cost efficiency. Technical efficiency is the condition when no production factors are wasted. Economic efficiency in terms of microeconomics can be seen as the realization of the minimum cost combination. While economic efficiency in this sense presupposes technical efficiency, technical efficiency does not require economic efficiency[4].

The difference between the input and output of a working system is considered as a loss. Losses can be incurred by the use of all factors of production.

It is necessary to define the input factors in more detail. In the existing literature, the interacting design objects are stated as factors of production.

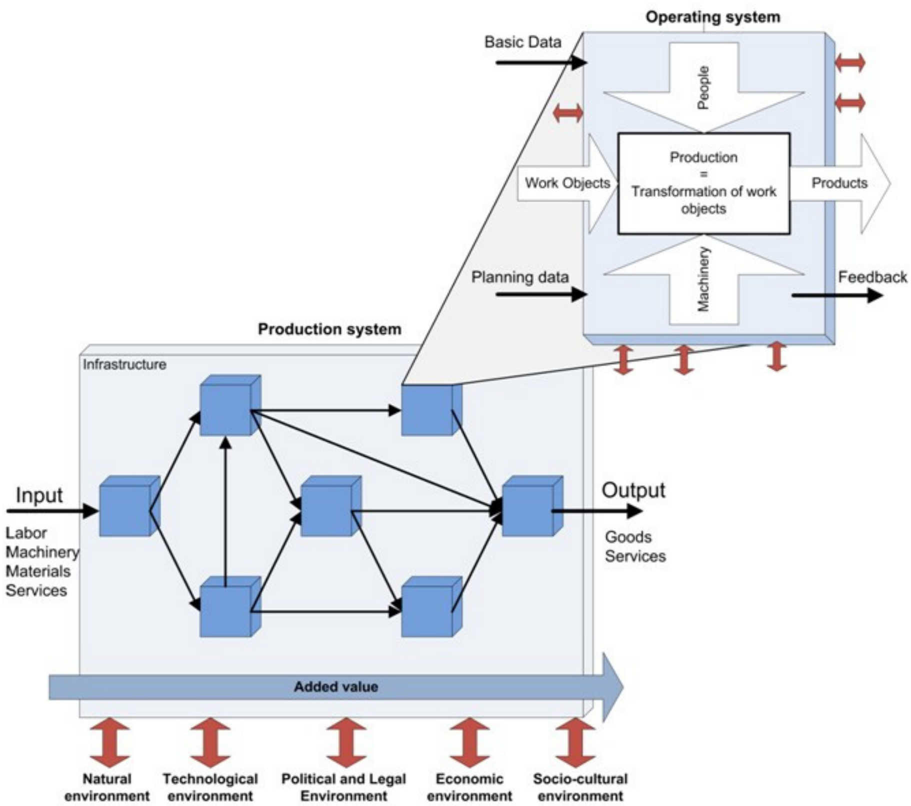

Figure 1. Production system and operating system[5]

1.2. Factors of production (FOP)

Literature gives several definitions of the term 'factors of production' (FOP). International economists see the conceptual factors of production as the economic factors (for example labor, capital, ground, and entrepreneurship) defined by ADAM SMITH and DAVID RICARDO[6].German business research suggests other FOP. GUTENBERG, as one of the first authors, has defined these factors. His work is fundamental for the description of dependencies and processes within a production system.

A basic view of production is the smallest element of the production system. The operating system just works with the existence of the design objects. These design objects can be classified into groups, such as elementary factors. Elementary factors include people or manpower, machinery, and the work objects (material, supplies). This group is only one part of the majority factors of production.

GUTENBERG divides these factors into two primary groups and structures input factors according to availability and independence. The first group includes the elementary FOP. These are divided into potential factors and consumable resources. While the potential factors like manpower and machinery affect the technical production capacity, they are not physically part of the product. They are present in the production in order to create value. Consumable resources are mainly materials and supplies which are used physically to produce output goods. Another possible classification is the categorization into primary and derivative factors. The primary factors are similar to elementary factors and the factor leadership, which, however, is not an elementary factor. Derivative factors include planning, organization, and control activities of the production system and the work system. They are responsible for the composition of the elementary factors in the production process [7].

