A THEORETICAL FOUNDATION FOR RESOURCE EFFICIENCY AND EFFECTIVENESS IN PRODUCTION SYSTEMS

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Abstract: As a consequence of recently increased activities in the area of improved resource use a multiplicity of terminology and its interpretation has evolved. Phrases as resource efficiency or resource effectiveness have become quite popular. However their interpretations vary depending on the scope and perspective taken. In order to clarify the meaning and to found a theoretical basis for researchers and practitioners this review discusses various expressions found in literature focusing on improved resource use in industrial production. The description of relevant terminology provides researchers with a notion of how the perception of improved resource use in industrial production has evolved. The description finally results in a conceptual model for production system evaluation.

Keywords: resource efficiency, efficiency and effectiveness, production systems

1. INTRODUCTION

There is a strong need for enhanced sustainable development in industry starting from purely economic growth towards sustainable growth which -among others- contains the proper exploitation of resources to be made consistent with current and future needs (Jovane, et al., 2008). As a consequence of recently increased activities in the area of improved resource use a multiplicity of terminology and its interpretation has evolved. Phrases as *resource efficiency* or *resource effectiveness* have become quite popular. However, their interpretations vary depending on the scope and perspective taken. While some authors, for instance, tend to either use one of the phrases resource productivity *or* resource efficiency, other authors equalize both expressions (Rashid, et al., 2008). The objective of this paper is to review and discuss terminology and contexts found in literature focusing on improved resource use in industrial production to found a theoretical basis for researchers and practitioners.

2. OVERVIEW OF APPLIED TERMINILOGY

2.1. Resource

The word “resource” has its origin in the French language and means “something that is a source of help” or “a means of supplying a deficiency or need” (Oxford University Press, 2013). From a classical economics view resources are recognized as land, labour and capital. In the field of industrial production interpretations regarding the term resource vary thoroughly reaching from broad perspectives as available money for operations in companies including patents, contracts or privileges (International Institution for Production Engineering Research, 2004) to more narrow perspectives as human and physical resources (Bernolak, 1997) or assets, humans, material, energy, equipment, machines, information, knowledge (Westkämper, 2006). Due to the manifoldness of what the term resource might imply depending on the context it is used in, specifications are necessary. The discussion of this paper focuses on operational resources on shop floor level, i.e. labour, energy, direct material for products and handling of direct material in daily production operations.

2.2. Resource productivity, resource efficiency, resource effectiveness

As the expressions “resource productivity” and “resource efficiency” are of much more frequent use in relation to “resource effectiveness” they are both discussed at first. To start with, Table 1 summarizes latest definitions of resource productivity and resource efficiency including their sources. While some of the definitions for resource productivity are quite broad, relating to the relative concept of outputs and inputs on a general basis (Wiktorsson, et al., 2008) (Pearce, 2001) others describe outputs and inputs as service and physical resource respectively (Hargroves & Smith, 2005) (Schmidt-Bleek, 1999). A likewise incoherent image is given by the definitions of resource efficiency. Some definitions match with the meaning of resource productivity (Europe Innova Eco-Innovation REMake, 2012) (Commission of the European Communities, 2003), while only one refers to efficiency in the light of physical production resources (Steinhilper, et al., 2012). A further definition refers to eco-efficiency (Schaltegger, et al., 2009) which is described as relation of environmental performance and product system value (International Standard Organization, 2012). Furthermore, on an international level both expressions are used interchangeably as explicit definitions do not exist (EEA, 2011). While some authors tend to either use one of the phrases resource productivity or resource efficiency, other authors equalize both expressions (Rashid, et al., 2008).

Table 1. Selection of definitions for resource productivity and resource efficiency including their sources.

