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Towards Factory Location Planning Using GIS

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Abstract

Today, companies face continuously increasing competitive pressure resulting from highly volatile markets, globalisation and constantly growing customer requirements. Against this background, the location of a factory has a significant influence on competitiveness. The process of location planning is crucial for future success, as the choice of location can determine competitive aspects such as the distance to customers and suppliers or the attractiveness for employees for decades. At present, location decisions are often derived heuristically by gradually narrowing down the object of consideration starting from the global level. In the future, geo-information systems (GIS) shall help to make a more holistic and future-proof factory location decision, which is less dependent on subjective feelings and takes less time and costs. In this paper, the necessary fundamentals for factory location planning with GIS are presented, and it is explained which factory planning information can support location planning using GIS.

Keywords

Factory Planning; Geo-Information Systems; Location Strategy; Supply Chain; Online Map Services

1. Introduction

In recent decades, the market situation of manufacturing companies has been shaped by the influence of change drivers such as advancing digitalisation, volatile internal and external requirements, environmental impacts and several others [1]. In addition, supply shortages and new regulations pose significant challenges to companies' global production networks [2]. Uncertainties of this kind lead companies to question whether the long-term success of a company's location is sustainable in terms of ecological and social aspects [1]. If a company's current location situation is no longer benefiting its strategic goals, a location planning process is triggered that can determine the company's future competitiveness. Location planning strongly influences the future, as the location decision has a long-term character of up to 30 years and determines the company's success [3,1]. It is, therefore, necessary to carry out location planning according to specific requirements to ensure future performance [4]. Among other things, a location decision may be influenced by the distance to customers and suppliers and the connections to inland ports or motorways [5,1]. A future-based solution for site planning could be to use geo-information systems (GIS) in this process. Depending on the context, GIS means either software systems or the basic conceptual idea underlying these systems, which is geographically based [6]. GIS is used today as a tool for performing tasks. In addition to routine tasks such as navigation in traffic, GIS also includes a deeper level of support. In this context, a GIS provides predictive support in decision-making in line with requirements, e.g. for a planning task [7]. With the help of this link, the planning process could show greater transparency, be made more efficient and increase the quality of the results. This paper presents current approaches and challenges and discusses premises and data requirements regarding the use of GIS in factory location planning.

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2. State of the Art

In this chapter, the basics of factory location planning are explained, including location factors and their subdivision, influencing factors in location planning, current considerations on the use of GIS in location planning and challenges in implementation.

2.1 Factory Location Planning

How exactly a location is selected usually depends on the production strategy as well as the reason for and scope of the planned relocation. Figure 1 shows how external and internal factors influence decisions regarding a factory location. Internal weaknesses can create certain motives for changing a location and perhaps influence strategic goals. The figure shows an example of a company having high production costs leading to the motive of cost reduction that can ultimately conclude in aiming for cost leadership in a market due to new circumstances and possibilities deriving from a new factory location.