Table 1. Factors of production (FOP)

FOP	Authors
Manpower	Gutenberg, Ishikawa
Material	Gutenberg Ishikawa
Machines	Gutenberg, Ishikawa
Leadership	Gutenberg, Ishikawa (Management)
Organization	Gutenberg, Ishikawa (Management)
Control activities	Gutenberg, Ishikawa (Management)
Example intangible rights	Weber
Services	Weber
Information	Weber
Environment	Ishikawa
Measure	Ishikawa
Energy	Gutenberg (supplies)

WEBER [8] expands the definition of GUTENBERG by additional factors, namely by intangible rights, services, and information. Another definition of the FOP is given by ISHIKAWA, who developed the cause effect diagram [9]. He defines four main factors describing the general conditions of an operational system. These are manpower, machines, material, and method (4M). Over time, other main factors have been added, namely management, environment, and measure. Energy as an additional factor belongs to the elementary factors and is classified as supplies. Table 1 shows the factors of production mentioned and the respective authors.

For a further definition of the perspectives of the scorecard and the strategy map, the factors materials, machinery, manpower, and energy are considered as essential for the scorecard method. It is possible to expand the perspectives by other dimensions like control activities or organization. Those depend on the identified losses and recorded data.

2. Production Losses

To have an efficient production, it is necessary to identify every loss in production. OHNO, the founder of the Toyota production system, determined that US and German car companies are more productive than companies in Japan. He noted that the lack of performance was caused by waste or losses in the production system. He defined seven core losses of production [10]:

- Overproduction
- Waiting
- Unnecessary motions
- Transporting
- Over processing
- Unnecessary inventory
- Defects

In addition to these original sources of loss, additional sources have been identified. These can be found in services and production. A part from the seven main losses – known as Muda - , Ohno defines two additional interlinked sources of performance loss, namely Muri and Mura. Muri stands for overburden, and Mura describes unevenness[11].

The total productive maintenance philosophy (TPM) describes another bundle of losses to measure the performance of machines. NAKAJIMA suggests the overall equipment effectiveness indicator (OEE) to measure machine performance [12]. This value combines the availability, performance, and quality losses. Additional to these losses due to the performance of the machines, TPM includes losses of human labor and administration. A case describes losses in the process industry which are almost equal to the OEE [13].

To design the new scorecard model, it is necessary to find a link between FOP and losses. BIEDERMANN suggests a classification of losses based on manpower, machinery, energy, and material [14]. This framework has been extended by the losses and factors of production mentioned above. First dependencies between these two factors are set by possible influences [15].

On that basis, it is possible to draw up a metric system to reduce losses in production. The appendix summarizes all losses mentioned in this study. For this purpose, the scorecard approach needs an adaptation.

3. The Balanced Scorecard Approach

The balanced scorecard approach (BSC) was developed by KAPLAN and NORTON in cooperation with twelve companies and management consultants. The BSC is a metric system to control the performance of companies. The method assigns vision, mission, and business strategies of a company to metrics, specific objectives and indicators. The main idea behind this approach is to look at business from four different perspectives. In the original concept, KAPLAN and NORTON described four perspectives [16]:

- A customer perspective
- An internal perspective
- Innovation and learning perspective
- Financial perspective

In the original BSC, each perspective has up to six specific indicators of the business. Each of them can be filled with objectives, management ratios, specifications, and provisions to attain the strategic goal. These four detailing steps help to implement the strategy and measure the strategic plans. Another advantage of the method is the combination of financial and non-financial indicators [17]

The four perspectives of the BSC are not independent of each other but stand in a cause effect relationship. This interaction shows the key lever for management control. For this purpose, Kaplan and Norton suggested a cause effect chain diagram named 'strategy map'.

Figure 2 shows an example of a strategy map with the four perspectives and visualizes the relationship between the objectives. Every indicator can influence another objective positively or negatively. This dependency is necessary to build up a metric system and to show how perspectives influence each other [17].

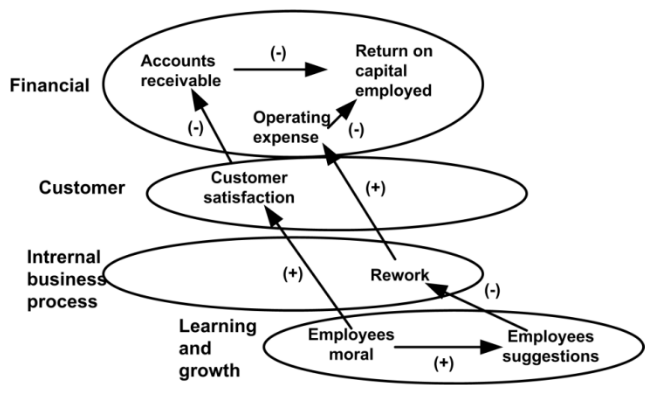

Figure 2. Example of a strategy map [17]

It is possible to modify the suggested perspectives to special industry and company needs [18]. The following section shows a modification of the BSC approach and suggests a new approach based on the factors of production and production losses.

