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Decision-Support for Production Strategies for Developing Economies

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Matthias Brönner

Abstract

The globalization of supply chains and the localization of manufacturing companies' value-added shares in sales markets have increased in recent years. As a result of this development, previously unsaturated markets in the so-called developing economies are coming into focus as production locations. In addition to the companies themselves, countries so far lacking industrial value creation benefit from this opportunity. For successful long-term operations in these new markets, it is necessary to base decisions concerning production sites and organizational structures on prevailing local conditions. Complexity results from the diversity of developing economies and the interconnections between socio-technical production system and surrounding conditions. Furthermore, the production site-specific decisions need to consider corporate objectives, available resources, and sales market conditions.

Consequently, successful production in developing economies requires a customized production strategy and defined content. In addition, decision-making in strategic planning must be supported to account for the complexity of internal and external dependencies of production sites. This dissertation examines the alignment of the prerequisites in developing economies, corporate-strategic orientations, and production strategy parameters. The results add to the existing approaches of production strategy development by offering new insights into region-specific and market-specific adaptability. This extension enables decision-makers to seize opportunities for opening up new markets through local production facilities, and, at the same time, contributes to the sustainable development of previously dependent regions. The central goal is developing an open-source model that allows for production strategic recommendations, aligning country, product, and company-specific conditions.

The method of defining strategic content and supporting decision-making in developing economies consists of four modules. The first module supports the identification of factors that influence a production location in developing economies. These factors are developed based on structured literature research and tested for relevance and practicability in a case study. For practical application of the first module, these influencing factors are available as a questionnaire. The second module supports the development of requirements resulting from prevailing conditions. For this purpose, a method known from requirements engineering is adapted. Subsequently, the parameters of a production strategy for meeting these requirements are derived and validated by experts. In the fourth module, a production strategy recommendation is derived using a knowledge-based simulation model. This recommendation is based on country, company, and product specific input data, drawing from the implemented knowledge base.

The method's application is based on the example of a small-scale automotive manufacturer, a spin-off from the Institute of Automotive Technology, aiming to produce an electric commercial vehicle for rural regions in sub-Saharan Africa. Within this use case, different scenarios for a local production plant are compared, and, based on the simulated results, recommendations for a production site in Ghana are derived.

Contents

List of Abbreviations

CBU	Completely Build Up
CKD	Completely Knocked Down
DMM	Domain Mapping Matrix
DSM	Design Structure Matrix
FBU	Fully Build Up
GDP	Gross Domestic Product
GDPpC	Gross Domestic Product per Capita
GNI	Gross National Income
GNIpC	Gross National Income per Capita
ILO	International Labor Organization
MCDM	Multi-Criteria-Decision-Methods
MNC	Multi National Corporation
OEMs	Original Equipment Manufacturers
SKD	Semi Knocked Down
SME	Small and Medium Enterprises
UN	United Nations
WTO	World Trade Organization

Formula Symbols

Formula Symbols	Unit	Description
x	-	Output quantity
d	-	Production speed
N	-	Number of operating material
t	s	Production time
a_{i}	-	Production coefficient
r_{i}	-	Factor input quantity
q_{i}	€	Factor prize
C_{F}	€	Fixed production costs
C_{f}	€	Jump fix production costs
C_{t}	€	Total production costs
$\mu_A(x)$	-	Membership function of x to the fuzzy set A
L	-	Linguistic variable
σ	-	Standard deviation
P	-	Significance value
g	-	Weighting of a membership function
n	-	Number of participants
EE	-	Elementary effect
μ^*	-	Absolute mean value of the distribution of elementary effects
p	-	Number of levels of the sensitivity analysis

1 Production in Developing Economies

The United Nations (UN) set out the orientation of global sustainable improvement in 17 Sustainable Development Goals in the Agenda 2030 [1, p. 3]. These include the goal of combating poverty in developing economies (Goal 1), to promote sustained economic growth (Goal 8), to reduce inequality within and between countries (Goal 10), to ensure sustainable production patterns (Goal 12), and to establish global partnerships (Goal 17). An essential component of sustainable growth is creating employment opportunities that provide a safe and fair working environment [1, p. 8]. In combination with a product that stimulates demand, an upward spiral is possible [2, p. 48]. With their products, automotive Original Equipment Manufacturers (OEMs) therefore have a great opportunity, provided they aim to create value locally in developing economies [3]. On the other hand, there is the added value of the vehicle itself, which the automotive industry offers with its far-reaching horizontal and vertical value chains [4]. Moreover, the unsaturated vehicle markets of developing economies offer an opportunity for manufacturers [5, p. 6, 6, 7]. The challenges that OEMs face are driven by technology, the market, customers, and society and thus affect the product and its fabrication [8, p. 5] (figure 1.1). The resulting field of tension between these different influences is described as follows.

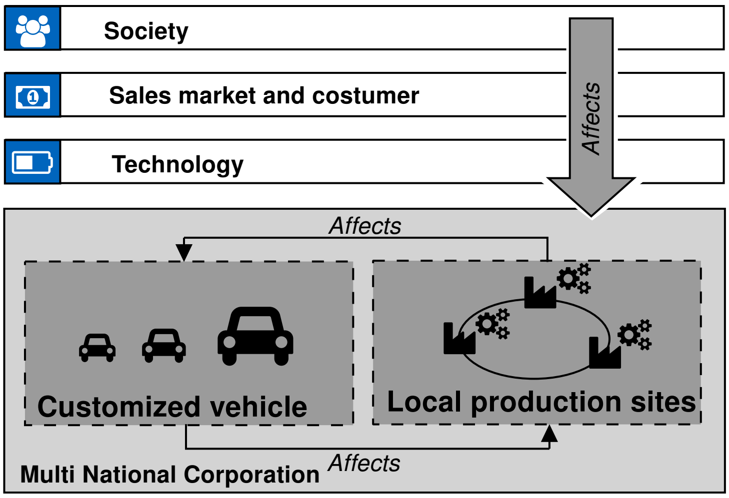


Figure 1.1: Influences from the local society, market and selected technology on customized vehicle development and production in developing economies.

Societies in industrially less developed regions of the world, such as sub-Saharan Africa, could benefit from local vehicle production. Therefore, one political goal of many sub-Saharan countries is to foster a domestic vehicle industry. For example, Nigeria created the New Automotive Industry Development Plan in 2013 and Uganda established a state-supported automobile company (Kiira Motor Corporation), to reduce vehicle import dependency [5, p. 6, p. 11, p. 14], and other developing regions, such as India, liberalized the automotive industry as one of the first sectors [6]. The manufacturers' strategy of only importing vehicles into small markets is countered by tariff and non-tariff trade barriers [5, pp. 12-16]. Furthermore, local content requirements are a common tool to put pressure on manufacturers, thus committing them to relocate their production and supply sources into the target market [9]. The sales market, and thus the local society, in developing economies, especially in Africa, is generally characterized by a growing and predominantly young population, and a rising middle class [10, p. 38, 11]. At the same time, low average living standards [10, p. 4] and poor infrastructure [12, p. 24] are characteristic for these countries, as is higher unemployment [2, p. 29] in comparison to the rest of the world. In sub-Saharan Africa, as an example of a region with a high density of developing economies, a large part of the labor force works in the agricultural sector. This number, however, is constantly decreasing in favor of industry and service sectors [2, p. 39, 5, p. 3], whereby industry employment is defined as an indicator of economic progress [2, p. 40]. Apart from these commonalities, developing economies are different in language and culture and therefore the solutions for these countries cannot be standardized [12, p. 25].

