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Introduction Of An Economic Assessment Approach For Factory Planning

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Abstract

Factories are characterised by a long life cycle and substantial investment costs. In particular, factory planning and reorganisation lead to capital-intensive investments and have a significant influence on the liquidity of companies. Reliable data are the basic prerequisite for a valid economic assessment of intended factory planning projects. However, especially in early planning phases, the available data are often uncertain and inaccurate. This problem significantly impedes the early and precise dimensioning of operating resources, production areas and employees as well as their cost calculation for planned factories. This also increases the risk of erroneous cost-benefit estimates and potential misinvestments. As a result, an early economic assessment and cost estimate for planned factories is essential.

Until now, a holistic approach that can quickly and precisely determine investment costs of different planning variants in an early factory planning phase with only limited and uncertain information is not yet available. In order to close this research gap, a holistic approach for calculating investment costs in an early stage of factory planning is in development within the framework of "ELIAS", a collaborate research project of the Institute of Production Systems and Logistics at Leibniz University Hannover and the GREAN GmbH. The central objective of this research project is the software-based development of an investment cost calculator in order to carry out an economic efficiency assessment for potential factory planning projects at an early stage. This article provides both a brief summary of the need and innovative capability of the research idea and the structured procedure for creating a planning tool that closes the research gap described above. By this means, companies are supported in making future-proof decisions at an early stage despite uncertain and inaccurate data.

Keywords

Investment calculation; planning tool; economic assessment; uncertainty

1. Introduction and need for research

Factory planning is a key factor in the economic success of manufacturing companies [1,2]. In the literature and in practice, the factory planning process can be divided into different planning phases [1,3–7]. The general phases of setting of objectives, establishment of the product basis, concept planning, detailed planning, preparation for realization, monitoring of realization and ramp-up support are defined as individual planning stages [3,7]. Generally subsequent planning phases are based on previous outcomes and thus lead to a successively more detailed state of results [6,7]. In contrast to classical and partially static approaches, there are factory planning concepts that allow individual adaptations for specific requirements during the planning process [8–12]. Approaches such as condition-based factory planning, enable a modular and parallel approach that can be adapted to specific circumstances [8].

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Increasing customer requirements, growing internationalisation, globalisation and individualisation combined with rising uncertainty are posing ever greater challenges for companies today [13]. Changing framework conditions such as an increased diversity of variants and reduced product life cycles also lead to changed requirements for factory planning. While companies rarely had to deal with the planning of a new factory in the past, factory planning has become a continuous process today [14,15]. The prerequisites for the functionality and utility of the planned project are already set in the early project phase. In particular, the factory as a planning object, which is characterised by a long life cycle and substantial investment costs, presents great challenges for planning [5,7]. Furthermore, in order to develop a sustainable and successful factory concept, the requirements from the process and spatial perspectives have to be considered synergetically and adapted with regard to the construction conditions [6].

Projects are generally characterised by uncertainties. The uniqueness of projects, the trade-off between cost, time and quality and the ambiguity of information, data and estimates lead to these uncertainties in projects [16]. In particular, future-oriented decisions are fundamentally influenced by uncertainties. However, if it is possible to quantify uncertainties or describe them in a model, these uncertainties can be transferred into a risk. A risk includes an expected value and a measurable or quantifiable deviation [17,18]. With such calculable risks, factory planners can already be supported in the early phase of factory planning. This is especially important because the early phase of factory planning presents planners with major challenges due to limited time and resources as well as inadequate information [19]. However, reliable information is the basis for factory planning [20]. Without reliable data and information, economic assessments of projects are often subject to considerable inaccuracies and uncertainties [21–25]. These uncertainties in early project phases can threaten the economic efficiency of entire factory planning projects. Expert and experiential knowledge of the planners that enable model-based expected values for dimensioning variables (as input data for planning) can contribute to managing this complexity [26]. However, in the early phase of projects, there are often only a limited number of resources available, such as planning experts, who can make the required planning accuracy possible in the short time available [19]. Furthermore, intuitive assumptions and estimates of individuals are based on a high degree of subjectivity and are therefore difficult to comprehend, reproduce and apply universally through systematic rules [19,27]. Overall, experts are confronted with two main problems. There is a high level of uncertainty and risk in the calculation as well as the lack of reliable cost data [28]. Recent literature also underlines these ongoing difficulties and the search for appropriate and practical solutions [20,23,29–32]. With current approaches and methods of cost assessment at the beginning of factory planning projects, costs are often quantified before sufficiently precise data and information are available. As a result, these numbers and costs are not always reliable. Cost-effectiveness assessments are therefore fraught with uncertainty [33]. In the previously listed classical literature on factory planning, the inclusion of uncertainty in an early planning phase is not or only insufficiently considered. As uncertainty is part of an early planning phase it is important to reflect recent approaches that explicitly deal with uncertainty in factory planning. For example, approaches can be identified that deal with the transfer of uncertainties into risks [34]. Furthermore, approaches exist that consider uncertainties for the quotation of products by aggregating risks [19] or by identifying central risks and afterwards considering them during the factory planning process [35]. However, final output parameters in terms of dimensioning and calculation often still need to be approximated with the help of expert estimates [35]. Another common method for dealing with uncertainty is fuzzy logic, which is applied in several approaches. It can be used to determine essential variables at an early stage of planning while dealing with uncertainties [36]. Parts of the approaches mentioned can be helpful in future research, but have to be tested for their practical applicability first.