4. Main Structure of the Losses Scorecard

To reduce losses in a production system, it is essential to follow a systematic course of actions. The BSC approach can help to operationalize the strategic goals and vision of a company. In the case of loss prevention, the main aim is an efficient lossless production. To gain this, it is necessary to define measures, target values, and activities. The four perspectives of the scorecard (SC) are given as material, machines, energy, and manpower. These are the FOP of Nakajima, who describes the general condition of a production system. Figure 3 illustrates the general structure of this scorecard approach.

In a following step, the allocation of losses is necessary. These losses may either be already described in the literature or new sources of loss must be defined. New losses can be identified by defining the considered system. To measure these losses, it is necessary to set indicators. For this purpose, already established production metrics can be used. The development of new variables is possible because newly identified losses cannot be measured.

The proceeding of the loss scorecard (Figure 4) includes a back loop. This is important to adjust the metric system and to check the objective achievement. This method does not have a static structure, so it is possible to adapt the metric system if objectives are reached or new losses occur. For the allocation of losses to the prospects, a catalogue is created in this context.

To see which losses influence others, it is recommended to draw up a strategy map (Figure 6). This mind mapping tool helps to identify losses and to choose the right indicators or main losses. Additionally, this tool shows dependencies of the occurring losses between and inside the perspectives. The case study shows how a scorecard can be implemented in a production system. The steps are mainly the same as described above. Some changes have been done in the definition of the performance indicators.

