International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume-2, Special Issue 8 (Nov-Dec 2014), PP. 87-92

METHOD TO EVALUATE SUSTAINABILITY OF A FACTORY PAPER

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Abstract— In the current economic climate, for many businesses it is generally no longer sufficient to pursue exclusively economic interests. Instead, integrating ecological and social goals into the corporate targets is becoming ever more important. In the scientific literature there are many approaches to evaluate sustainability. However, it was determined that none of the present approaches can be used to evaluate the sustainability of a factory and its stakeholders at one time and propose measures to use potentials. Therefore this article describes the conceptual framework of an approach to evaluate the sustainability using a maturity model. This model is based on the System Dynamics Method. With this approach companies are enabled to evaluate their sustainability regarding all dimensions of sustainability and their stakeholders.
Keywords— Sustainability, System Dynamics, Maturity Model.

1. INTRODUCTION

It was in 1992 that the Brundtland Commission drew up a notion of sustainability that is still valid and recognized today [1]. Based on the Brundtland definition, a select committee of the German parliament developed the three-pillar model of sustainability, which consists of ecological, economic, and social dimensions [2]. All three dimensions interact with each other and, in the ideal case, need a balanced relationship with each other [3].

In today’s economic climate, many companies mostly pursue just one of these dimensions and neglect the other two and the corresponding interactions. As a rule, the economic dimension is given priority, because most businesses operate in an environment characterized by considerable turmoil [4, 5] [5]. Therefore, to safeguard their competitiveness, they frequently initially focus on economic objectives. For example, again and again, companies find themselves having to face the challenges of growing globalization, the individual requests of customers, and shorter planning cycles for products or factories [6]. However, an additional, growing trend regarding the efficient use of resources in factories has been observed in recent years [7] [8]. This development is driven by a range of very diverse factors. It has been ascertained, for example, that customer demands for sustainably produced products are growing constantly [9]. At the same time, the ever faster rise in the cost of raw materials and energy makes it necessary to use resources more efficiently [9]. Furthermore, politics, e.g. in the form of more stringent environmental stipulations or political targets such as the turnaround in German energy policy, is constantly raising the importance of the ecological dimension in sustainability [10] [11]. Parallel with this, the social dimension is becoming more and more influential. This aspect includes, for example, taking into account the interests of employees; and where factories are located in urban areas, which is often the case, then listening to the opinions of local residents is also becoming increasingly relevant [12]. Furthermore the reputation of a company is a key factor for its economic success [13].

Given environmental and social objectives are currently assuming increasing prominence in company strategy, it is essential to devise methods facilitating positioning among the three occasionally contradictory objectives. These methods are required to assess the current situation of the company and these findings are taken as a basis for elucidation of appropriate measures to highlight identified possibilities and enable implementation of any potential new positioning. This article presents the concept of a methodology designed to enable users to quantify sustainability. Nevertheless it should be noted a large number of writers comment that sustainability actually involves considerations of a magnitude that defies direct quantification, since on the one hand it is marked by serious complexity, while on the other hand it is not directly quantifiable [14]. Thus this current approach outlines so-called sustainability enablers, which consist of traits of the factory, its factory objects and even its stakeholders. A maturity model taking this as its basis uses sustainability enablers designed to facilitate sustainability quantification. The approach described in this article allows for sustainability quantification on factory and stakeholders and indicates how to pinpoint relevant measures to capitalize on available potential. The first section contains an explanation of the procedure for deducing sustainability enablers, and the second section builds on this by outlining the conceptual framework of the maturity model.

2. DEDUCTION OF SUSTAINABILITY ENABLERS

Systems consist of a multiplicity of elements dependent on their inter-relationships and interaction with the environment encompassing them [15], while these elements constitute the system structure by dint of their inter-relationships and system limitations [16]. They may indeed in turn be systems themselves, and in this case they are designated sub-systems [17]. In fact all systems exhibit behavior that is either non-time-dependent (static) or time-dependent (dynamic) [8].