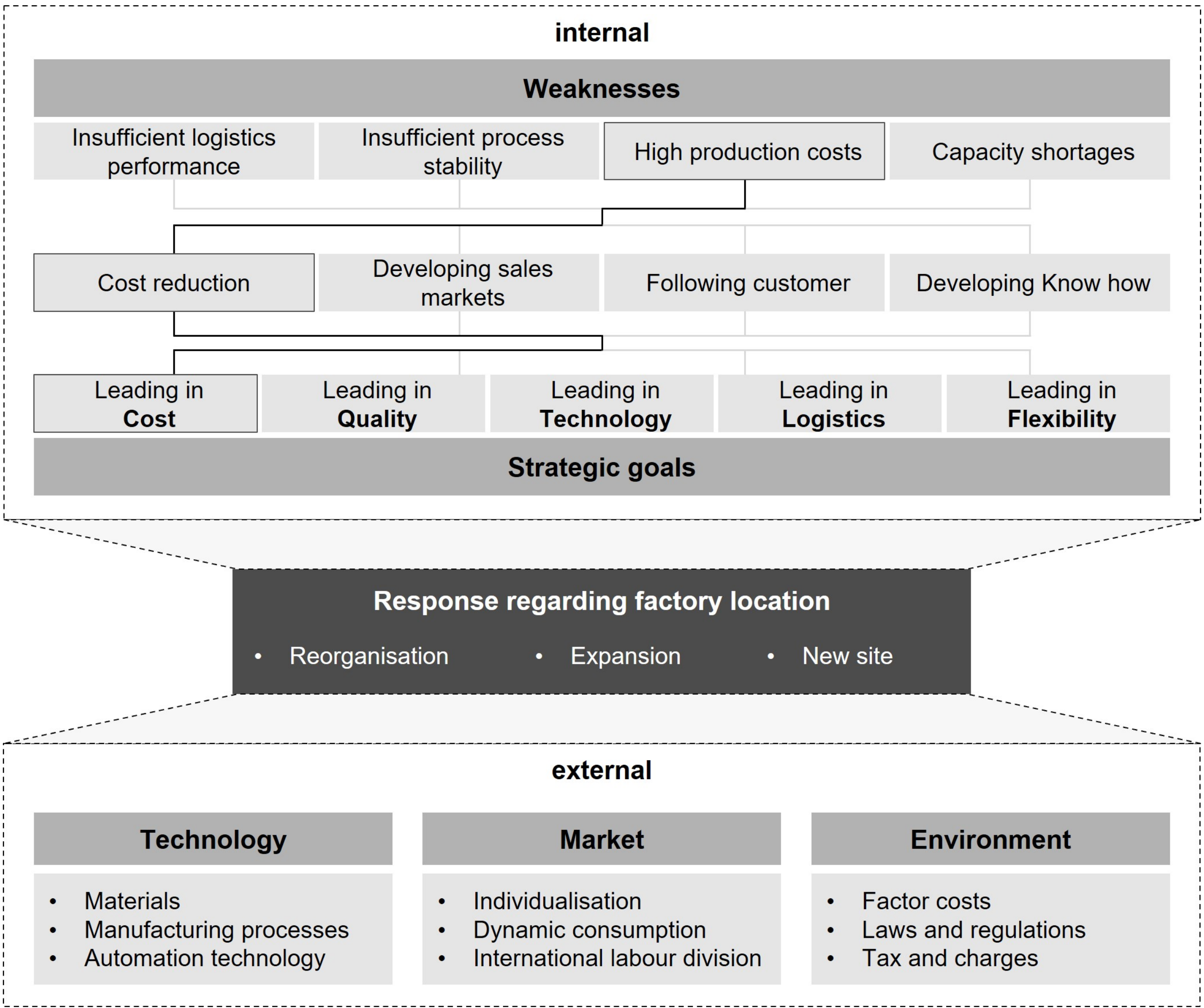

Figure 1: Internal and external influence on location planning

The planning case's complexity depends, particularly on the company environment [4]: A broadly defined product and process scope with comparatively little networking to other locations and suppliers prevails as a framework condition. Such a planning case occurs especially in smaller or medium-sized companies with few locations, customers and suppliers. Location planning can be triggered by an intended cost reduction combined with market development. If companies (often corporate groups) are active in a more significant number of business areas, the complexity of the planning case increases. This is especially true if the target markets and products have little overlap. The most complex initial situation exists for companies with a range of deeply structured series products (e.g. in the automotive industry) that have to take into account a globally distributed production network with different preliminary or intermediate products in their location planning. Of particular importance here are flows of goods that affect not only the company's internal supply chains but also its relationships with suppliers. Due to the diverse interactions, this type of relocation must consider a constant adjustment of the entire production network from the point of view of total costs [1].

The planning initiative for a location usually derives from the company management and can have various causes [8]. The exact procedure for selecting a location is influenced, on the one hand, by the production strategy and, on the other hand, by the cause and the scope of the planned change [1]. A location can have different location qualities depending on the various products, the desired processes and the production requirements of the companies [4]. In all cases, the location selection takes place under consideration of profitable market, production and sales conditions, and optimal location position and conditions in the global economic area [8]. Different location factors taken together define the attractiveness of a location. There are quantitative and qualitative location factors, which should be assessed or forecasted over at least five years, as companies plan to commit to a location in the long term [1]. Analytical decision models can measure quantitative factors, while qualitative ones are estimated subjectively or heuristically [3]. In location planning, a distinction can be made between qualitative and quantitative methods. Quantitative methods are often optimisation models. In continuous models, an infinite number of locations are analysed concerning an optimal objective function value, while discrete models use a finite number. One of the most studied problems in this framework is the minimisation of transport times or costs. A consideration of qualitative location factors characterises the qualitatively based methods.