Resource productivity		***Resource efficiency***	
Definition	*Source*	*Definition*	*Source*
Resource productivity: Doing more with less	Wiktorsson, et al., 2008	The resource efficiency of a manufacturing company is the relationship between product output and resource input.	Europe Innova Eco-Innovation REMake, 2012
The key idea behind resource productivity is to maintain or increase the service flow while radically cutting the physical resource requirements of the physical delivery platform.	Hargroves & Smith, 2005	Resource efficiency is efficiency of used energy, materials, machines and work force in order to add value.	Steinhilper, et al., 2012
Resource productivity means raising the ratio of ‘output’ to natural resource ‘inputs’.	Pearce, 2001	Resource efficiency is eco-efficiency which concentrates on the relationship between the economic performance and resource use performance respectively of a product or process which fulfills a function or serves a given need.	Schaltegger, et al., 2009
Resource productivity: Service unit or utility unit per material plus energy input	Schmidt-Bleek, 1999	Resource efficiency or resource productivity can be defined as the efficiency with which we use energy and materials throughout the economy, i.e. the value added per unit of resource input.	Commission of the European Communities, 2003

A common distinction between resource productivity and resource efficiency does not seem to exist. In many cases it appears that “efficiency” is rather equalized with the relative concept of “productivity”, i.e. the relation between output and input. One possible explanation for this might be the fact that efficiency is mostly associated with the utilization of resources emphasizing input oriented productivity improvements (Tangen, 2005) (Almström & Kinnander, 2011) whereas effectiveness implies focusing on output-related objectives possibly including rather intangible influences at higher system level. In general, no consistent use regarding scope and meaning appears to be deducible to facilitate understanding concerning the terms resources productivity and resource efficiency.

On the contrary, the expression “resource effectiveness” is scarcely defined in literature. There are indications that the scope concerns sustainable impacts regarding the ecological environment caused by manufacturing industry (Bauernhansl, 2013) (Sustainability East - Incorporating Climate East, 2013) and accordingly needs to be solved on a long-term base by decoupling natural resource use and environmental impact from economic growth as described by the United Nations Environment Programme (2011). However, clear definitions do not seem to exist.

3. CHARACTERISTICS OF EFFICIENCY AND EFFECTIVENESS

Considering the lack of coherence regarding the use of terminology within the field of resource efficiency and effectiveness a proper basis for development work seems missing. Consequently, a return to the fundamental meaning of efficiency and effectiveness is required in order to support identifying potential target areas for resource efficiency and effectiveness.

The two terms efficiency and effectiveness are of frequent use in academia and practice. Mainly shaped by Drucker and his perspective on management the terms can be described as “doing things right” and “doing the right things” respectively (Drucker, 1964). However, these descriptions are too wide to be useful for production system evaluation. Consequently, there are many ways in which both terms are interpreted and understood in specific contexts.

As indicated in Figure 1, both terms are closely connected to the concept of productivity which is defined as the relation between output and input of a transformation process. In this context efficiency and effectiveness have been discussed extensively (Tangen, 2005). The international standard organization (ISO) defines efficiency as “effort related to the usage” and effectiveness as “relation between a planned to an actual value” (International Standard Organization, 2013). Looking at each of the two terms separately, the meaning of efficiency is mostly associated with the utilization of resources and a rather input oriented perspective of a transformation process. On the other hand, effectiveness is mainly connected to an output oriented perspective and the creation of customer value of a transformation process. Another possibility to describe the term effectiveness is the ability to reach a desired objective. One highly significant characteristic is the fact that there theoretically are no limits of how effective one can be. In order to achieve high productivity both is required, high efficiency and high effectiveness. Figure 1 shows a summarizing picture of both terms including their main characteristics.