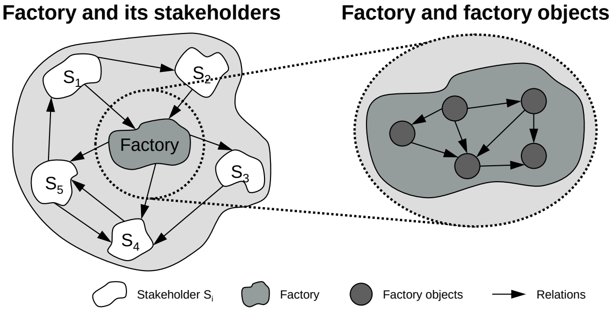

Figure 1 The factory and its stakeholders as a system

The system underlying this methodology comprises the factory and its stakeholders, and the factory accounts for a plethora of sub-systems, which are designated factory objects, with examples being means of production and transportation and the production concept. Factory objects are allocated to technological (e.g. means of production), organizational (e.g. production concept) and spatial (e.g. buildings) form fields, while stakeholders account, for example, for local community, suppliers and clients. Relationships between elements within the system possess a variety of characteristics covering, for example, flows of materials, staff, information and capital. The underlying system relationship is illustrated in Fig. 1.

A. Operationalization of sustainability

The first step involves compiling criteria and key figures lending themselves in the first instance to quantification of sustainability and aspects thereof. Scientific literature abounds with approaches to quantifying a single aspect of sustainability under certain parameters, e.g. [18]. Concurrently there exists a multiplicity of approaches in practice for quantifying partial aspects of sustainability, generally in the form of tools (e.g. sustainability of a building [19]). Extensive research analyzed 65 approaches from German and international linguistic areas and involved over 550 criteria and key figures in quantification, and this extensive list was whittled down to 98 criteria and key figures by thematic grouping of similar items. Simultaneously, analysis of existing approaches confirmed that current science and practice does not provide for any approach to quantification of sustainability in the factory that also takes account of both stakeholders and factory objects and highlights relevant measures to pinpoint possibilities. This is ample justification for the concept under review.

B. Application of System Dynamics method

The second step calls for a method with two purposes: on the one hand it should take account of the holistic nature of the system including factory, factory objects and stakeholders with their inter-relationships, not omitting any behavioral aspect. On the other hand it requires a representation of the numerous internal and often inter-dependent relationships between the elements. This acts to guarantee result transparency.

A methodology meeting these outline conditions is found in the System Dynamics method, which was developed by FORRESTER and facilitates holistic analysis of the structure and simulation of the behavior of complex and dynamic systems [20].

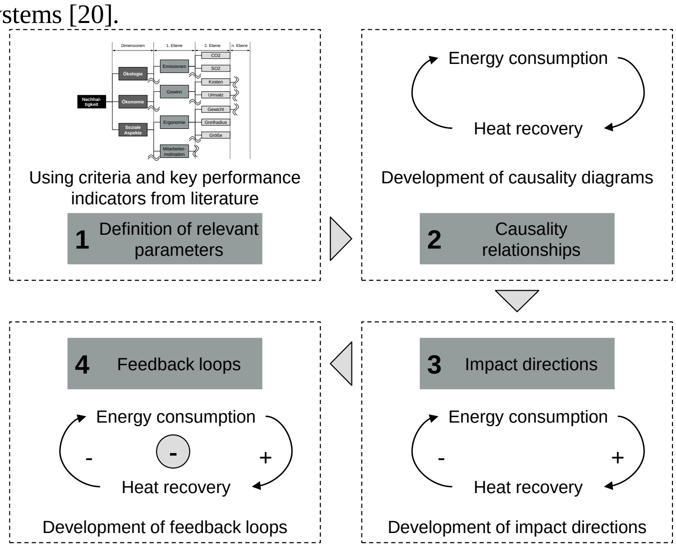

Figure 2 Steps for developing causality diagrams

Models of this type may be either qualitative or quantitative in nature. The qualitative method identifies and analyses self-contained functional chains with any feedback loops. Feedback loops involve reduction of an internal dimension leading to self-enhancement (positive feedback loops) or self-limitation (negative feedback loops) [21]. Every System Dynamics model possesses at least one central flow size, and in the present case it is a matter of sustainability dimensions. Functional chains are shown in terms of causality diagrams, c.f. Fig. 2, regarding to [22].