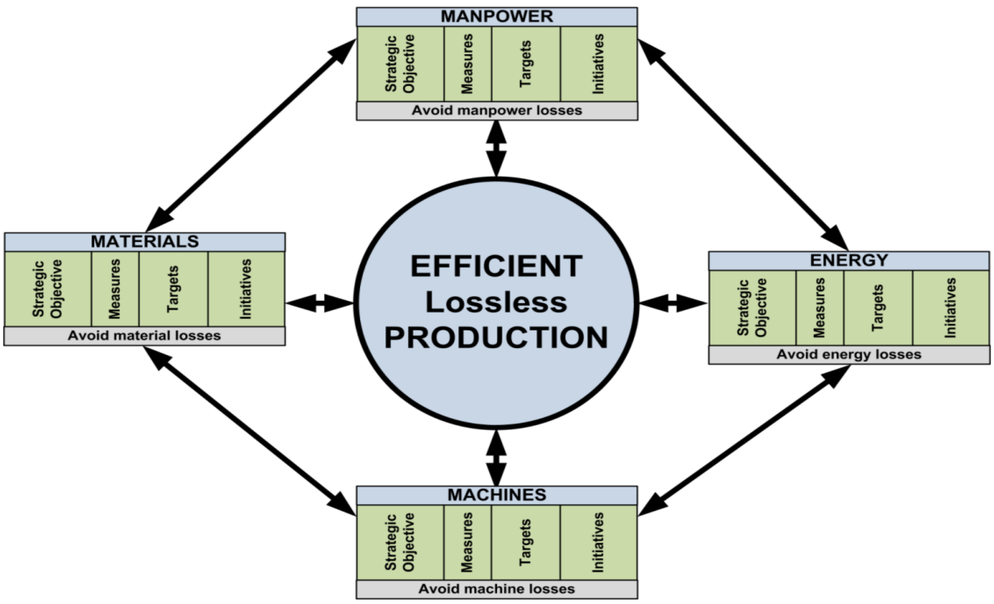

Figure 3. The general structure of the losses scorecard

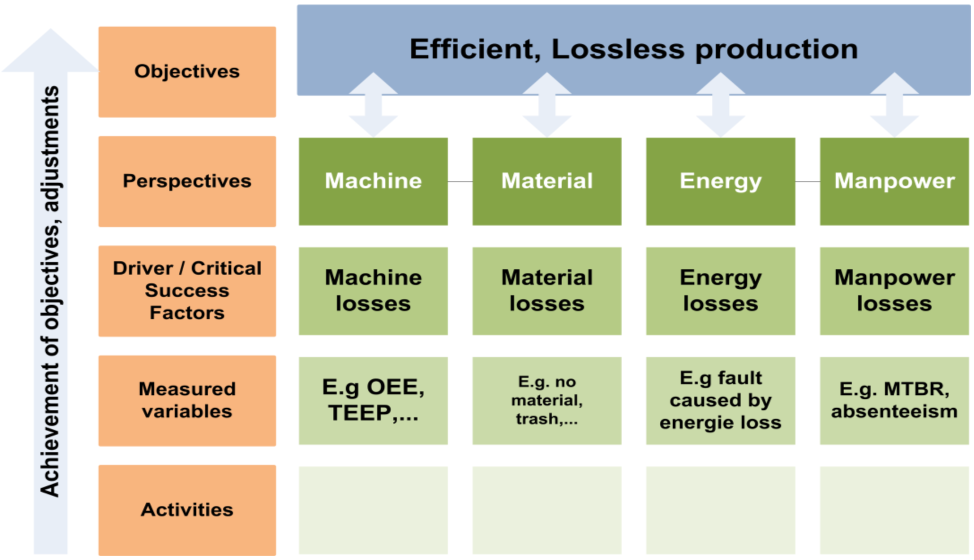

Figure 4. Proceeding of the losses scorecard

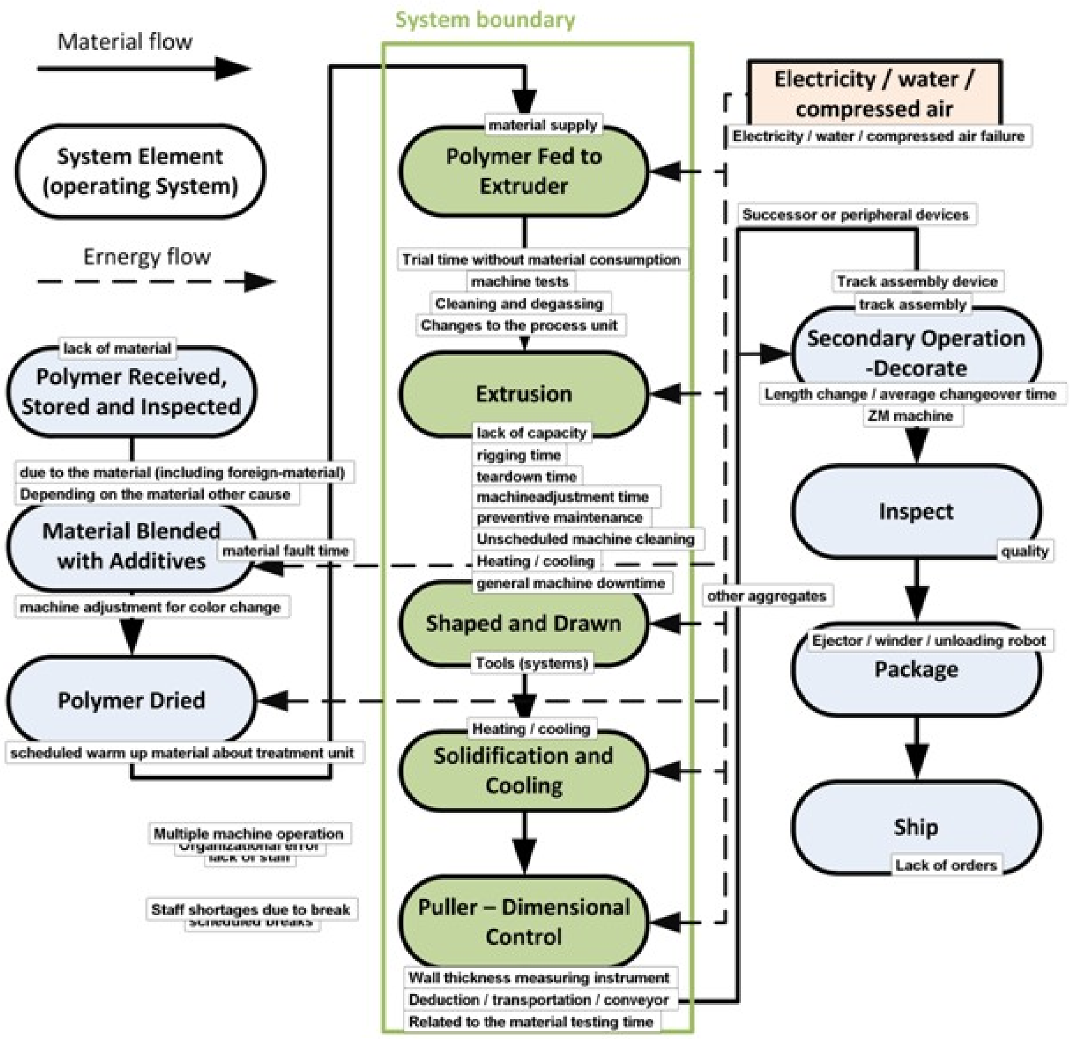

Figure 5. Production system of an extrusion process[19]