Since factory planning projects, as described above, require a lot of capital and thus have a considerable influence on the liquidity of companies, profitability assessments should be used for decision-making already at the beginning of these projects [4,5]. The largest part of the investments and thus of the project costs are determined in the early project phases. However, this also leads to the fact that in the early phase of factory planning, the greatest influence can still be exerted on future project costs [4]. The proper assessment of the economic efficiency of factory planning projects before starting their implementation is therefore of crucial importance. This is the only way to avoid both, overestimating the benefits of a project, underestimating costs, and thus making misinvestments. However, companies often lack reliable data for these economic efficiency studies in the early planning phase. Reliable and secure data are usually only available with advancing factory planning phases and the associated more detailed results [7].

This short overview demonstrates how difficult it is to estimate investment costs of projects and especially factory planning projects in an early phase due to two main reasons. In the early planning phase, data are often missing or uncertain and expert knowledge is needed due to the high complexity of such projects. However, it becomes clear how important economic assessments are at this stage in order to avoid misinvestments. Several relevant approaches in the field of classical factory planning, cost calculation and handling of uncertainty can be taken into account. In part, these approaches already provide helpful methodologies and can thus serve as a template. Often, however, it is questionable that these approaches can be implemented in a practical manner without high effort and expert knowledge. Furthermore, it can be noted that there is no holistic approach that can validly estimate the impact on dimension variables and investment costs from a synergetic spatial and process perspective in such an early stage. These problems and findings identify the research gap that new approaches need to be developed to support companies in turbulent times by providing target-oriented decision support in the context of economic efficiency assessments.

2. Idea to close research gap

As described above, early, fast and precise economic assessment can support companies in estimating the costs of factory planning projects. Monetary uncertainties can thus be quickly and reproducibly converted into assessable risks.

In this context, the digital factory and digital tools in particular can achieve excellent quantifiable benefits based on a scientific study, respectively a survey by the German Engineering Association. The main effects are the avoidance of planning errors, a reduction in planning time and a higher planning quality [20,37]. In order to determine investment costs in a target-oriented manner and to be able to intervene in time, it is therefore appropriate to use adequate software to support the decision-making process. It should be noted that no software tool exists yet that can be used to determine investment costs in the early planning phase based on the dimensioning of the operating resources, production areas and employees, despite inaccurate data. A planning tool of this type requires quick and precise cost estimation in order to create a common and objective basis for planning and decision-making for all stakeholders involved. Furthermore, it is intended to enable a large circle of users without expert knowledge or specific prior knowledge to carry out a cost estimate despite uncertainty in the planning data. The methodology and the final planning tool will be applied in an early planning phase, for example in early target setting, even before the established planning phases of classical factory planning. For this purpose, the effects on the dimensioning variables from a spatial and process perspective are to be determined under uncertainty and summarised in a holistic model for the final cost calculation. The research gap described above is to be closed by the research and development project "Economic Planning Assessment (ELIAS)", a collaborate project of the Institute of Production Systems and Logistics at Leibniz University Hannover and the GREAN GmbH. The main objective of the research project is to develop a methodology and a software-based investment cost calculator underlying the methodology to determine the cost values of a factory during the early planning phase.

