

Enhanced Economic Evaluation – Approach for a Holistic Evaluation of Factory Planning Variants

Candy P. Schulze, Michael Brieke, Prof. Peter Nyhuis

Abstract—The building of a factory can be a strategic investment owing to its long service life. An evaluation that only focuses, for example, on payments for the building, the technical equipment of the factory, and the personnel for the enterprise is – considering the complexity of the system factory – not sufficient for this long-term view. The success of an investment is secured, among other things, by the attainment of nonmonetary goals, too, like transformability. Such aspects are not considered in traditional investment calculations like the net present value method. This paper closes this gap with the enhanced economic evaluation (EWR) for factory planning. The procedure and the first results of an application in a project are presented.

Keywords—economic efficiency, holistic evaluation, factory planning

I. INTRODUCTION

THE factory represents a complex socio-technical system whose planning takes place in several steps and with the participation of a multiplicity of persons. Here, the future technical and personnel capacities are specified through the design of production factors like the building and the operational resources. Decisions made during the factory planning determine the basic economic production conditions for the long-term and are, for example, based on the classical economy calculation of hourly rates per employee or investments per square meter of factory floor area [1]. Consequently, the investment decision has hitherto been considerably affected by the initial investment. The reduction in operating costs brought about by a different design of the factory can, however, justify a higher initial investment due to the long service life [2], [3]. During the factory planning process, for example, the building and the production

processes can be arranged particularly energy-efficient; although a higher initial investment is necessary for this, the energy costs are reduced over the entire service life of the factory [4]. A further example is the need for the regular integration of new processes into the production, caused by new products or technical innovations. The ability of a factory to handle these changes as fast and as cost-effectively as possible is designated transformability. A transformable factory therefore experiences lower costs when changes occur during the service life [5], [6]. The effects described, however, can hardly be measured and are therefore not considered in the traditional investment calculation like the net present value method [7]. Because of this they are frequently evaluated by means of a costs–benefits analysis. The resulting benefits determined, however, are usually regarded isolated from the monetary result. A methodology that transforms the achievement of nonmonetary goals – like sustainability and transformability – into monetary variables and creates a link with the traditional investment calculation has been missing up to now.

II. APPROACH FOR AN ENHANCED ECONOMIC EVALUATION (EWR)

Factory planning can be considered as a creative process that permits several variants of a factory as a solution. In the context of the factory planning, therefore, a holistic evaluation of the variants, while considering the corporate goals, is necessary. To do this, a six-step procedure was developed by the working group “Enhanced Economy Evaluation” of the Verein Deutscher Ingenieure (VDI). Fig. 1 illustrates the composition of the methodology developed [1].

In the first step a goals system with appropriate criteria is drawn up for the evaluation. The second step is the selection of the factory objects, which are regarded in the context of the EWR. The nonmonetary evaluation of the variants and the determination of a net present value are the subjects of the third step. In the fourth step the enhanced net present value and the additional benefits of the planning variant are determined due to the effects of qualitative characteristics. In order to cover the influence of uncertainty on the result, a sensitivity analysis is performed (step 5). In the sixth and last step the results of the evaluation are validated and documented after realization of the factory. These steps are described in

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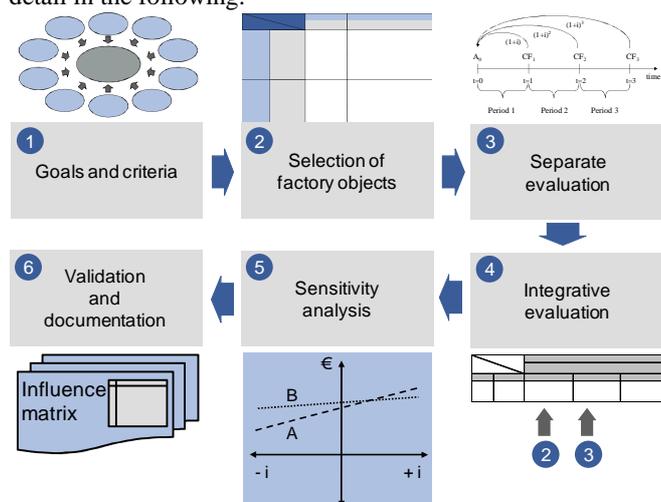


Fig. 1 Composition of the enhanced economic evaluation

A. Goals and Criteria (Step1)

The first step is to select the goals that might be expected to have a high economic influence on the planned system and exhibit the highest degrees of agreement with the corporate strategy. In the context of the EWR, 10 nonmonetary goals were identified, which are applied practically by deriving suitable criteria (Fig. 2). By comparing these in pairs their different significance for the corporate strategy is taken into account in the form of a weighting calculation [8], [9].