The first step in drawing up causality diagrams calls for the relevant system dimensions, which involves using criteria and key figures extracted from literature, and the second step involves establishing a qualitative relationship between these. In a visual sense this is achieved by linking the various key dimensions by means of impact arrows. The third step elaborates the effect of the identified impact factors by allocating negative or positive arrows. The final step identifies feedback loops existing within the system. If necessary this qualitative analysis can be followed by application of quantitative models involving conversion of the qualitative causality diagrams to flow diagrams and their simulation. This facilitates a detailed quantitative understanding of the system, but actually the qualitative understanding of the system is sufficient to acquire the understanding necessary for the desired opinion. In the context of this approach there are three different causality diagram segments, one for each sustainability dimension. Linking the individual segments with one another produces the overall causality diagram, and at the same time these links represent the varied impact and relationships between the sustainability dimensions.

C. Deduction of sustainability characteristics

The third step involves extrapolating sustainability characteristics, which illustrate the characteristics of system elements (factory, factory objects and stakeholders) that must be ensured to achieve a sustainable system. The feedback loops identified in the causality diagrams form the basis for sustainability characteristics. If the feedback loops are controlled by the system, they constitute sustainability characteristics. If the various characteristics are treated equally (i.e. no single characteristic is given preference), it is fair to conclude that the more characteristics a system fulfils, the more sustainable it is.

D. Enable cluster groups

The fourth step involves clustering the sustainability characteristics into sustainability enablers. This is necessitated by the variety in form of extrapolated characteristics requiring grouping. Thus the enablers constitute the key system characteristics that need to be achieved, in order to ensure sustainable system behavior. Identification of suitable cluster groups depends on cluster analysis, which involves coalescing the characteristics into individual groups very different from one another [23]. There is initial determination of similarities among the individual elements followed by selection and application of an appropriate fusion algorithm and identification of the most homogeneous clusters [24], c.f. Fig. 3.