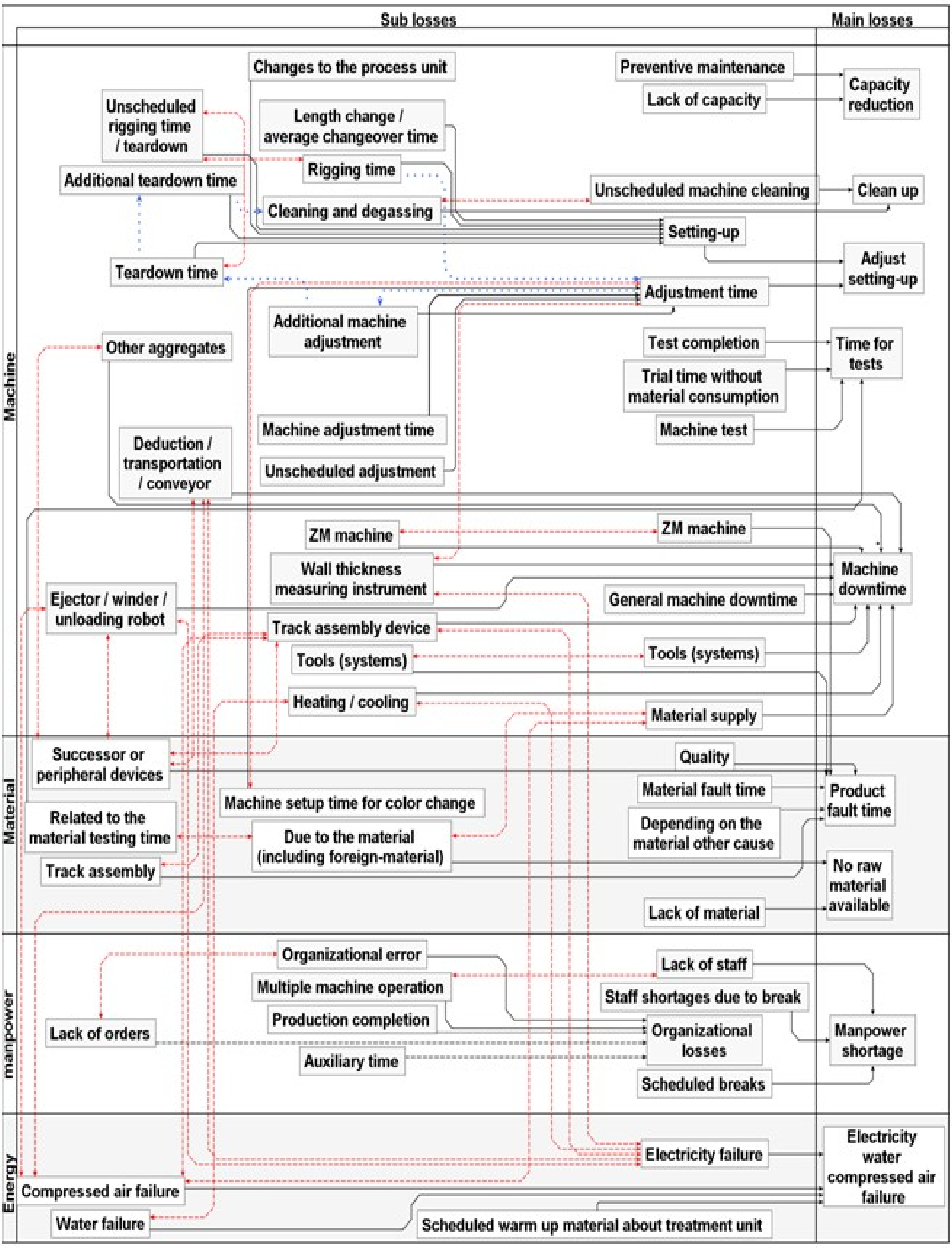

Figure 6. Losses strategy map of the system

5. Case Study

The following case study shows the application of the losses scorecard approach in the polymer industry. For this purpose, the defined production system and losses are assigned. To aggregate the losses, a strategy map shows the relationships between the losses and the occurrence in the defined perspectives (machine, manpower, material, energy). On that basis, some key indicators are defined in each perspective that sum up all defined losses. The comparison of two production systems uses these defined metrics.

5.1. Definition of the Production System

The general description of a production system is given in Section 1.1. These are the basis to describe the following production process in the polymer industry. The considered process is the extrusion process used to produce long plastic forms, like plastic profiles or tubes. Figure 5 shows the main parts of this production process and the material flow of the whole system. Additionally, the graphic shows the energy, water, and compressed air supply. The extrusion process is a continuous production process which ends with a discontinuous process at the end. This last process step is often cutting the endless profile in customer specific parts. The continuous production process is shown in Figure 5 as “system boundary”. The machines inside this system are strongly linked together. So if one of these parts fails, the whole system stops or cannot produce good products.