The increasing complexity of the economy and an increasing focus on the consideration of qualitative "soft" location factors has led to planning approaches using comprehensive location factor catalogues. Soft factors include regional network relationships, cultural proximity or the level of education at a location [3]. In the process, soft factors are transferred into maturity levels to establish comparability. Location factor catalogues, some very long, often mix location factors on a regional and global level, so a clear distinction is often not recognisable. Moreover, the exact contents of the location factors addressed are not specified [9,5,3]. It is important to note that the more complex planning cases occur particularly in large companies, which usually have their own departments or the necessary financial resources to advise on location planning. Smaller companies, on the other hand, often do not have either of these to a sufficient extent but are also less dependent on a complex network structure in their decision-making.

2.2 Current Approaches in Factory Location Planning Using GIS

Various generic process models describe the tasks of corporate location planning. Most of these models focus on global location decisions for implementing internationalisation strategies [10,3,11]. At the Institute for Production Management, Technology and Machine Tools at the Technical University of Darmstadt, a procedure was developed in cooperation with the management consultancy McKinsey & Company. Decisions have to be made on higher decision levels before a location selection can be made on lower decision levels [4]. Using such an approach, location planning can be divided into three decision-making levels [1]. First, a decision for a country is made at the global level. Then, a region within that country is selected at the regional level, and finally, at the local level, an estate decision is made. Before deciding, the company must clearly define the site requirements, as the requirements and the site conditions determine the site's quality [12].

Following the approach of narrowing down a location decision, SCHUH ET AL. have developed a system that accompanies and improves location planning in four steps through the use of GIS. The first step of the approach is analysing the industry with its dynamics and competition. In the second step, regional and location factors are analysed. The consideration of variables at the different geographical hierarchy levels for the analysis is described as case-specific and dependent on data availability. The third step compares potential locations using an objective value function method. The location factors are to be weighted case-specifically, e.g. by pairwise comparison. In the fourth and final step of the method, a sensitivity analysis should ensure robust decision-making. SCHUH ET AL. describe that the weighting of the evaluation dimensions in the described methodology is the only decision to be made subjectively by the management. All other steps in the site selection process are based on quantitative data [2].

2.3 Challenges

The approach of SCHUH ET AL. offers a good starting point for implementing GIS in factory location planning. The assessment dimensions, according to SCHUH ET AL., provide an appropriate framework [2]. However, for targeted application, expert knowledge is necessary both concerning the use of GIS and especially concerning one's own requirements for site planning. For small and medium-sized enterprises, in particular, the dimensions need to be broken down into case-specific criteria to support companies in the decision-making process. Especially small and medium-sized enterprises often lack the technical competence or financial strength to seek third-party support. Past research projects at the Institute of Production Systems and Logistics have shown that small or relatively young companies, in particular, firstly have difficulties translating their corporate goals into location requirements and, secondly, have no experience in translating location requirements into concrete location factors or even indicators. A methodology is therefore needed that considers a "translation" of the company's current requirement profile, its strategic orientation and, to a certain extent, its environment with few input parameters. To be able to carry out a data-based evaluation, however, it is necessary to convert soft factors into measurable criteria especially. An approach to location planning with the help of GIS should, therefore, also support companies in deriving their individual requirements for a location in order to enable a data-based assessment of location in the first place.

3. GIS in Factory Location Planning

This chapter introduces GIS in Factory Planning from a perspective of system theory, described under information processing. After this theoretical introduction, the premises and data requirements are then explained.

3.1 Information Processing

Looking at an application-oriented GIS method for site planning from the perspective of systems theory, an end user should, if possible, only have to come into contact with the functional concept of the system. Figure 2 shows the three concepts of the system theory.