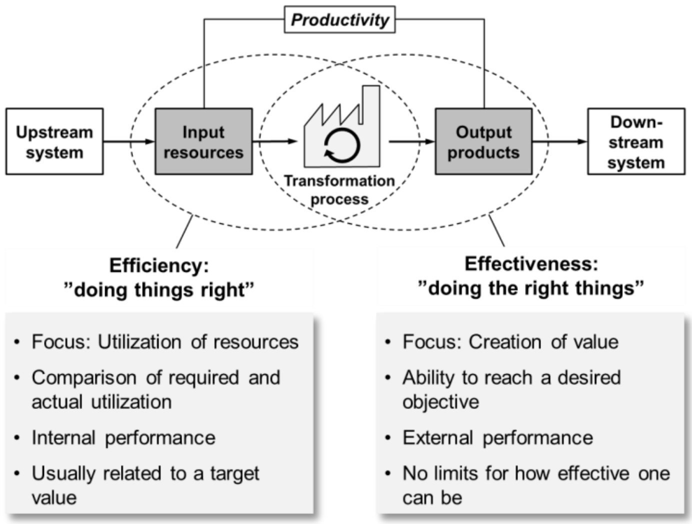

Fig. 1. Characteristics of efficiency and effectiveness within productivity based on (Drucker, 1964) (Sink & Tuttle, 1989) (Tangen, 2005).

4. STRATEGIC VIEWS ON RESOURCE EFFICIENCY AND EFFECTIVENESS

4.1. Strategic relevance of resource use

Resource use may be of high strategic relevance. Slack and Lewis (2008) summarize four generic perspectives on operations strategy, which is supposed to concern actions and pattern of strategic decisions namely the top-down perspective, the bottom-up perspective, the operations resource perspective and the market requirements perspective. The topic of resource efficiency and effectiveness can involve all four perspectives of operations strategy. However, the focus on operational resources in the context of industrial production, as previously defined in this paper, puts particular relevance on the operations resource perspective for this research work. The operations resource perspective looks at a company in terms of its resources rather than its products and is often referred to as resource based view (Wernerfelt, 1984). According to the long-term character of strategic planning the interpretation of what is considered as resource involves an immensely broad scope covering tangible and intangible assets of a company. Hence, examples of resources can consist of brand names, in-house knowledge of technology, employment of skilled personnel or trade contacts. Although this strategic definition of resource is rather wide it suits the scope of operational resources as this view emphasizes resources instead of products with inputs and outputs.

One further significant matter within the operations resource perspective is the differentiation and content of strategic decision areas in terms of structural and infrastructural decisions. These two decision categories determine in what way a company’s capabilities and resources are used in order to succeed in the market (Slack, et al., 2010). Structural decisions deal with design activities concerning, for instance, process technology, new product or service design or facilities. Infrastructural decisions in turn concentrate on workforce organization, planning and control or improvement activities. A figurative example of distinguishing structure and infrastructure in this context can be a computer with its “hardware” and “software”. While the hardware sets capability constraints, the software runs the system and exploits its potential within. For production systems this implies that physical constraints are set in structural decisions by determining the physical shape of a transformation system as for instance buildings, capacity or technology. This again means that efficiency and effectiveness of resource use are affected by both types, structural and infrastructural decisions, thus resulting in a necessary distinction of short-term and long-term objectives. Consequently, resource efficiency and effectiveness should not be regarded as a goal itself, but rather as a means to a strategic purpose as, for instance, cost reduction, lower dependency on suppliers, environmental protection or marketing purposes (Schmidt & Schneider, 2010). It is therefore crucial to discuss and determine the strategic relevance and scope of efficient and effective resource use.

4.2. Strategic contexts for resource efficiency and effectiveness

Sustainability means considering economic, social as well as ecological aspects (Elkington, 1998). In an increasingly globalised world in which natural resources have replaced labour as determining factor, companies cooperate with each other as they build global networks for value creation in order to fulfil customer needs (Seliger, et al., 2008). Within this global network useful functionalities are evaluated according to ecological, social and economic criteria with the motivation to switch from pure profit orientation towards sustainable orientation. In this connection, the role of resource efficiency and effectiveness consists of reducing environmental pressure while ensuring economic growth. Moreover, its role covers several sustainability criteria and is placed on the ecological dimension of sustainability dealing with, for instance, environmental protection, waste and emissions and raw material acquisition.