In developing economies, it is striking that the automotive market is dominated by used vehicles [5, p. 5]. Nevertheless, the number of vehicles per inhabitant is low in countries with low Gross Domestic Product (GDP) per Capita (figure 1.2). In 2002, for example, 70 % of globally produced vehicles were sold in high-income countries. This percentage of sales distribution is expected to be reversed by 2023 in favor of low-income countries [13, pp. 42-43]. Abele and Meyer [14, p. 44] see a correlation between rising Gross Domestic Product per Capita (GDPpC) in less developed regions of the world and rising demand for vehicles. A critical GDPpC value in their analysis is 800 $ GDPpC, as the demand for vehicles increases starting from this value. Saturation of vehicle demand can be observed starting from a GDPpC of 20 000 $ [14, p. 44]. Thus, with increasing income in Africa, the demand for vehicles will increase [5, p. 9]. Furthermore, an increasing demand is having an impact on vehicle production sites, as shown by locations in China, India, Malaysia, Indonesia, Argentina or Mexico. These sites produced small series for the local market to begin with, and nowadays produce large series for the global market [5, p. 6]. For customers in India, as an example of a developing economy, demand is mainly focused on products with a good price-performance ratio, and thus it is not enough for OEMs to concentrate on the reduction of vehicle prices. Nevertheless, functionality and economic-friendly standards must be met by the products even for consumers with low purchasing power [12, p. 29, pp. 33-35]. As a consequence, increasing demand for vehicles that meet the customers' requirements in terms of functionality and price can be predicted for developing economies.

Besides digitization, ecological sustainability is one of the current drivers that is transforming technologies in the automotive industry. Battery electric vehicles enable local emission-free mobility, but pose a challenge to established development and manufacturing processes. Nevertheless, this driver opens up an opportunity for OEMs to improve their production location concepts, which have so far concentrated on large-volume production, and to achieve economically small-scale production [18]. This development offers the opportunity to dissolve conventional production structures and move towards decentralized automotive value creation [19]. With the electric vehicle, familiar production structures are reshaped. If this change can be used to create a global repositioning with local production sites and adapted vehicles in unsaturated markets, which is planned consistently from the outset, there is major potential for OEMs, as sustainability both as a product and in value creation can be achieved [20]. In summary, local vehicle production in developing economies must deal with the tension between society, customer and market as well as technological development of the vehicle and its local production [15, pp. 20-22, 21, p. 144].

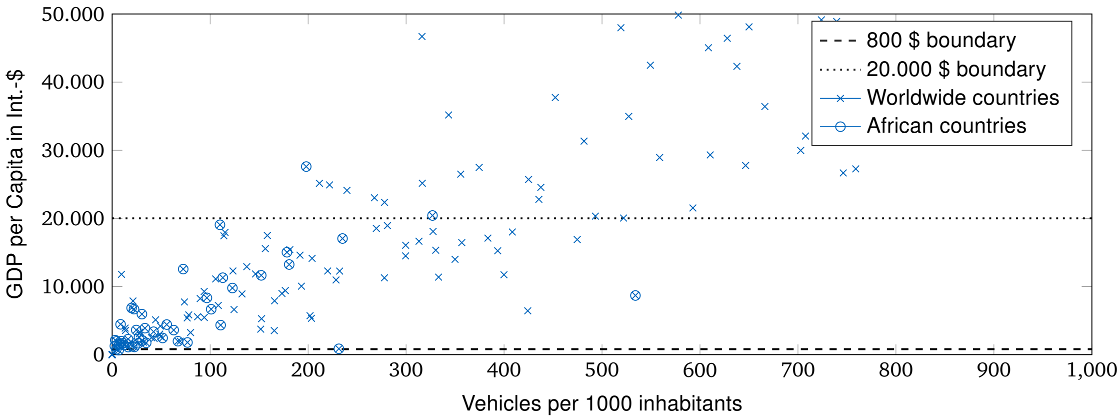


Figure 1.2: Vehicles per 1.000 inhabitants by GDP per Capita (below 50.000 $) and boundaries of the unsaturated markets (800 $ and 20.000 $ GDP per Capita). Data Source [16, 17, p. 46].

1.1 Application Case

This thesis was developed within the aCar mobility project, which aims to support rural regions in developing economies, especially in sub-Saharan Africa. The project objectives are closely linked to the economic development of the region, including sustainable jobs and added value. The conditions prevailing in sub-Saharan Africa are characterized by a lack of infrastructure, which impedes access to educational facilities, medical care, and local markets [22, p. 461, 23, p. 9]. Starkey et al. [23, p. 8, p. 21] highlight a lack of access to transportation as a major obstacle to economic and social development. Therefore, an essential part of improving conditions in rural areas in sub-Saharan Africa is developing an affordable transport system that replaces walking as the predominant means of travel. This is why the aCar has been developed, an electric vehicle designed to meet the basic need for mobility by overcoming existing infrastructural challenges. The vehicle's development process, its application and characteristics are described in Šoltés [24, pp. 28-30].

For the previously defined conditions, an electric drive-train was identified as the most suitable solution. This drive-train topology offers low total cost of ownership, independence from fuel station infrastructure with high fuel costs in rural areas [23, p. 27], and possible decentralized energy supply. Also, the electric drive-train is low-maintenance and robust compared to conventional combustion engine-powered drive-trains, to counter the prevailing difficult supply of spare parts and services. The drive-train and an interior and exterior made of folded aluminum sheets, allow this robust and low-maintenance vehicle to adapt to challenging conditions. The electric drive-train allows for a low target price, which is lower compared to a conventional vehicle with a combustion engine. The 48 V batteries drive two 8 kW motors, that enable all-wheel drive and acceleration up to a maximum speed of about 60 km/h. A battery capacity of 20 kWh is sufficient for a range of 80 km in rural regions. Figure 1.3 shows the aCar from different perspectives to visualize the application of the ladder frame structure and the vehicle body.

Due to its expanding functions, the aCar is designed to be used, for example, for fieldwork, where it can serve as a transport vehicle for goods up to one ton or as an energy source for tools. Another vehicle application may be a mobile water treatment plant that can be operated on the platform by the traction battery. An ambulance module allows the aCar to be used in the field of medical care. Cooling of medicines, the operation of a defibrillator or other electrical devices is possible through the 230 V supply of the loading area. Equipped with seating, the aCar transforms into, for example, a bus to enable access to education by transporting kids to

Figure 1.3: Side view (top left), top view (top right), front view (bottom left) and side view with cargo superstructure (bottom right) of the aCar.

school. Table 1.1 summarizes the specifications of the second aCar prototype.

Table 1.1: Technical data of the aCar prototype.

EG vehicle class	L7e-C
Type of drive	Electric four-wheel drive
Power (constant)	2 x 8 kW
Power (overload)	2 x 12 kW
Maximum speed	60 km/h
Number of gears	i = 1
Range	approx. 80 km
Length	3890 mm
Width	1548 mm
Height	1990 mm
Rear track width	1320 mm
Front track width	1266 mm
Wheelbase	2403 mm
Payload	1000 kg

1.2 Scope and Terminology

This work aims to support strategic decision-making within the scope of local vehicle production in developing economies. For this purpose, the content of the production strategy suitable for this scope must be defined, and the decision-making process within the strategic planning must be supported. Within content development as well as decision-making, complexity arises from unknown local conditions, such as regulations, environmental aspects, employee qualification, market size or suitable investment volume. This thesis introduces a method to incorporate this complexity of local conditions into the definition of strategy content and subsequent decision-making. The developed method supports an entrepreneurial evaluation of production strategies in developing economies, whereby the intended user is a team or person responsible for planning the strategy for local production. The definition of central terms of a production strategy's parameters, local production and developing economies are described hereafter.

Parameters of a production strategy: The parameters of a production strategy are the information necessary to define a production site. The production strategy includes operating, human resources, logistic processes, financing and product development [25, p. 526]. According to Schuh et al. [26], both internal decisions regarding product architecture (e.g., variety) and production structure (e.g., process standardization), as well as external influences such as the product range (e.g., customization) and the supply chain (e.g., delivery performance) are domains of a production site. According to Eversheim et al. [27, p. 128], the goals of strategic production planning are high productivity and flexibility with low inventories and throughput times. Colledani and Tolio [28] highlight the complexity of early production planning phases based on the multitude of alternative decision possibilities. Starting from that early phase, the production strategy development is a sequence of decisions [29, p. 32].