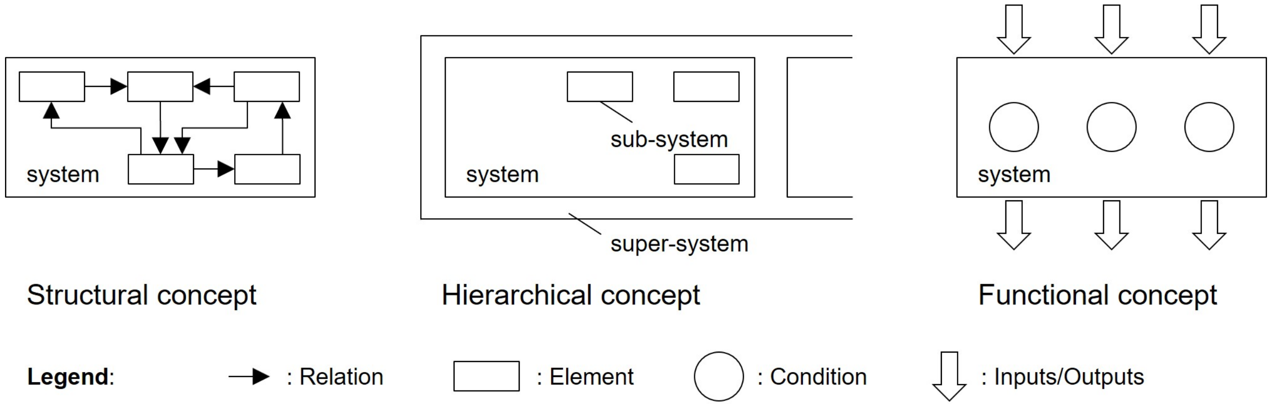

Figure 2: Different concepts of systems theory

According to ROPOHL, a system can be examined from three different perspectives. The functional concept comprises those properties of a system that can be perceived from the outside [13]. The focus of this concept lies on input and output variables (or, in short, inputs and outputs) [14]. Furthermore, states are considered that provide information about the status and situation of the system. This system concept can be explained in the following example. A person without technical expertise expects an output of a technical device (system) when pressing a button (input). The functional concept focuses on the behaviour of the system environment. This concept sets the frame for what the end user should be confronted with if he lacks expert knowledge of the system. The system's interior is not considered in detail [13].

In the structural concept, the system is viewed holistically as a set of elements that are related to each other via relations [13]. A vital point of this approach is not to see a system as the sum of its components but to consider their relationships in equal measure [14]. An element cannot be understood in isolation, but only in the context of the entire system. In addition, the specifics of the elements are taken into account, which determine how well elements can be integrated into a system, determining the 'integral quality' [13].

In the hierarchical concept, the system is divided into smaller systems called subsystems [14]. The totality in the form of the system considered initially is placed into a more comprehensive system which provides a context and constitutes a supersystem. A subsystem provides detailed explanations of the system, while the supersystem shows the meaning of the system [13].

Transferred to an application-oriented methodology for the use of GIS in location planning, this means that a user can generate an output (location recommendations) via the input of clearly defined input parameters (location factors and indicators on the competitive situation and strategic orientation) (functional concept). The locations themselves would be identified based on the different observation levels from global to local (hierarchical concept). A translation of the input factors into a data structure usable by GIS would be generated and analysed by looking at different specifications or levels of maturity (structural concept).

3.2 Premises and data requirements

A manufacturing company's competitiveness and economic success depend significantly on the location decision. Since the location selection is based on the available data when using GIS for location planning, even more attention must be paid to the availability of reliable data when using GIS compared to classic heuristic methods. The information quality of the data used concerning requirements and location profile can thus indirectly influence the success of the company. The quality of data can be ensured by different models, e.g. by considering the 15 dimensions of information quality (IQ) according to WANG ET AL. [15]. These dimensions can help to define requirements for the quality of the data to be used. They are divided into the categories of intrinsic data quality, contextual data quality, representational data quality and accessibility data quality. Some of the dimensions of information quality are interdependent. For example, both the objectivity and credibility (or reputation) of a data set can be violated if it is not fully available. In international location planning, it is crucial to remember that institutions and governments repeatedly withhold or change information [16]. A deeper examination of the data sources is therefore necessary, especially if the user only considers the functional concept of the system.

To make soft location factors measurable, transforming them into data that can be used for GIS is necessary. For this purpose, location factors can be broken down into indicators which, taken together, allow a statement to be made about the characteristics of a location factor, e.g. in the form of a maturity level. To use indicators, a theoretical investigation of the subject area must be carried out, e.g. through literature in the context of the location factors. The interdependencies must then be checked and validated. To be able to guarantee functionality, data sources must be identified, and their contents analysed based on the dimensions of information quality. Data sets that do not meet the 15 IQ criteria are not used for analysis and maturity level determination. In the case of incomplete data sets or a future-oriented assessment of indicators, the approach might be extended by methods such as kriging or the support of artificial intelligence.

The transport infrastructure can be mentioned as an example for translating a location factor into indicators. At the regional level, this factor can be broken down to different modes of transport such as ships, commercial vehicles, aircraft or rail [4]. A consideration of the infrastructure for different means of transport does not appear helpful at the global level. Consequently, the assessment of transport infrastructure should be done on a superordinate level due to the regionally different characteristics. Various indicators can be determined in the evaluation of the transport infrastructure. For example, the "Road Connectivity Index" can describe the road network. This index measures the average speed and straightness of a route, considering the ten or more largest cities, which together contain at least 15% of the country's total population. Greater speed and direct connections between economic centres correspond to a better-developed road network. The existing railway kilometres per 1000 km² can be considered to describe the rail network. A higher value implies a better-developed rail infrastructure. The calculation is made using the existing railway kilometres and the country's total area [17]. Figure 3 shows the visualisation of the road and rail network for India, representing the infrastructure on a course level and information about accidents across the country.