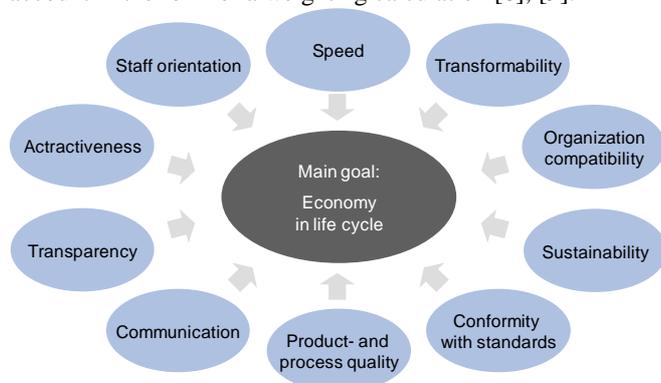


Fig. 2 Nonmonetary goals in factory planning [10]

Staff orientation refers, among other things, to aspects of employee motivation. The motivation of an employee affects his performance on the job. Thus, it has a substantial influence on productivity and the quality of the processes [11], [12]. It is possible to influence employee motivation by, for example, designing ergonomic workstations. Criteria with which the ergonomic design of a workstation can be evaluated are the “strain on the body due to static and dynamic physical activities” and the “working environment”. They indicate, on the one hand, physical forces affecting the body and, on the other, the loads in the form of dust and heat.

The speed of a factory is understood to be, on the one hand, the time from planning up to reaching the comb line, i.e. the

planned production capacity. On the other hand it includes the throughput time of the products. These two criteria represent a direct indicator for the fulfillment of the customers’ needs and thus form a competitive advantage [13].

Transformability is the capability of a factory to adapt to changes in the environment or to develop proactively [6]. Changes can thus be mastered fast and with little expenditure. The transformability of a factory can be described by transformation enablers such as scalability, mobility, and modularity [14].

The organization of an enterprise can be divided into the organizational and operational structures. They specify the working hours models and remuneration systems as well as the necessary qualifications of the employees for the individual jobs. The organization compatibility describes the technical and spatial suitability of a factory with respect to the existing or planned organizational structure [15].

Sustainability is the avoidance of emissions as well as the conscious deployment of resources on all levels of the factory. Among other things, sustainability has an influence on the image of a factory and can positively affect the acquisition of personnel and business partners [4]. In the context of factory planning, both the sustainability of the building and the processes can be influenced.

Standards refer to, for example, industrial safety stipulations, codes of practice, and guidelines. The conformity with standards can be expressed in the form of certification or higher quality standards, which are also useful as references in the competitive environment. Conformity with standards is measured, for example, by the implementation of holistic production systems, industrial safety, hygiene, and cleanliness [16], [17].

The quality of products and processes is generally defined as the agreement between achievements and requirements [18]. In the context of factory planning, the product and process quality can be affected, for example, by the choice of technology and the layout of areas with different requirements, e.g. concerning the room temperature. The aspect of process stability refers to the prevention of production downtimes and the resulting costs [19].

The communication capability designates the possibility for an unimpaired information exchange between the areas and hierarchy levels of an enterprise. Here, the passing on of information is also important, apart from the chains of communication. This aspect refers to both formal and informal communication [20], [21].

Transparency helps to describe the degree of clarity in a factory regarding the structure and internal processes. High transparency renders possible a better and fast evaluation of the internal processes and responsibilities [1].

Attractiveness refers to the external representation of the factory, the working conditions, and the spatial connection between functional units. Outwardly, this helps in marketing activities with customers; inwardly, the facilities and amenities have an effect on employees [1].

B. Selection of factory objects (Step 2)

Due to the multiplicity of elements as well as the connecting materials and information flows, the factory represents a highly complex, socio-technical system. The identification of the relevant elements for the evaluation initially makes use of the subdivision of the factory according to Nyhuis (Fig. 3) [2], [22].