Thus, in this thesis, parameters of a production strategy summarize both, product and production-specific decision options. These parameters depend on the respective surroundings of the production site. Incorporating supply chain and market influence, the boundaries of a production strategy are extended beyond the physical production facility itself. The strategy parameters describe the production resources, logistical systems and product characteristics. The decision on production strategy parameters thus has the goal of ensuring long-term competitiveness and must therefore account for future changes coming from external influences. The parameters of the production strategy are influenced by management decisions on production and long-term decisions on the operational level.

Local production: A local production site is intended to open up new markets and is mainly independently operated from the home factory [14, p. 5], and, furthermore, is commonly used to counteract local content requirements and prohibitive tariffs [30]. Thus, local production usually involves a high financial risk for this location, but simultaneously opens up a major opportunity for companies [14, p. 46]. Commonly, local production is a domestic production to solve the local need of the product [31, p. 13, 32] and is often referred to as local for local production [14, p. 164, 33]. The World Trade Organization (WTO) ascribes the positive effects of increasing local production for the local society to a rising employment level [2, p. 48], whereby a local production site can be owned domestically, internationally or jointly. In addition to this, a local production site in a developing economy is defined in this thesis as a domestic production location, where products are predominantly produced for the local market.

Developing economies: Common terms to describe countries with a development deficit compared to European countries are low-income countries, developing countries, least developed countries, emerging markets, global south and developing economies. The distinction made between developing countries and developed countries is commonly based on the degree of industrialization. This definition, however, is not generally valid, due to highly differentiated individual markets, and thus there is no unified international definition of the term [34]. According to the German Federal Ministry for Economic Cooperation and Development, the common characteristics of countries generally referred to as developing countries are low Gross National Income (GNI) per Capita, generally poor provision of basic needs to the population, inadequate health care, difficult access to education, and high unemployment [35].

The World Bank [36] offers another approach to the classification of countries following purely economic aspects: low-income countries, lower-middle-income countries, upper-middle-income countries and high-income countries. The World Bank's [36] classification in 2020 is based on the following Gross National Income per Capita (GNIpC):

- Low-income countries are countries with a GNIpC of less than 1 025 US-$
- Lower-middle-income countries are countries with a GNIpC of at least 1 026 US-$ and at most 3 995 US-$.
- Upper-middle-income countries are countries with a GNIpC of at least 3 996 US-$ and at most 12 275 US-$
- High-income countries are countries with a GNIpC of at least 12 276 US-$

The UN follows the World Bank's definition of the so-called least developed countries, while additionally considering the Human Assets Index and the Economic Vulnerability Index. The Human Assets Index takes into account the indicators nutrition, health, education and adult literacy rate. The Economic Vulnerability Index considers population size, remoteness, merchandise export concentration, the share of agriculture, forestry and fisheries, the share of population in low elevated coastal zones, instability of exports of goods and services, victims of natural disaster, as well as instability of agricultural production [37]. Currently, the list of least developed countries includes 33 countries from Africa, for example Uganda [38].

The emerging markets, as described by Khanna and Papula [10, pp. 3-5], are characterized only by economical measures. They define these markets as transaction areas where manufacturers and buyers cannot easily or efficiently come together. Although this may apply to any economic area, it is significantly more common in developing countries. These emerging markets are characterized by poverty, meaning low to middle income, low average living standards, and no industrialization. Furthermore, low capitalization in relation to the GDP, low levels of stock appreciation, and low maturity rate occur in these markets. Yet these emerging markets are characterized by liberal economic policies, openness to foreign investment, and thus great growth potential [10, pp. 3-5].

Consequently, each of the established terms comes with its own difficulties of definition. In this thesis, the term developing economies is used, which is also preferred by the UN to address the world's economic situation and prospects [39, p. 166]. The term developing economies covers the geographical regions of Africa, East Asia, South Asia, Western Asia, and Latin America as well as the Caribbean [39, p. 2]. In the scope of this term, countries are classified according to basic economic conditions into the categories developed economies, economies in transition, and developing economies.

1.3 Structure

Figure 1.4 illustrates the structure of this thesis and shows that the introductory part consists of the description of the application case, the scope, and terminology used. The second section describes the state of the art emphasizing production and corresponding strategies. This explanation of production strategies is divided into the content of a production strategy, approaches toward production strategy development, and application with the focus on the automotive industry and developing economies. In the literature review, existing approaches are evaluated for their suitability to the scope of this thesis, and subsequently the research question is derived.

To answer the research question, the method for decision-support for production in developing economies is introduced in the third section, whereby, the research process for the conception of the method, as well as general requirements and limitations of the method, are presented first. The method introduced consists of four modules, which support to collect the respective influential factors for the company in the target country (*Module 1*), to develop the appropriate requirements (*Module 2*) and to define the respective production strategic parameters (*Module 3*). Afterwards, within *Module 4*, these parameters are implemented in a simulation model, which allows for a simulation of scenarios. Based on *Module 4*, a recommendation for a strategic site concept can be derived. The basic simulation model is available for users of the method and has been validated within the development process.

The method introduced is applied in the results section, using as an example the aCar project. Different scenarios, for example regarding increasing production volume or changing customer requirements, are compared. Based on this, the simulation results are transferred into recommendations for a future aCar production site in Ghana.

Afterwards, the method and simulation model are evaluated, and limitations as well as added value are highlighted. Furthermore, the fifth section includes the discussion of the managerial and scientific implications.

This thesis concludes with a brief summary of the content discussed and the method developed in section six. Additionally, an outlook on local small-scale automotive production in developing economies is given.