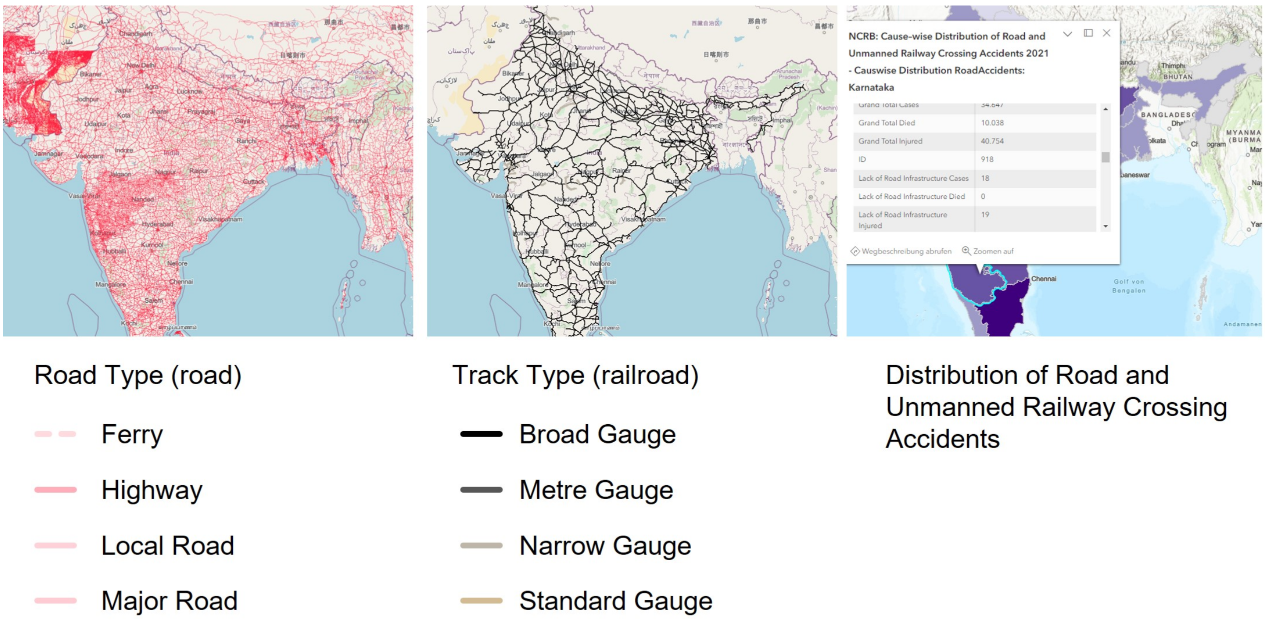

Figure 3: GIS - Visualisation of road and rail network in India

The data about accidents can give a first hint at the reliability of different areas and connecting routes. Countries with sufficient infrastructure in relevant aspects can be further analysed regarding the actual conditions at the regional level. As described above, this analysis should be carried out with only input decisions by the user, making it superfluous for him to understand the hierarchic concept of location planning or the structural concept of influencing indicators on the different levels of observation.

4. Summary and Outlook

This paper showed to what extent GIS can support location planning and why an application-oriented approach is needed, especially for small and medium-sized enterprises. For this purpose, requirements for the structure of such an approach were presented from a system-theoretical point of view, and conditions for transforming input factors into location factors and indicators were discussed. In future studies, it will be necessary to concretise the matters presented and to transfer them into a system for use in an overall design. For the determination of indicators, it can be assumed that there are different demands on the contents of the location factors between the economic sectors. An application-oriented approach to location planning with GIS should therefore enable a sector-specific and company-specific evaluation of the location factors and associated indicators, taking into account appropriate input parameters. These can, in turn, be validated via empirical studies.

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Biography

Justin Hook (*1994) studied industrial engineering with a focus on production technology at Leibniz University Hannover and the University of Southern Denmark. He has worked as a research associate in factory planning at the Institute of Production Systems and Logistics (IFA) at the Leibniz University Hannover since 2020.

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