The factory can be divided into three factory fields: means, organization, and space. Apart from the partitioning into fields, a factory can be additionally divided into factory levels. Four levels of specification can be differentiated here, with higher levels embracing all lower levels in each case: site, factory, system or cell, and workstation. Setting up a relationship between the factory fields and the factory levels results in a matrix. The elements of a factory, which are called factory objects in the following, can be arranged with their aid [2]. The factory objects can now be used to identify the influence on a nonmonetary goal (step 2). For example, the object real estate does not have an influence on the organization compatibility. A very strong influence is to be expected, however, with the object labor organization. An influence matrix can be set up for the systematization and retention of the existing connections between the factory objects and the goals [1]. Here, the factory objects are arranged according to the four factory levels in the lines of the influence matrix. The goals (e.g. staff orientation) and the related criteria (e.g. working environment) are entered into the columns. The information entered into the influence matrix can also be used to design a factory with a high goal attainment.

Factory fields		Means	Organization	Space
				
Factory levels				
Level I: Site		<ul style="list-style-type: none"> Provision of media and energy – centralized hubs 	<ul style="list-style-type: none"> Organization structure 	<ul style="list-style-type: none"> Real estate Building development External facilities
Level II: Factory		<ul style="list-style-type: none"> Provision of media and energy – distribution IT 	<ul style="list-style-type: none"> Structure Logistics concept Production concept 	<ul style="list-style-type: none"> Factory layout Girder Shell Form Impression
Level III: System/ Cell		<ul style="list-style-type: none"> Means of storage Means of transportation and handling 	<ul style="list-style-type: none"> Labor organization 	<ul style="list-style-type: none"> Fitting-out
Level IV: Workstation		<ul style="list-style-type: none"> Production technology Production means Additional equipment 	<ul style="list-style-type: none"> Quality assurance concept 	<ul style="list-style-type: none"> Workplace design

Fig. 3 Objects of a factory

C. Separate Evaluation (Step 3)

Following step 2, the factory objects considered are planned. Here, different variants are created, which must be

evaluated regarding fulfillment of their criteria. Therefore, in this step the net present values of the variants are first calculated from the directly determinable payment streams [23]. The associated payments are complied based on the factory objects selected (step 2). The costs of the machine and the appropriate tools are relevant here, for instance. In addition, the evaluation period is limited. Finally, the interest rate for the discounting of the future payments is set.

Furthermore, in this step a degree of achievement for the nonmonetary goals for the planning variants is determined with the aid of the relevant criteria. This indicates to what degree a planning variant fulfills a criterion. The nature of the fulfillment depends on the criteria. For example, whereas the “throughput time” of a factory can be indicated by time units, the evaluation of the criterion “awareness level of the factory” (goal attractiveness) is realized with qualitative expressions like “poor”, “average”, “good”. The following scales can be used [24]: ordinal, interval, and ratio. The information from step 2, entered into the influence matrix, can be used to determine the degree of goal attainment.

D. Integrative Evaluation (Step 4)

The degrees of goal attainment determined in step 3 can be transformed into payments by way of causal chains [1]. Initially, transformation aids for each criterion are set up. These represent a cause–effect relationship between a criterion and a payment. If a criterion cannot be transformed directly into a payment, a transformation into an interim parameter is necessary, which can be transformed into a payment afterwards by means of another transformation rule. The cause–effect relationship between a criterion and a payment or parameter is specified case-by-case by the planning team. Fig. 4 shows a transformation using the example of staff orientation. All transformations can be systematized in this way in the so-called matrix of transformations. The matrix thus fulfills two functions: on the one hand, all possible effects of factory objects on the criteria are embraced by the systematic comparison; on the other, the cause–effect relationships identified can be used in the ex-post analysis and in following factory planning projects.

		Staff orientation (goal)		
		strain on body due to static & dynamic physical activities		
Level	Object	Transformation	Transformation rule	Payment
Workstation	Production means	Days absent	Days absent x Value of amount produced per day	Lost sales

Fig. 4 Extract from the matrix of transformations

For example, on the workstation level, a connection between the physical loads on an employee and hence the lost sales caused can be identified for the workstation design. Firstly, the number of days absent of an employee can be concluded from the design of means of production. Subsequently, the days absent can be converted into lost sales using the value of the goods produced per day. This payment refers to the effect of one criterion on one factory object. The criterion can, however, also entail different payments with the

same factory object. For example, the ergonomic design of a workstation can increase the efficiency and thus the quantity produced through simplified processes. In addition, lost sales may arise for the same or other factory objects as a consequence of other criteria fulfillments.