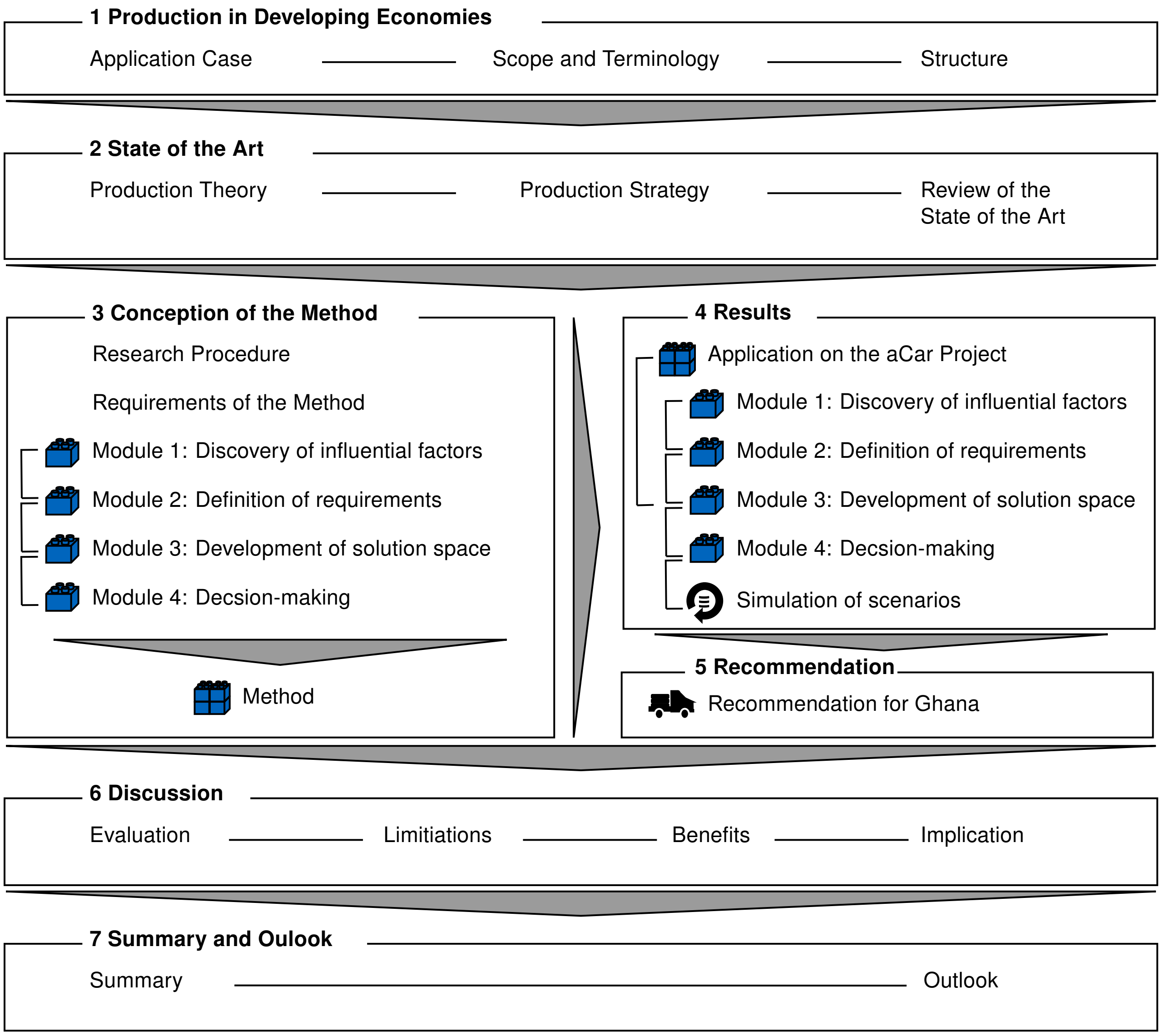


Figure 1.4: Structure of this thesis with the focus on the conception and application of the method.

2 State of the Art

The globalization of value chains is not a new corporate strategic trend, but the degree of globalization of companies is increasing. This trend of globalization is primarily driven by the sales potential of new markets [14, p. 4, 33]. Especially increasing market liberalization [14, p. 9] and factors such as access to resources and digitization [33, p. 2] enhance the globalization of companies. For companies, entering new markets is easier when they establish a local production site [14, p. 16]. Lanza et al. [33] name this trend of increasing globalization of companies and thereby the localization of production "glocal production". When entering a new market, initial strategic planning of the production is a crucial task, as production makes up the largest part of product costs [40, p. 6]. Production costs are divided into manufacturing and assembly costs. These costs are largely influenced by total production time, of which up to 70 % is accounted for by assembly time, depending on the product [41, p. 26]. Furthermore, to allow for a competitive edge, strategic production planning must interact with other corporate activities [29, pp. 197-199]. These are located both upstream of the value chain (e.g., supply logistics) and downstream of the value chain (e.g., marketing and sales). Hence, the value chain summarizes company activities that contribute to product manufacturing [42, p. 65]. Primary activities of the value chain are activities that directly facilitate product manufacturing. Those that support them, such as human resource management, are considered support activities [42, pp. 69-73]. Hereby production is the part of the value chain, where the input is transformed into the product form [42, p. 69]. Figure 2.1 shows the value chain and illustrates, for example, the overarching influence technology development has on primary activities. Thus, product and production technologies need to match [29, p. 198]. Especially in developing economies, this match of technologies is of particular importance, because, in addition to creating value for companies, an added value for the local society must be created to ensure the long-term success of the company [43]. In conclusion, to ensure the long-term success of a production site, the latter must be shaped with foresight by the production strategy [29, p. 25].

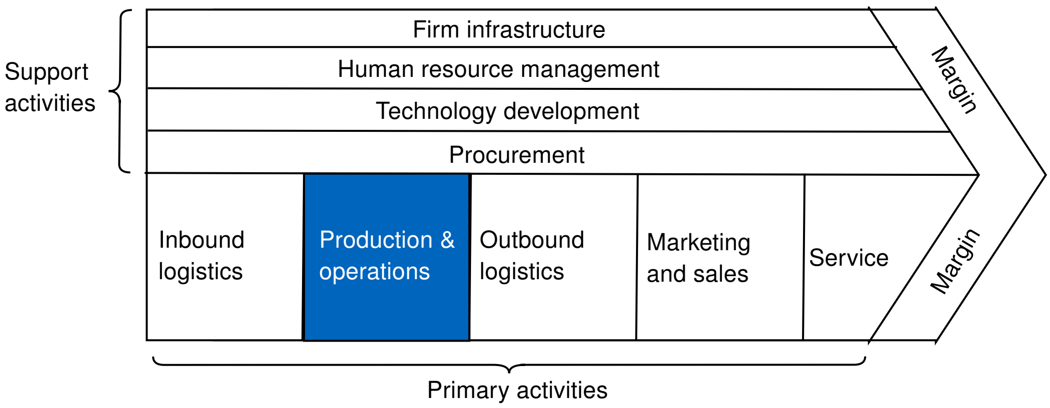


Figure 2.1: Porter's value chain model [42, p. 64]. Classification of the tasks of manufacturing companies into primary activities and support activities to achieve product creation and product margin.

After a summary of the theoretical production fundamentals, the classification of production strategies and their content is described. Subsequently, the development of production strategies is presented as a decision problem, and methods of decision-making are brought forward. The influence that surrounding conditions have on the strategy, strategy application in the automotive industry, and production strategy focusing on developing economies are presented. Finally, after a critical evaluation of the current literature, the research question of this thesis is outlined.

2.1 Production Theory

Production is a complex and multiform system that requires a certain level of abstraction to describe [44, p. 1]. It depicts the systematic transformation process of value creation initiated and directed by a human operator [44, p. 7]. Production process can be described as input, throughput and output processes, that transform input variables into yields [8, p. 12, 44, p. 11]. In production theory, manufacturing companies are understood as systems that can be divided into subsystems [27, p. 9]. These subsystems contain all value-creating and productive resources [44, p. 11]. As a system, production interacts with external economic, social, and environmental processes [44, p. 3]. Apart from this, companies must integrate the internal effects of interaction between product, technology, employees, operating resources, organization, and finances when they design a system [8, pp. 18-19], since this integration allows for a flexible production [40, p. 99].

From an economic perspective, production includes functions and activities of goods production, including technological, economic, and organizational measures. To fulfill its production task, a company utilizes production factors such as labor, operating material, and resources [45, p. 3]. Production processes in production theory are therefore defined as the transformation of production factors to produce a defined quantity of goods [46, p. 20]. According to Gutenberg [47, p. 199], the output quantity x is the product of production speed d, the amount of operating resources N, and production time t (equation 2.1).

$$d \cdot N \cdot t = x \tag{2.1}$$

If sales numbers increase, and the planned output quantity x has to be varied, the variables of the decision are therefore production time t, number of plants N, and production speed d [46, p. 20, 48, p. 89]. Adjustments to these variables are based on the change of production factors i. The production factors i have a quantity r_i for each of the units x to be produced [46, p. 22]. This dependency is visualized in figure 2.2.

These factor input quantities, also known as consumption quantities [47, p. 225], are determined by the factor input function, which is the product of the consumption function a_i and the realized output quantity (equation 2.2). a_i is hereby defined as a plant's performance and depends on production speed d [46, p. 19]. With this dependency, Gutenberg [47, pp. 220-221] assumes that an increase in factor i also leads to an increase in yield x.

$$r_i = a_i(d) \cdot x = a_i(d) \cdot d \cdot N \cdot t; \forall i \in [1, n] \tag{2.2}$$

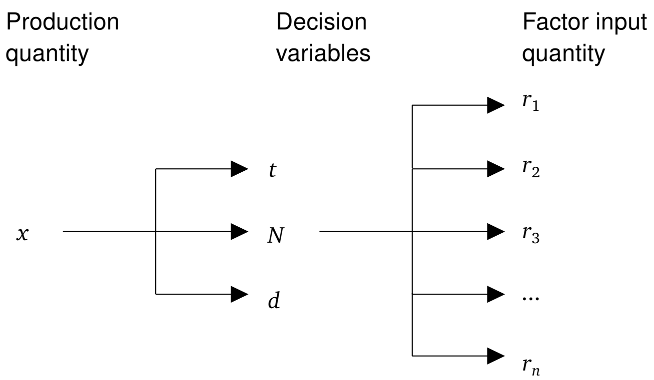


Figure 2.2: Connecting output quantity, decision variables and factor input quantities [46, p. 20].