A hierarchy for sustainable strategy is suggested by Rashid et al. (2008). In this hierarchy the concept of resource efficiency remains a subordinate scope to eco-efficiency while embracing the rather tangible and simple to measure scope of material efficiency as well as waste minimization. Consequently, eco-efficiency is regarded as the broadest strategy incorporating tangible, as well as intangible dimensions such as added value, environmental issues, social aspects and quality of life. As part of the resource efficiency scope, material efficiency emphasizes an improved use of material and reduction of environmental impacts. Waste minimization contains the narrowest and most tangible scope as it is relatively concrete in its definition and simple to measure. Activities regarding minimization of waste are considered as first step by industry towards sustainable production whereas in comparison the implementation of resource efficiency into operative action is not regarded as a simple task. The effectiveness perspective remains unconsidered in the hierarchy for sustainable strategy, but can be implied taking the alignment with sustainability.

A paradigmatic view which considers efficiency and effectiveness as shop floor strategies for improved resource use in production is given by Bauernhansl (2013). In this perspective efficiency and effectiveness are perceived as belonging to different paradigms. The understanding of efficiency in general is based on the reduction of resource use, following the statement “the less, the better”. This comprises that efficiency approaches in practice aim at minimizing negative impacts, such as economic and environmental waste. Efficiency approaches accordingly include approaches as increase of material utilization, minimization of energy consumption or optimisation of existing processes. Occurring losses referring to low efficiency ought to be kept at minimum. On the other hand, effectiveness is based on enabling sustainable production activities following the approach “the more, the better”. This is to be achieved through economic feasible as well as entirely environmentally conscious production activities, as for instance zero-waste processes, closed-loop material life-cycles or use of renewable energy. In doing so, environmental issues are not perceived as a contrary or negative counterpart towards economic performance, but rather as beneficial enabling an infinite source of resources for sustainable production and business activities. In this two folded view the effectiveness paradigm concerns fundamental and hence structural decisions while the efficiency paradigm aims at improvement activities and infrastructural decisions.

Following this paradigmatic description in production, a switch from the efficiency paradigm towards the effectiveness paradigm is suggested since efficiency strategies solely focus on the minimization of negative economic impacts instead of eliminating them and consequently lack a long-term solution in terms of sustainability. The underlying issue seems to concern decoupling resource use from environmental impacts whilst ensuring economic growth. More specifically, a transition is promoted from a short-term economic decision scale towards a sustainable, i.e. long-term decision scale considering environmentally feasible solutions for manufacturing businesses. However, implementations towards effectiveness in this perspective are more likely to have the character of radical changes connected to large invests as they lead to complete makeovers, which again increases risk and therefore lowers attractiveness for industry.

It can be observed that recent research efforts investigate development strategies promoting a rather radical shift towards sustainable production. For instance, the practical feasibility of closed-loop systems aiming at the conservation of energy, material and value added with waste prevention and environment protection is examined considering all elements of a production system, i.e. business model, product design, supply chain and the technology infrastructure (Rashid, et al., 2013).

5. A PROPOSED MODEL FOR EFFICIENCY AND EFFECTIVENESS EVALUATION

Based on the resulting description of resource efficiency and effectiveness a model has been developed to give an overall view of how relevant terminology can be put into each other's context and to build a foundation for future development work. The model is based on the terminology from the previous sections and includes two separate but generic views to emphasize the differences between the terms. On the right hand side of Figure 2 efficiency and effectiveness perspectives are described in relation to each other including their characteristics. The efficiency perspective on the production system describes utilization of operational resources during operation phase. This input oriented perspective is limited to a maximum value of 100% fully utilized resources, meaning in turn 0% waste at its best. The effectiveness perspective on the production system emphasizes outputs and deals with the ability to reach a desired objective depending on the perspective on the production system. As this perspective is based on structural, i.e. fundamental decisions regarding design of the production system, there is no limiting scale of how a desired goal can be reached.