The first step of the scorecard procedure is to identify the losses in the system. Additionally, every kind of losses is put in the flow chart of the general extrusion process. To build up the scorecard, it is necessary to find similarities and links of these losses. Here a strategy map helps to do this task.

5.2. Building up the Strategy Map

First of all, it is necessary to define the perspectives of the losses scorecard. In that case, it is useful to set four factors. Derived from the FOP theories, the factors machine, manpower, material, and energy describe the production system best. Therefore, these factors are set for the strategy map.

Assigning the identified losses to the defined perspectives is the next step. It is important to know which losses are caused by production factors. Figure 6 shows the strategy map with all identified losses assigned to the perspectives. For each term, the losses are aggregated to main losses. The red dashed lines show the links between losses. These losses depend or influence each other. For example, a lack of orders can be caused by an organizational error, or rigging time causes additional unplanned rigging time. The blue dotted line represents losses which are coupled with time. This correlation takes place in the adjustment and setting up loss. Several steps are accomplished sequentially. To produce products it is necessary to rig the machine, tools, and successor system elements first. Next the system has to be adjusted to produce the right product quality. After fulfilling a production order, teardown and cleaning the system are the next steps before a new order can start. These dependencies have to be considered when summing up the losses as the main losses. In that case, system time is the connecting element that connects all losses. This is good for controlling the losses in each perspective as well as for scaling and comparing them.

5.3. Controlling the System

After combining the losses as main losses, measurement and evaluation is necessary. The basis of the data is the system time. This time is stretched over the whole year and is limited by total production stops, weekends, and holidays. Additionally, the production shift system defines the time capacity of the system. If the production works with one shift, only eight hours per day are available to produce products. If there is a lack of capacity, the shift system can change to two (16h/day), three (24h/day), or up to four (24h+weekend) shifts.

Figure 7 illustrates the allocation of the time capacity. In this example one month is the time frame, so both systems have the same amount of time capacity available. The used capacity differs slightly because System 2 uses extra shifts ordered by the management to produce all orders. System 1 has an extreme lack of orders and auxiliary time where no products are produced. System 2 is fully occupied by orders, but the auxiliary time is also high. It seems that the operators use this time code for losses. But nevertheless the focus of this method is to reduce losses, which are marked with a burst in the diagram. To improve the data quality, it is useful to automate the time measurement or change the behavior of the operators.

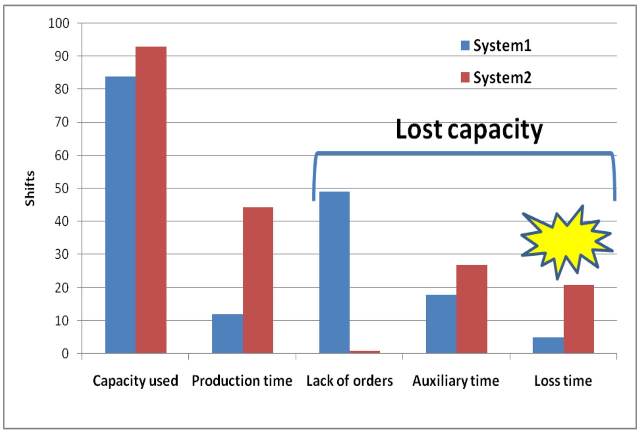

Figure 7. Capacities of the two production systems

The following figures show the results of the evaluation. The spider diagrams compare two systems with the same loss structure. The measure scale is one shift (eight hours), and the data represents the loss time of the system.

The first diagram (Figure 8) illustrates the four defined FOP. It is apparent that a lot of losses depend on the factor machine in both systems. System 2 has additional material losses. It seems that System 1 is more efficient than System 2. For a further analysis, a second diagram shows the main losses of the FOP perspective machine (Figure 9). System 2 has much more setting-up and adjustment loss time. To improve this situation, it is necessary to reduce these losses with rigging and adjustment workshops. Another cause for this situation is that System 2 produces a larger product mix. If possible, a production sequence optimization can be done.