The production coefficients relate input to output, such as the employee hours of production per vehicle, are discussed within the framework of the limitation of the output quantity [47, p. 208]. Within this, linear limitation production structures, in which the production coefficients are identical for all output quantities, must be distinguished from non-linear limitation structures. For the latter, a variation of the output rate changes at least one of the production coefficients [46, p. 43].

To determine the total costs C_t of an operational service provision per period, the production factors are multiplied by their respective costs q_i [48, p. 78]. Besides variable costs, which depend on output quantity, fixed costs have to be calculated. These are independent of output quantity. Thus, the share of fixed costs C_F is added to the cost function [48, p. 85]. Also, costs that increase in a fixed jump rate C_f must be added separately [46, p. 22]. Thus, the costs of a production place are determined as in equation 2.3.

$$C_t = \sum_{i=1}^{n} r_i \cdot q_i + N \cdot C_f + C_F \tag{2.3}$$

Analyzing production costs in Africa, the study of Gelb et al. [11] concludes that labor costs are not generally low. They show that, in Kenya, Tanzania, or Senegal, labor costs in the industry compared to domestic purchasing power—measured in labor cost per worker relative to GDP per Capita—are expensive compared to countries in the same income class, such as Bangladesh. It also becomes evident that African countries should be regarded as heterogeneous when it comes to labor costs. For example, Ethiopia has low labor costs and a low-income level and thus a better cost-competitiveness compared to other African countries [11]. Comparing further costs, the corporate tax rates stick out. In countries such as Kenya (58 %), Uganda (60 %) or Senegal (51 %) they are higher than China (37 %) or India (35 %) [49, pp. 24-27]. Further studies show that indirect costs in African countries are comparatively high. In 2006, for example, the indirect costs in Kenya were 20.1 % of sales relative to 6.2 % in China [49, p. 25, 50]. This also applies to other, mainly poor African countries [51, p. 25]. One reason for this can be found in high energy costs [49, p. 24, 50, 51], but also the cost of transportation, land prices, and security issues increase indirect costs [49, p. 24, 51]. It can be concluded that indirect costs are essentially dependent on regional factors and thus directly affect the manufacturing industry [51]. This economic production perspective highlights how decisions regarding production factors on the one hand, and the regional influence on production costs, on the other hand, are relevant. Decisions on the design of the production system must, therefore, be considered at an early stage of planning to ensure the adequate performance of the planned local operation [52, p. 32].

2.2 Production Strategy

Hayes and Wheelright [29, p. 32] describe strategic planning in production as a "pattern of structural and infrastructural decisions that constitute the manufacturing strategy". According to Porter [53], the integration of all relevant stakeholders along the value chain is essential for a sustainable competitive advantage to align value-added activities on this basis. This section presents the basics for developing such a pattern of decisions. First, the production strategy is integrated into the overall corporate strategy. Subsequently, content and goals are described to present their influencing variables. Approaches for the development, evaluation, and selection of a strategy are depicted afterwards. Finally, research on production strategies in developing countries and the automotive industry relevant to the focus of the thesis is discussed.

Nowadays, there exists no consistent definition in the literature for the content of a production strategy, according to Akca and Ilas [54, p. 4]. But the beginnings of production strategy research are known since Skinner [55] is the first to mention manufacturing as a missing part in corporate strategy and describes a concept to combine corporate strategy and production operation. From this, Löffer and Westkämper [56, p. 35] deduce that production strategy and the entire company must aim at securing future value creation. Slack et al. [57, p. 63] use the term "operations" to describe the resources that create a product. For them, "operations strategy concerns the pattern of strategic decisions and actions which set the role, objectives, and activities of the operation". Thereby, operations strategy involves the translation of market requirements into decisions and exploiting corporate capabilities of operations resources in specific markets [57, p. 63]. Hill and Hill [58, p. 138] understand this part of corporate planning as a manufacturing operations strategy, whereby operations refer to the business aspects of production. Therefore, the terms production strategy and operations strategy are used synonymously in this thesis in consistency with Díaz–Garrido and Luz Martín–Peña [59].

Research and implementation of strategic aspects of production can be divided into two categories. First, referring to the strategy's content and, second, referring to the development process of the strategy. The content is the specific set of decisions to be made, and the process is the method that guides the decision-making process [57, p. 63]. The following chapter is structured according to this division into production strategy content and development.

2.2.1 Content of a Production Strategy

The following section presents the content of a production strategy. For this purpose, the production strategy is first classified into the strategic framework of companies, and then the strategic priorities of companies are presented. Based on these priorities, companies make strategic decisions. The following subsection, therefore, describes the categories of strategic decisions in production.

Classification of Strategies

In a company, there are three levels of strategies: corporate, business unit, and functional level. As one of several functional strategies, the production strategy is subordinate to the corporate strategy and business unit strategy [29, p. 28, 58, p. 24, 60, p. 65, 61, p. 292]. These strategies are highly dependent, despite their hierarchical classification [58, p. 17]. The corporate strategy is the overarching mission of a company and determines its orientation and priorities in a market segment [58, p. 24]. The business unit strategy is subordinate to the corporate strategy, with the main task being the selection of markets. After selection, the respective business unit operates within this market [58, p. 24]. The corporate and business strategy's goal is to provide the necessary capabilities to operate competitively in the respective market [58, p. 24]. Defining the long-term direction of operations within the market is the goal of the subordinate functional strategies [57, pp. 64-65]. As one of the functional strategies, the production strategy has an outstanding role, as it determines the value-adding part of a producing company [62]. Figure 2.1 visualizes this dependency of strategies and planning elements.

Table 2.1: Classification of strategy levels and planning elements according to Kreikebaum [60, p. 65].

		Strategy level		
		Corporate	Business unit	Functional
Planning elements	Intention Strategy Measures Objectives			

Strategy development is a crucial planning task [60, p. 65]. Commonly, strategies are formulated based on intentions and lead to objectives and measures [56, p. 33, 60, p. 65]. This dependency on intentions demonstrates that a specific objective cannot stand at the beginning of strategy development, with respect to the dynamics and complexity of internal and external influences, such as surrounding conditions. The effects on target values should not be recorded and evaluated at the beginning of the planning process. Growing competitive pressure and technological change further contribute to increased complexity [60, p. 63]. Consequently, a strategy evolves through iterations over time. To support strategic planning, the comparison of scenarios serves to incorporate the effects of dependencies into the planning process [14, p. 75, 21, pp. 46-49].

Besides lacking a standard definition of production strategy [54, p. 4], its content can be defined, as is commonly done, to "align [manufacturing] resources through a cohesive strategy" [29, p. 35]. Thus, a production strategy contains both strategic and operational elements [60, p. 72, 63, p. 15, 64]. Various authors, like Hayes and Wheelright [29, pp. 36-37] as well as Hill and Hill [58, pp. 162-163], divide the strategy content into decision categories and subordinate parameters of the strategy. Figure 2.3 visualizes the production strategy structure described by Swamidass and Newell [64].

Strategy Priorities

According to Slack [57, p. 36], a production strategy follows three goals. First, to put the business strategy into practice. This means designing of all processes that serve to implement the overarching strategy. Production strategy's second aim is supporting the business strategy. After the initial implementation, this support means enabling ongoing improvement and revision of strategic goals. The final goal of the operations strategy is driving the strategy. This means ensuring a long-term competitive advantage.