Figure 1 shows the basic idea of the approach, which is briefly explained below.

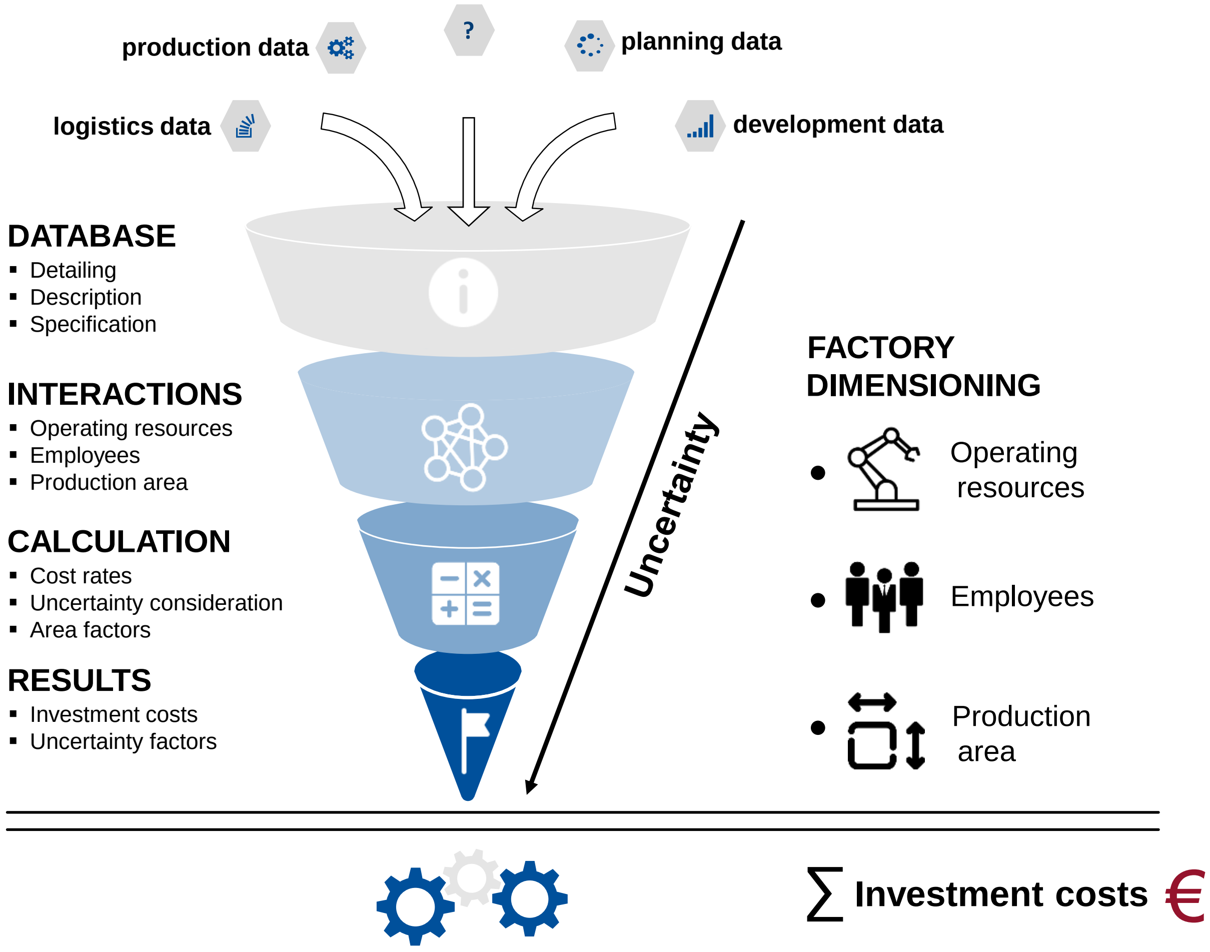

Figure 1: Idea of ELIAS – An economic assessment approach for factory planning

A structured factory planning project successively dimensions operating resources, production areas and employees, which represent a central output of factory planning [6]. The output values of this dimensioning serve as input values for the investment costs of a factory. For example, the decision to use a make-to-stock production instead of a make-to-order production as an order processing strategy increases the space required for the finished parts warehouse. The increase in factory area then also raises the investment costs. The quantities, however, have an effect on the number of operating resources. In addition, there are interactions to be analysed between the above-mentioned dimensioning variables. In some cases, reliable information about the future monetary effects of an investment can already be made with a high degree of probability, as in the case of construction costs, for example [38]. In addition, the dimensioning variables and their interactions have to be analysed first from a process and spatial perspective before central output values are described with cost values in a last step. Whereas usable specifications for determining investment costs already exist for area values and room ratios [39–41], these cost values are missing for production-related costs. As a result, a valid and reliable overall cost estimate is not feasible. It is generally known that the input data for this approach (logistics data, production data, planning data, etc.) are only fully available in the progress of a factory planning project. This is partly because, as explained in the previous chapter, planning phases build on each other and information is not yet completely accessible at the beginning of the planned factory. However, this data and information has to be collected and determined in order to be able to estimate the planned costs at an early stage. Due to the higher uncertainty at the beginning of factory planning projects, assumptions and approximations may have to be made and transferred into a holistic model. Automatic default values are included into the method in order to be able to carry out calculations for dimensioning and cost estimation in case of fuzzy data. Based on these assumptions, the necessary output variables can then be determined. Furthermore, this uncertainty will also be incorporated into the cost estimation in the form of uncertainty factors. As the planning phase progresses and the level of information increases, the dimensioning calculations and the derived cost calculations naturally become more detailed and more reliable. However, the strength of the methodology is to enable dimensioning and cost estimation, especially in the early phase.