The aggregation of the payments determined on the basis of the matrix of transformations and the net present value calculated in step 3 results in the enhanced net present value. In the ideal case this represents the sole, holistic, decision-making basis for the factory planning. The difference between the direct present value and the enhanced present value thus represents the monetary effect of transformed criteria fulfillments for the period under review. Any criteria fulfillments that cannot be transformed with causal chains are aggregated to form a parameter, the so-called additional benefit. This is then available as an additional decision-making criterion beside the enhanced present value.

The transformations described are based on different cause-effect relationships. The following approaches, which allow a practical application of these cause-effect relationships, are introduced by way of the following examples: estimation, functional connections, artificial neural net, and regression analysis.

With estimation the fulfillment of a criterion is transformed by experts into a payment. This estimation is based on no or only little knowledge of the cause-effect relationship. Therefore, heuristic methods, like the Delphi method and the beta method, are applied because of their prospective character. For example, with the beta method the level of payment or a characteristic that results from criterion fulfillment is estimated by a planning team. Here, best-case and worst-case estimates have to be determined, which are combined to form a mean value.

A functional cause-effect relationship in the context of this article is understood to be the relationship between two variables. This indicates the kind of influence that a criterion fulfillment has on a payment or a parameter. Cause-effect relationships can be mapped with transformation functions. BLOHM differentiates between three types of transformation function: discrete, piecewise-constant (defined in sections), and constant transformation functions [25]. The discrete transformation function assigns exactly one function value to each input value. With a piecewise-constant transformation function the values of a certain interval are transformed into exactly one function value. The so-called stair functions and alternative functions are among these. With the aid of a constant function, arbitrarily small differences of an input value – on the assumption of monotony – can be transformed into function values.

Another possibility for the transformation of criterion fulfillment into payments is to use a so-called artificial neural network (ANN). These are information-processing systems that consist of a multiplicity of primitive, parallel-working computational units, which are called neurons [26]. These artificial neurons emulate biological neurons and their

processing strategies. Within this ANN, input parameters are processed and appropriate outputs generated. Using such networks, nonlinear relations can be re-created by interactions of the variables, or rather neurons. Thus, no knowledge of the cause-effect relationships of the emulated system is necessary [27], [28]. The method can be used in the context of factory planning because the data of payment streams in projects realized can be fed into the ANN.

With the aid of the regression analysis, a functional connection between a dependent variable (regressand) and one or more independent variables (regressors) can be created on the basis of past data. We distinguish here between simple linear regression (one variable) and multiple regression (two or more variables) depending upon the number of independent variables considered. The historical data form so-called points of observation. The designed, linear cause-effect relationship can be described by an equation that intersects the focus of the cluster of points formed by all points of observation [29], [30]. Here, the criterion fulfillment represents the independent and the payment the dependent variable(s). A multiple regression can be used if several criteria have the same cause-effect relationship with a factory object and are covered by the same payment. In this case only a total payment for all criteria is determined, not one payment for each individual criterion. This has the advantage that no detailed knowledge of individual cause-effect relationships is required.

E. Sensitivity Analysis (Step 5)

A ranking of the variants can be determined by comparing the enhanced net present values of different planning variants. A sensitivity analysis supplies information about the potential influence of uncertainty regarding the ranking [31], [9]. For example, the breakeven analysis is suitable for a single input parameter. Varying the interest rate, for example, enables the point to be determined at which a change in the ranking of the variants occurs. In this way it is possible to determine whether even minor changes to the interest rate lead to changes in the ranking order or whether the ranking of the variants remains constant over a wide range of change.

F. Validation and Documentation (Step 6)

This step takes place after the realization of a variant and serves for result validation and knowledge management. Here, the evaluation results obtained are compared with the real values and documented. If, for example, new influences between factory objects and criteria were identified, these can be fed into the influence matrix. Validation also includes examining, in particular, to what extent the payments or characteristics determined agree with the real values. In case of a deviation, the underlying cause-effect relationships must be adapted.

III. EXAMPLE OF APPLICATION

The EWR procedure shown here has already been used within the scope of industrial projects in order to identify the most economic variant from a holistic point of view. In the

following, examples of EWR results are shown that arose when deciding between two factory variants. Variant A was based on partial use of the existing factory building and a small extension to the factory. In this way existing resources were to be used and the initial investment limited. Variant B planned the building of a new factory and thus led to a high initial investment.