A production strategy's success is measured using the following strategic priorities [57, p. 39, 58, pp. 123-125, 65]:

1. *Quality*: The grade of fulfillment of the consumer's expectations regarding the

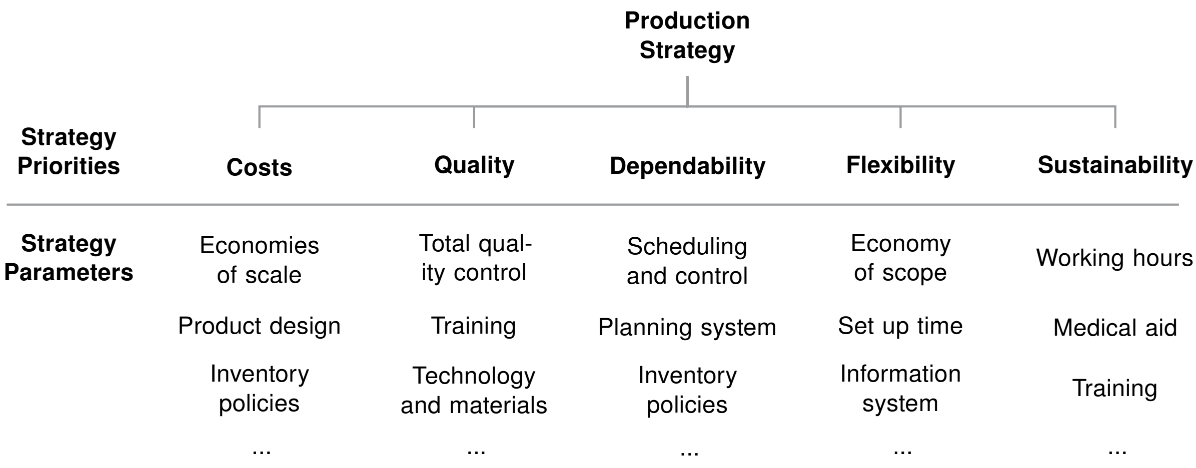


Figure 2.3: The priorities of a production strategy and its parameters adapted from Swamidass and Newell [64].

process or product.

2. *Speed*: The period of time between which the product or service is requested and delivered.
3. *Dependability*: The reliability of meeting promised delivery or execution dates.
4. *Flexibility*: The degree to which a process can be adapted in terms of quality, quantity or product mix.
5. *Cost*: Possibility to keep the costs of value creation low.

These performance targets intend to ensure a competitive advantage [29, p. 35, 58, p. 31]. In addition, these targets help minimize waste of resources [57, p. 51, p. 470]. In this context, the manufacturing strategy plays a proactive role in supporting the company's competitive strategy [29, p. 41, 58, p. 31].

Decision Categories

The relevant literature offers various definitions for decision categories of a production strategy. Four common approaches are presented subsequently.

- Hayes and Wheelright [29, p. 31] define a total of eight categories. From capacity, which defines amount, timing and type, to facilities, which define size, location and specialization, to technology, which includes equipment, automation and linkages. Additional categories are vertical integration, workforce, quality, production and material control, and organization.
- In contrast, Hill and Hill [58, p. 163] name the categories product and market, operations, investment and cost, and infrastructure as decision categories of an operations strategy.
- Skinner's [55] publication deals with plant and equipment, production planning and control, laboratory and staffing, product design, and organization and management as overarching categories.
- Finally, Fine and Hax [66] propose nine categories that are part of the manufactur-

ing strategy. For example, human resources, vendor relations, vertical integration and manufacturing infrastructure are part of strategic operations management.

Within these decision categories, the respective strategy parameters have to be decided upon. For example, for the category technology, the parameters equipment, automation, and linkage require decision [29, pp. 36-37]. Table 2.2 summarizes the decision categories and parameters of the authors presented above. It becomes clear that the authors differ both in their choice of decision categories and respective parameters.

Table 2.2: Comparison of decision categories and parameters of a production strategy [29, pp. 36-37, 55, 58, pp. 162-163, 66]. The categories of the authors differ according to the focus of their development approaches.

	Decision category	Production strategy parameter
[29, pp. 36-37]	Capacity	Amount, timing, type
	Facilities	Size, location, specialization
	Technology	Equipment, automation, linkages
	Vertical Integration	Direction, extent, balance
	Workforce	Skill level, wage policies, employment security
	Quality	Defect prevention, monitoring, intervention
	Production Planning / Material Control	Sourcing policies, centralization, decision rules
	Organization	Structure, control / reward systems, role of staff groups
[58, pp. 162-163]	Products and Markets	Type of product, product range, customer order size, level of product change required, rate of new product introductions
	Operations	Nature of the process, process flexibility, operations volume, dominant utilization, changes in capacity, key operation task
	Investment and Cost	Level of capital investment, level of inventory, percentage of total costs
	Infrastructure	Appropriate organizational, most important operations management perspective, level of specialist support to operation
[55]	Plant and Equipment	Span of processes, plant size, plant location, investment decisions, choice of equipment, kind of tooling
	Production Planning and Control	Frequency of inventory taking, inventory size, degree of inventory control, what to control, quality control, live of standards
	Labor and Staffing	Job specialization, supervision, wage system, industrial engineers
	Product Design / Engineering	Size of product line, design stability, technological risk, engineering, use of manufacturing engineering
	Organization and Management	Kind of organization, executive use of time, degree of risk assumed, use of staff, executive style
[66]	Human resources	Job design, hiring or screening policies, motivation and stimulation of employees
	Vendor Relations	Buyer-supplier relation, supplier training
	Vertical Integration	Supplier, make-or-buy, integration risk, product quality
	Manufacturing Infrastructure	Organizational infrastructure, materials management, production planning, scheduling, control
	Processes / Technologies	Process type, production cost
	Scope / New Products	Scope and range of new products, new product introduction, speed of product introduction
	Quality	Quality control, allocation of responsibility for quality, quality improvements, quality assurance
	Capacity	Plant, equipment, human capital, management
	Facilities	Kind of facilities, economies of scale, product or location focus, size, location, capabilities

Furthermore, these decision categories can be divided by structural and infrastructural content [58, 67, 68]. The respective production strategy parameters must be assigned to the structural or infrastructural decisions (figure 2.4).

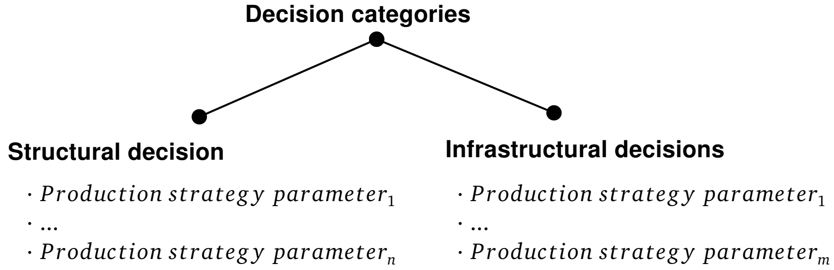


Figure 2.4: Division into structural and infrastructural content in production strategies.

Decisions on structures mean defining the form and shape of an operation, whereby infrastructural decisions influence the systems and procedures determining the operation in practice [57, p. 80]. The structural content of a production strategy is based on strategic priorities like cost, quality, sustainability, and operations planning. Structural content, for example, entails manufacturing controls, procedures, systems and technology [57, p. 80, 58, p. 17, 68] and the product life-cycle [67]. Within decisions on the structural content, existing processes and infrastructure are considered as boundary conditions. Therefore, the content is oriented towards the production's performance targets, based on which decisions must be made.

In addition to the planning of the structural part, the choice of infrastructural content of a production strategy is crucial. The choice of production concept, for example, is such an infrastructural decision [54, p. 9], whereby the production concept is a series of organizational processes, methods, and the production's philosophy. As an example, Lean Production, Total Quality Management, and World Class Manufacturing are components of a production strategy. For the implementation of these production concepts, production instruments and methods such as Just-in-Time, Kanban or Kaizen/Continuous Improvement are available [54, p. 7, 58, p. 77]. Furthermore, decisions regarding workforce and management are classified as infrastructural production strategy parameters [67]. This includes decisions on the organizational culture. Infrastructural parameters are crucial for production strategy, as they are difficult for competitors to imitate [68]. The decision categories used in this thesis include both structural and infrastructural content. Figure 2.5 offers a visualization.