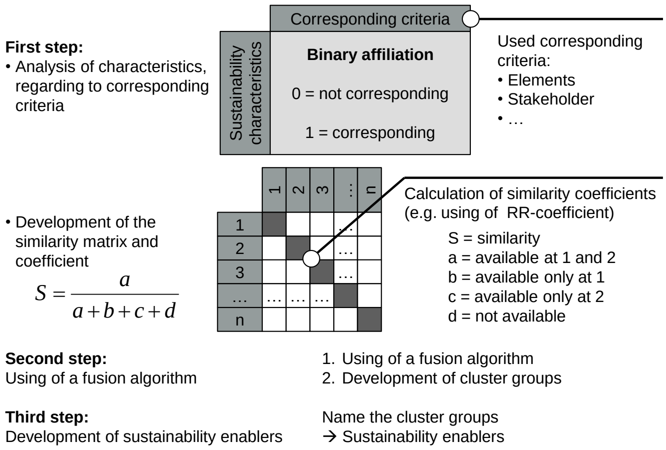

Figure 3 Steps for developing sustainability enablers

Determination of element similarity involves quantifying dissimilarity or similarity between individual elements by using either metric or nominal procedures. Metric procedures generally calculate dissimilarity between elements, whereas by contrast nominal procedures describe element characteristics by means of binary variables. Both metric and nominal procedures result in a matrix of all elements considered [24]. Appropriate allocation criteria are defined to establish the similarity between individual sustainability characteristics, so allowing consideration, for instance, of factory objects or stakeholders concerned. One matrix shows the individual combinations of characteristic and allocation criteria via binary variable "related – 1/unrelated – 0," and the binary data contained herein are then transformed into similarity values. For example recourse is taken here to the RR coefficient [24], which offers the advantage of considering even cases in which any characteristic is not fulfilled by any single element. The equation needed to calculate degree of similarity is found in Fig. 3, and the result is a related similarity matrix. Sustainability characteristics can be synthesized on the basis of the similarity matrix by using a fusion algorithm. Selection can be made between procedures of inclusive or divisive nature, but in scientific circles so far the inclusive procedures (e.g. single linkage, complete linkage and average linkage) have been more widely used [24]. In this way, for example, the single linkage procedure assures identification of possible rogue clusters [25]. The single linkage procedure allows for calculation of similarity value for a new group in relation to the other elements, by taking the highest of the previous similarity values as the new value, and in conclusion the cluster groups identified are denominated according to the characteristics they contain. The cluster groups identified and denominated constitute sustainability enablers.

E. Sustainability potentials

The sustainability enablers derived can be applied to factory objects and stakeholders to show how they affect sustainability. The following diagram sees this as sustainability potential, c.f. Fig. 4. Overall it was determined that there exist three different sections per sustainability potential: the unusable section contains sustainability enablers that are not applicable to the factory objects or stakeholders, while missing sustainability enablers describe the potential section containing usable, but missing enablers, and the final section is characterized by inadequate quality of enablers applied, for example when they are not applied correctly.

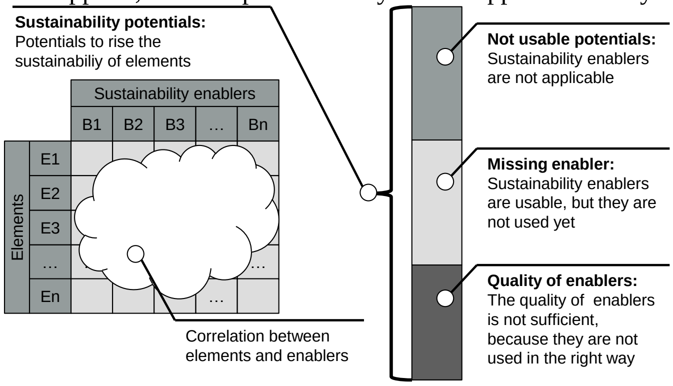

Figure 4 Various types of sustainability potentials

3. DEVELOPMENT OF MATURITY MODELS TO QUANTIFY SUSTAINABILITY

F. Development of maturity models

The results achieved up to now are funneled into an evaluation procedure, because it has been shown logical to use a maturity model-based procedure. This has the following advantages, namely firstly that it is very user-friendly for maturity description, and secondly that it ensures a high degree of subjectivity through existing individual maturity description. The general maturity model used in this methodology comprises six maturity levels with each level describing the applicable percentage sustainability realization, and these six levels lead to the use of fulfilment levels 0% – 20% – 40% – 60% – 80% – 100%.

G. Determination of target sustainability

Calculation of target sustainability is a precondition for interpretation of the figure for actual sustainability. By reason of the various partially contrary target dimensions it is generally not sensible and sometimes not even possible for a factory and its stakeholders to score 100% for sustainability across all maturities. Target values are calculated with reference to usefulness [26]. Application of this method presupposes identification of the elements to be assessed, an appropriate evaluation scale and key values, the latter commensurate with system elements (factory objects and stakeholders). Generally it is necessary to determine a target value per enabler for each element. The evaluation scale follows the underlying maturity model, and target values are determined with reference to sustainability characteristics, so as a result the group of characteristics to be fulfilled in each area under scrutiny represents the desired sustainability target value. Since general practice dictates not all characteristics need to be fulfilled, target values are usually below 100%, c.f. Fig. 5. In order to determine overall target sustainability of the system under scrutiny, it is necessary to calculate target values for individual elements of each enabler, and to use these to calculate the arithmetic mean to reflect target sustainability of the whole system. A similar procedure takes place to determine individual element target sustainability, and it should be stated how high the proportion of sustainability characteristics to be fulfilled at each level is.