In the factory planning project reviewed, the product and process quality, the transformability, the speed, and staff orientation were designated as the most important goals of the enterprise. Appropriate criteria were derived and weighted for the goals. Since the planning of a factory was concerned here, all factory objects were included in the evaluation and planned so that a comparison of the two variants was possible. Afterwards, the degree of goal attainment and the net present values for the planned variants were determined for the criteria.

The nonmonetary potential of the new factory was estimated by the planning team to be high, however, due to the reorientation of the production processes. This effect became clear in the following transformations. Different procedures for determining the cause-effect relationship were used depending on the acceptance of the proposed transformation. Experience shows, for example, that the criteria "strain on the body due to static and dynamic physical activities" (F_S) and "working environment" (F_W) of the staff orientation goal have an influence on the number of days absent (T). This connection is shown qualitatively in Fig. 5 in the form of a regression plane.

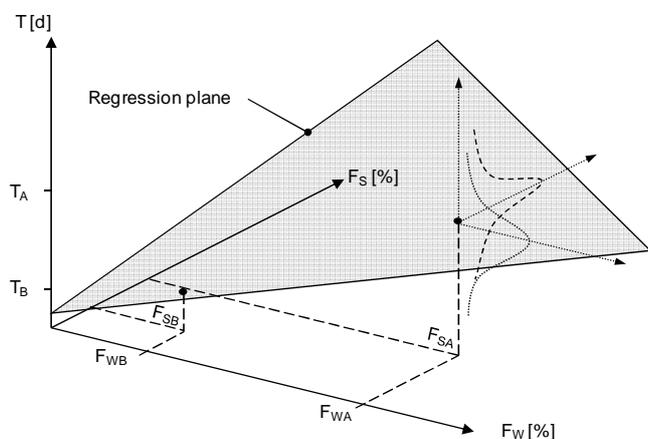


Fig. 5 Regression plane to determine the days absent

Based on extensive past data, two criterion fulfillments could be transformed into the number of days absent expected in the variants. In the illustration the two variants with different criterion fulfillments are shown qualitatively. As a consequence of a less ergonomically favorable design of the workstation regarding the loads, variant A (T_A , F_{SA} , F_{WA}) exhibits a higher number of days absent than the new factory, i.e. variant B (T_B , F_{SB} , F_{WB}). The common transformation of the two criteria appears reasonable here because it avoids the need for a separate analysis of the number of days absent. Such a procedure is recommended if the criteria have a similar effect but are not analyzed separately by the enterprise.

Because of the characteristics of a regression analysis, the number of days absent is determined from estimates based on past data. The true number of days absent can therefore deviate from the calculated value. This aspect is represented with the help of a normal distribution curve for a number of days absent determined for variant A. Assuming that the average production output of an employee is not realized on days absent, the value of lost sales can be expressed as a payment.

As a further example, the energy efficiency of the existing building was evaluated. The heating costs saved in variant B were considered in the form of a decreased payment due to the higher energy efficiency. The payments determined as a result of the transformation were combined in the enhanced net present value. During the entire review period, different payments could be identified through which the high initial investment for variant B could be compensated and a positive net present value achieved. It was thus clear as to which positive monetary effects are to be expected from the nonmonetary goals. In order to consider uncertainties in the result, a sensitivity analysis was carried out as well. A change to the preferred variant occurred due to the significant payment differences between the variants in the course of the review period only with high interest rate changes. Thus the economy of variant B could be considered as ensured. The execution of the EWR, in particular the transformations, took place in all cases together with the client's experts. In this way the internal corporate knowledge regarding possible cause-effect relationships could be used and the acceptance of the evaluation results improved.

IV. CONCLUSION

In a factory planning project the economic framework conditions for the production are specified on a long-term basis. In addition, the monetary effects of a planning variant, which are also described by nonmonetary goals, are rather long-term and indirect. These effects cannot be handled by the traditional economic calculations and are thus usually left unconsidered in investment decisions. In the present paper a five-step procedure was presented that makes a holistic, economic evaluation of investments possible. To do this, a comprehensive nonmonetary goal system was first set up, from which criteria for the execution of the enhanced economic evaluation can be derived. The criteria indicate the degree of goal attainment for a planning variant and are transformed by cause-effect relationships either into payments or into benefits. Four different approaches were introduced as examples of this: estimation of the level of payment, transformation functions, artificial neural networks, and regression analyses. In order to consider uncertainties as well, a sensitivity analysis was also carried out. The applicability of the enhanced economic evaluation was shown by means of a practical example. For a comprehensive validation of the methodology, further applications in industry are planned.

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