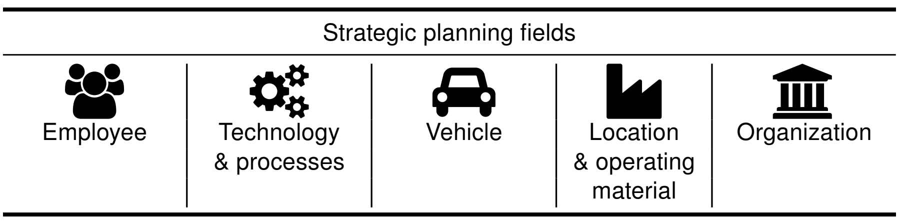


Figure 2.5: Planning fields of a production strategy.

2.2.2 Development of a Production Strategy

With the content of a production strategy defined, methods for developing a production strategy are now presented. Based on Abele and Reinhart [69, p. 124], Michaeli [63, p. 30] divides the production strategy development methods into structure-oriented and process-oriented contributions. Structure-oriented contributions focus on the description of a production strategy, while process-oriented contributions emphasize the strategy development process [63, p. 17].

Structure-Oriented Methods

Structure-oriented approaches divide the production by its parts. In the following two exemplary approaches of structure-oriented production strategy planning are considered.

Skinner [55] proposes to work with the following elements: plant and equipment, production planning and control, labor and staffing, product design and engineering as well as organization and management. Within these elements, a decision must be made based on a selection among different alternatives. Skinner [55] emphasizes the influence of cost, time, quality, and technological limitations in prioritizing alternatives. In this approach, management decisions are based primarily on the analysis of the competitive situation, which is related to the company inventory; that is, the internally available resources and capabilities. The goal is to achieve consumer-oriented manufacturing of products.

Slack et al. [70, p. 30] divide production strategy development into the components process design, layout and flow, process technology, and people in operations. They also specify the tasks: planning and control, capacity management, supply chain management, inventory management and planning and control systems, materials requirement planning, and lean operations [70, p. 30]. The purpose of these tasks is to design processes that can create products and services efficiently [70, p. 183]. The production strategy includes priority decisions regarding quality, speed, dependability, flexibility, cost, and sustainability of the processes. Thus, lean processes, that avoid waste, reduce in-process inventory, and guarantee short waiting times for customers are made possible. Processes should be standardized as far as possible and react sensitively to environmental influences to achieve these goals [70, pp. 185-186]. Processes are mainly influenced by the number and variety of the manufactured products [70, p. 189]. The planning of layout and flow includes the operating resources, their positioning, and the allocation of tasks to these resources. The objectives of this selection are, for example, layout security, delay minimization, reduction of work-in-progress, but also the sensitive use of available space and minimization of necessary investment capital [70, pp. 217-219]. Planning the layout significantly influences the workforce, since temperature, volume, and ergonomics are determined by the workplace [70, p. 231]. Process technology hereby is "the machines, equipment, and devices that create and/or deliver products and services" [70, p. 247]. The process technology selection thus includes manufacturing and information technology [70, p. 249]. Within this selection, advantages, maturity, duration, and implementation of the technology are evaluated [70, p. 271]. The element people in operations focuses on the working environment' design, allocation of working hours, creation of group and individual jobs, and must be consistent with the human resource strategy [70, p. 277]. Job design, for example, defines the division of labor, ergonomics, teamwork, work behavior, and flexibility at work [70, p. 286]. This significantly determines an organization's work atmosphere [70, p. 277]. When the basic elements of operation have been designed, the planning tasks are necessary to control the day-to-day business of resource transformation. This ensures that appropriate products and services are delivered to the market [70, p. 315].

These two examples indicate that structure-oriented methods base their strategies on the decision categories and the subordinate decision parameters. For instance, Skinner [55] offers a flow chart to support decision-making within decision categories. The problem with these approaches arises from their limited comparability since, as shown in section 2.2.1, the authors define their decision categories individually. Decision processes described within the methods are therefore always linked to the individually defined decision categories.

Process-Oriented Methods

In contrast to structure-oriented approaches, process-oriented contributions attempt to focus on the strategy development process [63, p. 36]. In this respect, the requirement of Hayes and Wheelright [29, p. 42] that a strategy development process "should be an ongoing interactive process, with inputs and perspectives contributed by all functions" [29, p. 42], is taken into account.

Hill and Hill [58, p. 114] confirm this requirement by stating that "strategy development is an iterative process". Their procedure integrates production strategy development into corporate strategy and provides a methodology for selecting the elements of a production strategy, which is presented here as an example (table 2.3) [58, pp. 40-41]. This strategy development procedure follows the top-down approach, beginning with a marketing strategy that is defined based on the company's objectives. For their marketing strategy, companies use market analyses with the definition of future product groups in these markets [58, p. 118]. With this basis, companies can define product specifics such as price, design, and quality [58, pp. 122-123]. Among other things, these are used as input for operations strategy development, which is divided into process choice and infrastructure development [58, p. 41]. The choice of the process determines the factors that serve value creation. Thus, product type, complexity and volume are therefore essential factors in this process phase. Specifying this information, the manufacturing process type can be selected from five existing types (project, jobbing, batch, line, and continuous processing) [58, p. 138]. Furthermore, logistics and inventory are determined, and make-or-buy decisions are made. Following this decision, the process capacity is determined and subsequently the design and management of the supply chain [58, p. 242]. Finally, the infrastructure is projected. The decision on infrastructure contains a series of complex interacting elements, which have to be coordinated to satisfy the market. Operations planning and control systems, work structure, and the organization of manufacturing are examples of coordinated elements of production [58, p. 302]. Importantly, Hill and Hill [58, p. 39, p. 114] point out that manufacturing strategies are characterized by complex interdependencies within and across decision-making levels.

Table 2.3: Decision pattern starting with corporate objectives and ending with the production strategy according to Hill and Hill [58, pp. 40-41].

			Production strategy	
Corporate objectives	**Marketing strategy**	**Qualification and orders**	**Process choice**	**Infrastructure**
Growth	Product markets and segments	Product (price, design, quality)	Choice of alternative processes	Function support
Survival	Product (range, mix, volume)	Delivery (speed and reliability)	Trade-offs within process choice	Operations planning and control systems
Profit	Degree of standardization	Demand increases	Role of inventory	Quality assurance and control
Return on Invest	Innovation level	Design	Make or buy	Operations systems engineering
Other financial measures	Leader vs. follower strategy	Brand name	Capacity (size, timing, location)	Clerical procedures
		Technical support		Compensation agreements
		After-sales support		Work structuring Organization

Mefford and Bruun [71] also propose an approach that develops decisions within a five-step process that should be applicable in every country (table 2.4). First, they choose the strategic orientation of the plant based on its integration into the global network and its concentration on the domestic market. After this choice, processes and their properties are selected. The product design is determined at this stage due to the different processes required by a complex customized product compared to a standardized product. Furthermore, they propose to decide on a production system on this basis. This can vary between a fixed-line design and a variable flow, supporting standardized or individual processes. Subsequently, operational methods are defined, such as production control, inventory, quality, suppliers, and job design. These in turn provide input for human resource decision-making. At this point in strategic planning, employee integration, work team planning, training, and hierarchy are defined. Human resource planning needs to consider the work tasks, which can either be simple and repetitive or multi-skilled tasks [71].

Table 2.4: Decision pattern starting with the plant strategy and ending with the human resource strategy according to Mefford and Bruun [71].

Plant strategy	**Process**	**Production system**	**Operational methods**	**Human resource**
Network coordination	Product choice	Product choice	Production control Inventory Quality Suppliers Job design	Employee participation Work teams Training Hierarchy

More generic methods are proposed by Dombrowski [72] and Michaeli [63, p. 16]. Dombrowski [72] defines a manufacturing strategy as a six step process, summarized in table 2.5. Michaeli [63, p. 16] adapts these phases for his production strategy development process, consisting of four phases (table 2.6).