In order to develop a digital planning tool based on the methodology, it is necessary to develop a model that combines technical and commercial calculation methods. Technical input data for this model and the subsequent calculation include production data, development data, logistics data and other planning data. The data have to be collected, detailed and analysed. In particular, this involves the effects of the input data on the dimensioning variables, including the necessary operating resources, number of employees and resulting production area (cf. Figure 1). Each input has an impact on the dimensions of the factory. In order to identify these needs, numerous own and third-party experiences and previous work are used and analysed. This technical analysis and calculation of the dimensions of the future factory is followed by a commercial calculation. Using cost rates, area and scaling factors, these demands can be assessed monetarily.

Due to the early phase of factory planning and the previously discussed information and data affected by uncertainty, the demand calculation is also characterised by uncertainty. Additionally, these uncertainties are potentiated in the output values of the dimensioning, which represent the input values of the investment cost calculation. The aim is to transfer these uncertainties into an assessable risk by applying suitable quantification methods. To achieve these objectives, the parametric calculation method is used, for instance, as it enables simple and quick application and is well suited for the early project phase [27,42,43]. This calculation method will then be supplemented with stochastic methods to enable the investment costs assessment with the specification of a percentage uncertainty. Subsequently, this developed method has to be implemented in a software-based planning tool. Agile working methods are being developed to enable a clear and intuitive structure of the software. In this way, an investment cost calculation can also be carried out without expert knowledge. The digital planning tool will thereby also support decision-making in the selection of different factory variants. The possible evaluation options allow different planning scenarios to be compared with each other. Another benefit of the tool is thus the possible fast reaction time to external changes, such as innovations and modifications in building standards.

3. Procedure for the development of the planning tool

In order to achieve the research goal and the previously described project results, the sub-steps according to Figure 2 have to be worked out. These individual steps are described in detail below.

In **step 1**, functional and non-functional requirements for a software-based investment cost calculator are identified. Functional requirements define which input data have to be processed by the methodology. They include, for example, the consideration of different factory types (e.g. low-cost factory, variant-flexible factory), planning cases (e.g. development planning, replanning) or different order penetration points (e.g. make-to-stock, make-to-order). It is already obvious that, for example, the planning of a completely new factory has different effects on the calculation of the dimensioning variables and on a final cost calculation than just an expansion of a factory. In addition, non-functional requirements for users can be identified, such as ease of usability, maintainability of the software and reproducibility of the planning results, as well as the safe handling of uncertain data. Non-functional requirements in this context can be understood as requirements on how well and simply the methodology and ultimately the planning tool provides the results.