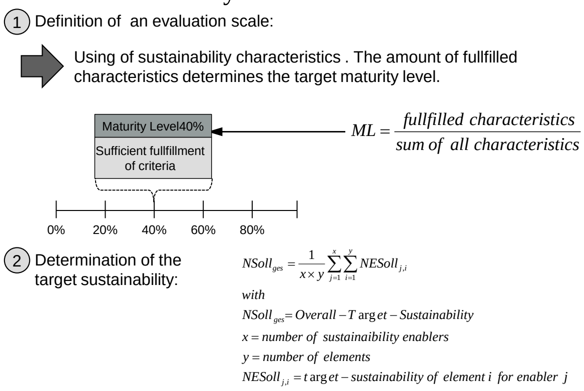

Figure 5 Determination of target sustainability

H. Determination of actual sustainability

Actual sustainability is required to be used in conjunction with target sustainability to deduce relevant potential increases. Just as with target sustainability this presupposes the elements to be assessed, an appropriate evaluation scale and key values. Individual steps for calculating actual sustainability are shown in Fig. 6.

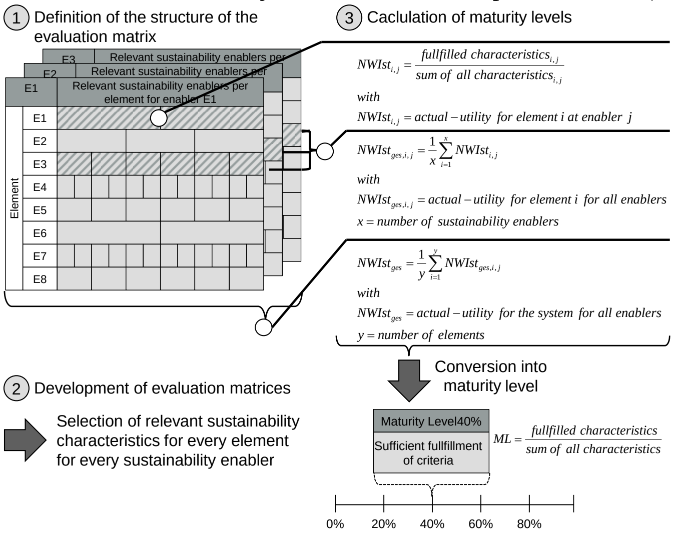

Figure 6 Determination of actual sustainability

The initial step is to develop an evaluation matrix per sustainability enabler including the elements under scrutiny, which comprise factory objects and stakeholders, and these elements are combined with sustainability enablers in such a way as to contribute to whole system sustainability. The elements are matched with certain criteria governing the relevant sustainability characteristics for the element in the sustainability enabler under scrutiny. The proportion of characteristics fulfilled in the evaluation process constitutes the desired useful value for actual sustainability.

I. Consolidation into maturity models

It has been shown how sustainability characteristics and enablers can be used to calculate target and actual sustainability for a system consisting of factory and stakeholders, and the concluding step is to consolidate figures into a maturity model. Maturity models offer the advantage of being amenable to graphic representation in a network diagram.

Now following successful definition of targets and calculation of actual sustainability values it is possible very simply to conclude the appropriate potentials in a visual fashion. An appropriate knowledge database can be used to save measures that can be utilized to ensure an increase in maturity level for individual elements, and this is achieved by ensuring fulfilment of missing sustainability characteristics. The envisaged knowledge database should be a living entity, whereby it is expanded on an on-going basis by the addition of appropriate measures for increased sustainability.

4. Conclusion

Under current economic circumstances a large number of companies have an equal right to ecological, social and economic objectives, but there exists a degree of tension between these. However every company should be able to position itself properly and this is only really possible with the aid of a methodology to evaluate sustainability for companies and their stakeholders and proffer appropriate increased sustainability measures. Literature research has shown that there is still a lack of appropriate methodology, so this contribution describes the concept of evaluation facilitating sustainability quantification. This methodology is tied to maturity models and thus ensures simple practical application.

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