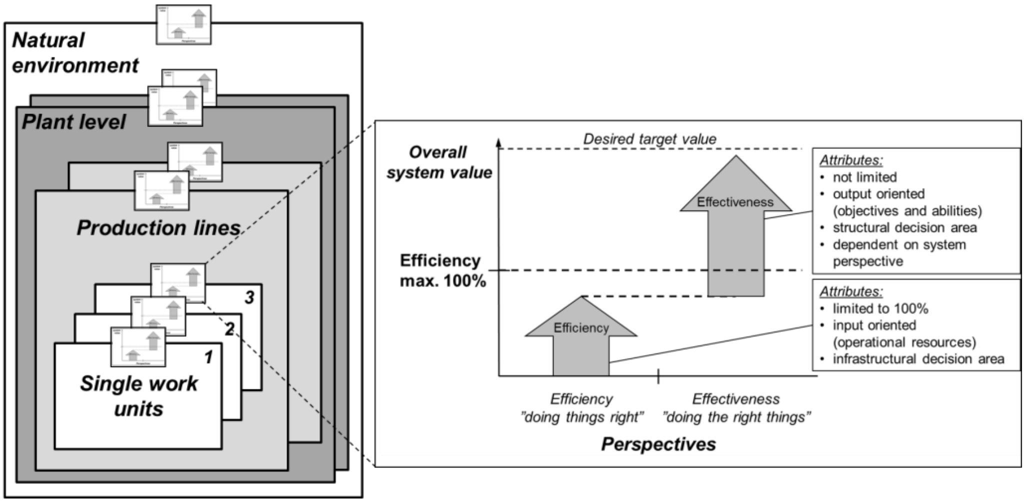

Fig. 2. Integrated model for resource efficiency and effectiveness within a production system hierarchy.

Both, efficiency and effectiveness perspective are finally considered to determine an overall system value which reflects the system's overall performance. Since objectives and abilities within the effectiveness perspective depend on the adopted system perspective, this integrative model is embedded into a hierarchically classified system of three levels as shown on the left side of Figure 2. These four levels consist of single work unit, production lines, production plant and the natural environment. In doing so, the model allows for flexible definitions of objectives and abilities from different system perspectives.

As indicated on the left side of Figure 2 a system may be defined as, for instance, single work unit for which resource efficiency and effectiveness can be evaluated. A single work station may for instance consist of an assembly station or a CNC machine using time-based utilization measures for efficiency evaluation and output of parts as effectiveness measure. Exemplary measures on work unit level for human and automated systems might include the use of time material use, energy consumption and cost, which need to be matched with proper measures on the effectiveness side as minimum and maximum output or productivity ratios. Simultaneously, numerous work stations can form a production line while several production lines make up an entire production plant. On plant level resource efficiency and effectiveness criteria can be quantified as e.g. number of employees and profitability respectively. In the highest level, the natural environment, effectiveness concerns sustainability incorporating social, economic and environmental aspects, while the sourcing and use of natural resources can be evaluated as part of the resource efficiency perspective.

This consequently, leads to a discussion regarding hierarchical relations between resource efficiency and effectiveness perspectives between various system levels. As an example, having equipment operating locally at high efficiency but simultaneously not covering customer demands on plant level indicates suboptimal use of equipment and therefore not the highest possible overall value on plant level. On the other hand, a reduced focus on the efficiency of work stations while securing fast delivery to customers through the entire production line increases the overall system value by keeping the work in progress low. Increased flexibility for offering altering production volumes and product variants stands for another example of oppositional relationship between resource efficiency (time and cost for changeovers) in production lines and effectiveness (competitive factor) on plant level. Hence, the awareness and comprehension of system thinking, including differentiation and priorities of short-term and long-term objectives, represents a basic requirement for a successful application of the model.

6. CONCLUSION

This review paper discussed terminology and perspectives focusing on resource efficiency and effectiveness in industrial production resulting in a conceptual model. The initial description of relevant terminology provides researchers and practitioners with a notion of how the perception of resource efficiency and effectiveness has evolved. The fundamental meaning of efficiency and effectiveness is investigated and put into production context. The following discussion including strategic views deliver an insight into state of the art challenges to be addressed towards sustainable production. Furthermore, the conceptual model finally describes how terminology can be put into each other's context to build a foundation for future development work. While it is common to share vocabulary in academia one has to still accept that in practice and especially common language the emphasized terms will most likely be interpreted in different ways. To be practically feasible and to get a more thorough and concrete comprehension of the model the future development work comprises the elaboration of suitable measures for quantification for comparability and scalability. These case specific quantification attempts need to include relevant system dependencies, which can be addressed using models of system dynamics.

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