As the planning tool is designed for a wide range of users, it is particularly important to take these requirements into account. For the final identification and selection of the requirements, data from factory planning projects that have already been carried out are also used in addition to a detailed literature research. In this way, a structured catalogue of requirements is created in the form of a performance requirement sheet.

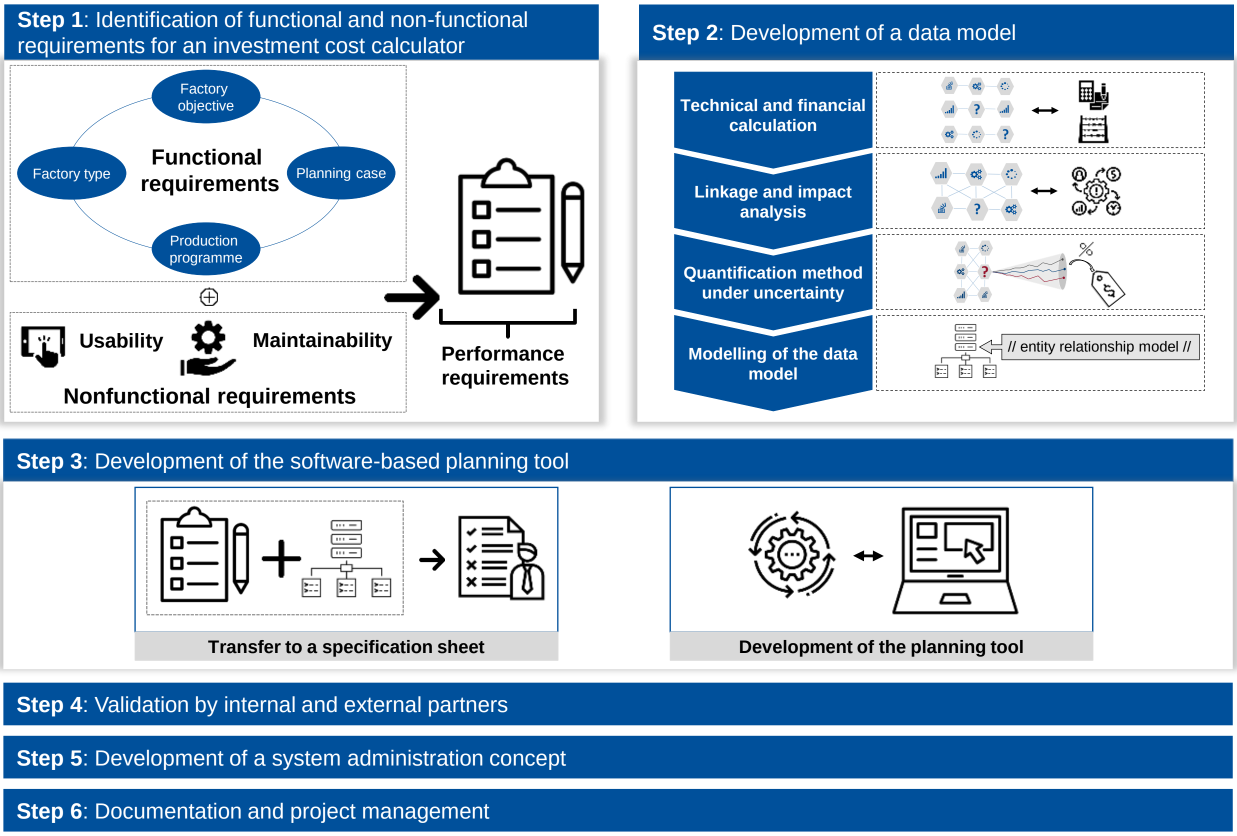

Figure 2: Structured procedure for the development of the planning tool

The **second step** includes the development of a data model of the investment cost calculator based on technical and commercial calculations. In general, it has to be ensured that the data model is based on correct calculation principles and standard values. To assure this, the already existing technical and commercial calculation options for determining investment costs of a factory are first analysed. Parametric calculations, for example, can be used to determine the expected values of certain dimensioning variables. On this basis, it is important to analyse the interconnections between these various calculations. For this purpose, existing data sets and expert knowledge can be used, and covariance and correlation analyses can be carried out. Subsequently, it is analysed which kind of influence the given planning information (such as planning case, factory type, production and logistics data) have on the calculations. It is important to consider the effects on the dimensioning variables from a spatial and process perspective in the data model. Only in this way, it is possible to validly estimate the output values of the dimensioning for the planned factory and finally enable a cost calculation. Furthermore, the interactions between the dimensioning variables have to be taken into account. For example, operating resources have a direct effect on the production area due to their machine area. Machine areas can be calculated using mathematical calculation methods such as the substitute area method or the functional area calculation [7]. Combined with the use of surcharge factors, modularisation can then be applied to estimate the operating resource and the overall production area at an early planning stage. However, these calculation methods and approaches first need to be validated and included into the holistic approach. Moreover, a suitable quantification method has to be selected and integrated into the data model. In addition, uncertainties are taken into account within the calculation, e.g. by means of normal distributions. Parts of the previously presented approaches can already be implemented to handle uncertainty. However, these findings first need to be tested for their practical applicability and integrated into a holistic approach. The conceptually developed data model can then be visually displayed in a suitable form of modelling (e.g. entity-relationship model). This ensures a transparent and comprehensible structure of the data model for the subsequent software-based implementation. As a result, the data model provides a holistic overview of all calculations from input (data) to output (investment costs). In general, technical calculations (area requirements) can thus be linked to commercial calculations (area costs).