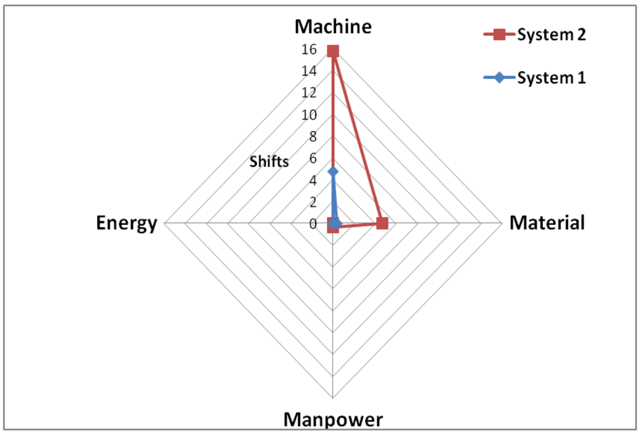

Figure 8. Comparing two production systems

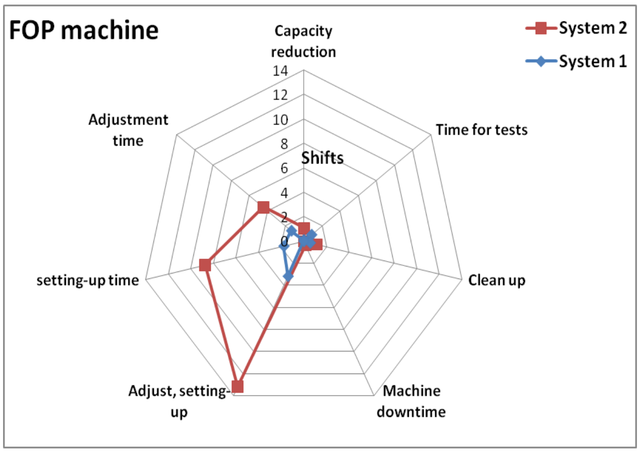

Figure 9. FOP machine comparison

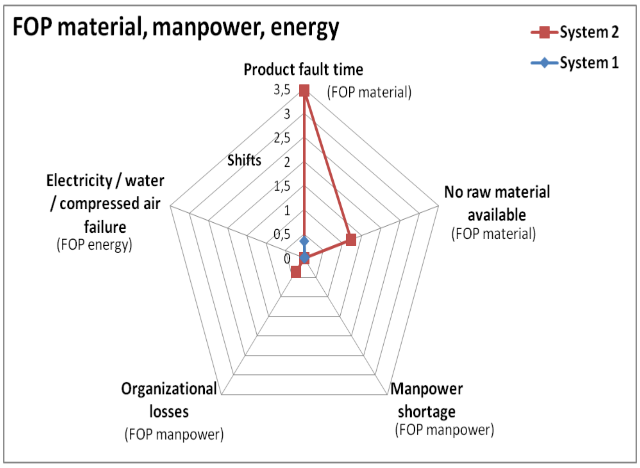

Figure 10. FOP material, manpower, energy comparison

Figure 10 illustrates the factors material, manpower, and energy. It can be seen that product fault time and raw material currently available are the most intensive losses for the factor material.

Besides the system time as a loss metric, another loss has to be measured, namely the physical material loss. This happens per manual counting of the produced waste. Figure 11 shows the sub-losses were physical material loss is created. The main material is wasted by adjustment activities. In that case the process produces products, but they do not fit the customer defined dimensions. The same applies to the quality loss. During the production time, material is also wasted. The cause for that loss is to cut or punch the products in the secondary operation element. Summing up, one can say that every process activity (sub-losses) with material use produces waste.

Finally, it is not necessary to define key indicators in that case. The main losses are the indicators to see where which losses occur. For comparison of two production systems with the same prosperities, it is sufficient to use main and sub-losses for the evaluation. For a benchmarking analysis of two or more different processes, it will be necessary to either define key indicators or use key indicators described in the literature. A good metric will be the overall equipment effectiveness.

3. Conclusion

Industry faces the fact to produce their products as resource efficient as possible. Resources can be see as the defined factors of production, so producing companies try to reduce every loss of these resources in their production systems. This method shows the possibility to identify methodically losses in a production system. It adapts the balanced scorecard method to find losses and their links and to set metrics to reduce them. The perspectives of the method can be extended by other FOP, but for the first try to implement this approach the suggested views fits best. The result of the case study shows the central focus of the sources of loss. On that findings, it is possible to specify measures to reduce them. The method has a back loop, so after the first definition it is possible to do some changes in the loss structure to get more accurate measurement results or focus some hot spots. Further research is required to define metrics to measure standard losses in the production system. It is also possible using this method in other production near organizations like maintenance. The development of detailed losses in the energy perspective is the next step of research.