In **step 3**, the performance requirement sheet (step 1) and the developed data model (step 2) are first transferred into a specification sheet. These specifications are then transferred into a sophisticated programming environment in order to generate the final software. The software architecture is developed gradually around the established data model. In this way, single functionalities of the software architecture can be successively developed, implemented, tested and extended by new functionalities. This allows errors to be detected and corrected at an early stage. The user interface and visual representation has to be designed for the purpose of an intuitive and user-friendly operation.

In **step 4,** the software is available for a detailed final validation. All functionalities as well as underlying data are verified both internally and by external case study partners. Both industry and research partners will be involved in the validation process. In addition to a general system test, all functions are checked for completeness and errors are identified and corrected. Apart from the involvement of case study partners, fictitious use cases can also be simulated. In this way, a validated and multiple-tested software is created that can be released for use.

In **step 5**, a system administration concept is established to continuously ensure the applicability and practicability of the digital planning tool. This concept includes maintenance routines to assure the functionality and topicality of the software-based investment cost calculator in the future. Continuous project management and documentation of all results (**step 6**) are carried out simultaneously with the above-mentioned steps.

4. Summary and outlook

Factory planning projects are capital-intensive investments that have a significant impact on the liquidity of companies. Companies thus need to be able to estimate the investment costs of factory planning projects at an early stage in order to avoid misinvestments. At the same time, valid information and data are lacking, especially in the early planning phase, in order to be able to estimate these investment costs. The research project "ELIAS - Economic Planning Assessment" aims to assess the economic efficiency of factory planning projects at an early stage, despite missing or inaccurate data. To close this research gap, a methodology is being developed by which investment costs can be estimated quickly and reproducibly with just a small amount of data. In this economic assessment approach for factory planning, key dimensioning variables are determined at an early stage, also with the help of methods for handling uncertainty, which are then quantified by means of a cost calculation. This sophisticated methodology is then transferred into a software-supported planning tool. The approach ensures companies an early assessment of the economic efficiency of projects and thus supports them in making future-proof decisions.

The entire project is in development at the Institute of Production Systems and Logistics at Leibniz University Hannover together with the GREAN GmbH. The project is currently in an early development phase. First results regarding identified requirements and input data for the underlying data model have already been obtained. Initial objectives with regard to the technical and commercial calculation have also been achieved yet. Additionally, important correlations between the dimensioning variables have been identified. These initial results now need to be detailed according to the structured procedure described above and then successfully transferred into a software environment. Afterwards, the developed software-based planning tool will be validated in close cooperation with research and industry partners.

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Biography

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