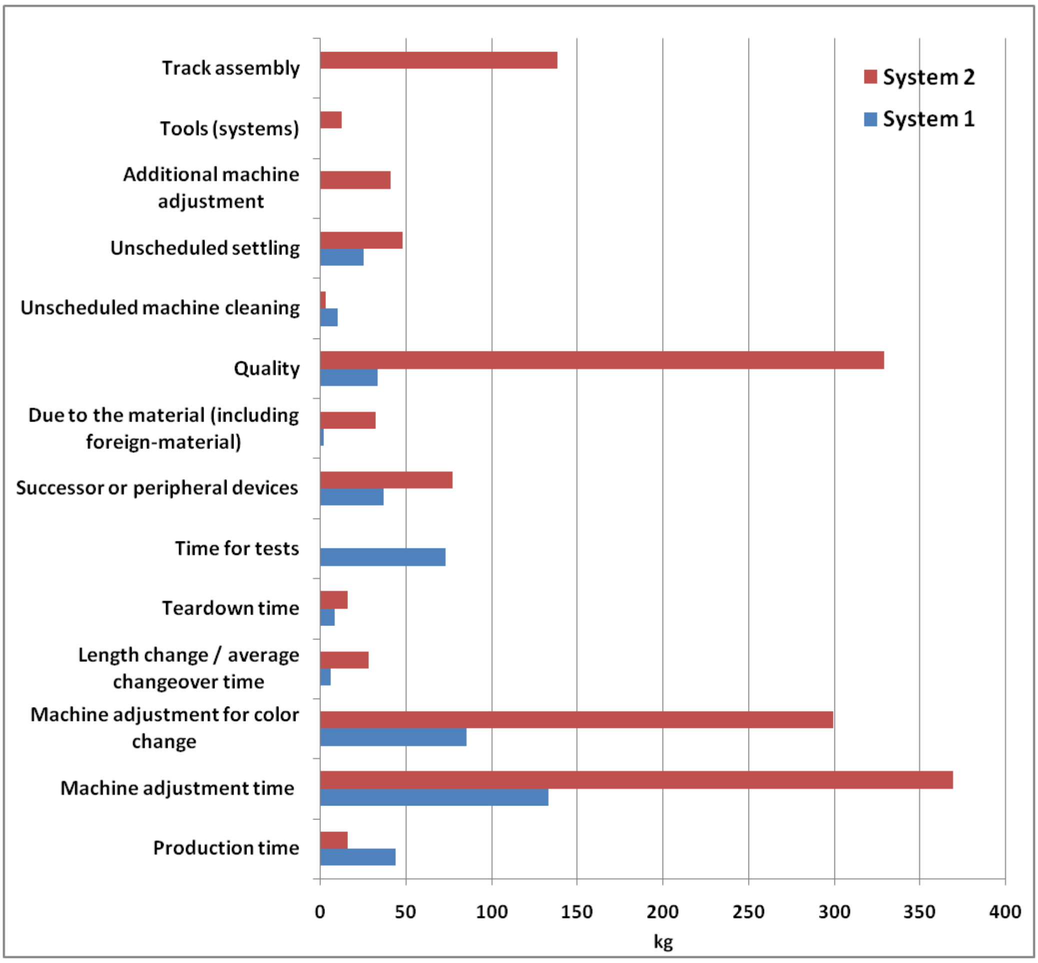

Figure 11. Physical material losses

Appendix

Table 1. Additional new lean management losses

Management System	Losses
Lean management / production	Untapped human potential
	Excessive information and communication
	Time
	Inadequate systems (EDP)
	Energy and Water
	Natural Resources
	Variation
	Knowledge
	Not exploit the potential for improvement
Lean Management / services	System failure due to faults
	Setup and adjustment
	No-load and short stops
	Decreased velocity
	Quality losses
	Reduced output and start-up losses
Major losses	Muda
	Muri
	Murai

Table 2. FOP and losses

FOP	Losses
Manpower	Vacation, sick leave, collective agreement
	Planning losses
	Flow losses
	Organization losses
	Quality losses
	Overtime
Machine	Scheduledstops
	Systemdisorders
	Setup timelosses
	Shortstopandload losses
	Procedural and organizationallosses
	Ratelosses
	Loss of quality machine
Material	Loss of quality material
	Cutting scrap
Energy	Unused energy consumption during production
	Unused energy consumption with reduced production

Table 3. TPM losses by management system

Management System	Losses
TPM / Overall Equipment Effectiveness	System failure due to faults
	Setup and adjustment
	No-load and short stops
	Decreased velocity
	Quality losses
	Reduced output and start-up losses
TPM / humanlabour	Organizational losses
	Movements
	Line organization
	Logistics
	Measuring / Setting
TPM / process	Energy losses
	Losses due to molds, tooling and fixtures
	Loss of volume
TPM / Administration	Procurement losses
	Supplier's losses
	Employment losses
	Distribution losses
	Inventory losses
TPM / process industry	Losses due to sudden failure
	Losses due to idle and small stops
	Capacity losses
	Start up losses
	Operating Losses
	Quality losses

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