Table 2.5: Decision pattern starting with the external and internal analysis and implementation and review of the production strategy according to Dombrowski et al. [72].

External and internal analysis	Analysis of competitive position	Coordination with other functional strategies and the corporate strategy	Determination of the strategic objectives	Definition of the strategy	Implementation and review

Table 2.6: Decision pattern starting with the requirements definition and ending with the implementation of the production strategy according to Michaeli [63, p. 16].

Requirements definition	Internal and external analysis	Evaluation and selection	Implementation

Decision Trade-Offs

In summary, within a framework to develop a production strategy, decisions are made regarding processes, product, and infrastructure [55, 58, p. 17, 66]. Continuing processes in the supply chain, for example, make-or-buy-decisions, are also part of the decision fields of a production strategy [58, p. iii]. These choices can be made between two extremes, such as using only supplied components or concentration on low automation. Moreover, these choices depend on previous design decisions [58, p. 45]. Skinner [55] also refers to production strategic decisions as trade-offs, describing that a production system can optimally perform a task, but always at the expense of other possibilities. This balancing of trade-offs is also described by Slack et al. [57, p. 78] and extended by the option to overcome trade-offs and increase efficiency. Furthermore, Hayes and Wheelright [29, p. 33] highlight the trade-off decision as essential for competitive advantage. For example, Hill and Hill [58, p. 161] describe the choice of processes as a function of production volume. A relatively low volume A_1 results in a choice between jobbing and batch processes, while a relatively high volume B_1 allows for a line or even continuous production (figure 2.6) [58, p. 161].

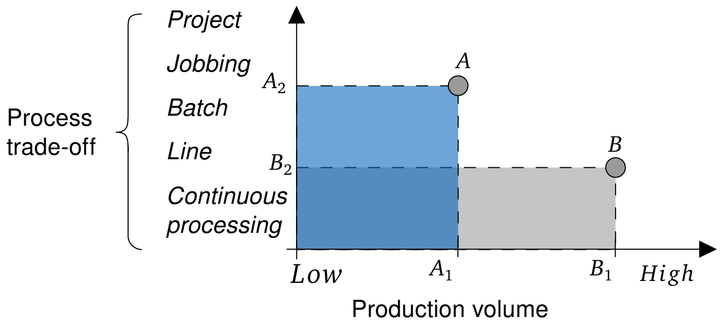


Figure 2.6: Process trade-off in dependency of the production volume according to Hill and Hill [58, p. 161].

Slack et al. [57, pp. 78-79] characterize this balancing of trade-offs as an "efficient frontier", that forms the border between two trade-offs. So the choice between variety and cost-efficiency can be made in favor of high variety and low-cost efficiency (A), vice versa (C), or in between (B) (figure 2.7). This "efficient frontier" lies on a convex line that describes the balance between the decision parameters. The decisions of a company are based on its strategy. In case a company is planning to expand this "efficient frontier", operations improvements are necessary. Therefore, a distinction must be made between positioning a company on the "efficient frontier" and aiming to expand it. To achieve this, a company can focus only on its operations, whereby processes, products, and infrastructure have to be adapted appropriately [57, p. 79].

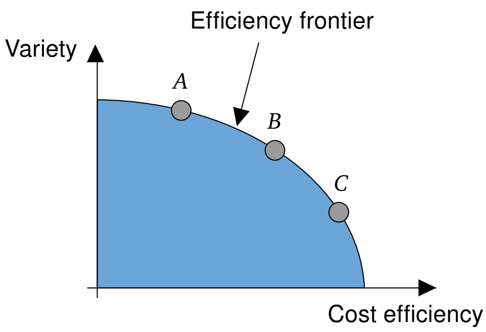


Figure 2.7: Efficient frontier between product variety and cost efficiency according to Slack et al. [57, p. 78].

Decision-Making within Production Strategy Development

Regardless of whether the method is structure or process-oriented, information within the methods must be mapped and processed as accurately as possible to be used by a decision-maker [60, pp. 84-87]. Therefore, a manufacturing strategy can be evaluated according to the criteria of consistency and for its contribution to competitive advantage. Consistency should be given between the overarching strategies (corporate and business unit) and the production strategy [55, 63, p. 57, 66]. Furthermore, the strategic choices in the decision categories must be consistent with each other. Additionally, an agreement must be found between existing resources, competitive behavior, policy restrictions, and the designed strategy [29, p. 33]. Competitive advantage is evaluated based on explicit decisions regarding trade-offs and priorities [55, 58, p. 17, 66]. The production strategy is furthermore assessed by its ability to secure a competitive advantage in the long run [29, p. 33]. Decisions on production strategy are unique to a company and depend on the product, market, and available technology [66]. Accordingly, the primary task is selecting appropriate production capabilities [29, p. 33]. The difficulty with this, results from the ability to derive general capabilities from specific decisions through prevailing uncertainties and lack of information [29, p. 33, 60, p. 87]. As a result, companies use Multi-Criteria-Decision-Methods (MCDM) to support strategic decision-making [73, 74, 75].

MCDM are different concerning their planned time horizon, granularity, update cycle, and automation in decision-making [76, p. 2]. Furthermore, they are used either to compare solutions, to sort solutions, or to select a specific solution [77]. In their study, Velasquez and Hester [78] summarize MCDM, including their field of application, advantages, and disadvantages, thus this publication is referred to for a detailed evaluation of MCDM. To select a MCDM for a production strategy development, it has to fulfill the following requirements:

(1) A method for production strategy decision-making must be able to correlate trade-offs of the production strategy [73].

(2) Relevant to the decision-making process is, furthermore, weighting the trade-offs according to company and application specific criteria [57, p. 161].

(3) At the early stage of a strategy development, the data basis is uncertain [56, p. 33], which is why a corresponding methodology must perform robustly with uncertain data.

(4) Thus, a further requirement is the successive expandability of the MCDM to include new knowledge about the system and its behavior.

Table 2.7 summarizes the area of application and evaluation of MCDM. Hereby, (**+**) stands for the integration of the ability, (**-**) for the lack of this possibility and (**o**) for no preference. In conclusion, fuzzy set theory, which is based on the fuzzy logic of Zadeh [79], best meets the requirements. The advantage in balancing trade-offs [75, 80, p. 36] and the possibility to deal with large numbers of stakeholders [74] are benefits of fuzzy set theory. Additionally, there is the potential to link other MCDM approaches to fuzzy set theory to use imprecise input data [75, 76, p. 281, 80, p. 353]. Fuzzy set theory is therefore presented in detail in the following.

Fuzzy Set Theory and Fuzzy Systems

In fuzzy set theory, a fuzzy system is an area that represents reality in an observable and measurable way and therefore interacts with the environment [80, p. 1]. Systems can be divided into interdependent subsystems [81, p. 4]. The goal of defining a fuzzy logic-based model is to create a mathematically sound model for decision-making (figure 2.8). The function of a fuzzy system is based on the translation of sharp input signals x_i to a linguistic scale of values [80, p. 163, 81, p. 10]. With this translation, the fuzzy controller can derive the output values $y_i(x)$ using *IF...THEN...*-rules [81, p. 10, 82, p. 86].

The *fuzzyfication* translates a linguistic statement into a mathematical expression. An example

Table 2.7: Evaluation of the ability of MCDMs to rate trade-off relationships (1), weight of criteria (2), the necessary data basis (3), and necessary system knowledge for decision-making (4) [74, 75, 76, pp. 7-8, 78].

MCDM	(1)	(2)	(3)	(4)	Exemplary Fields of Application
Multi-Attribute Utility Theory	**o**	**+**	**-**	**-**	Economics, finance, actuarial, water management, energy management, agriculture
Analytic Hierarchy Process	**-**	**+**	**+**	**o**	Performance-type problems, resource management, corporate and political strategy, planning
Case-based Reasoning	**o**	**o**	**-**	**o**	Business, vehicle insurance, engineering design
Data Envelopment Analysis	**+**	**+**	**-**	**-**	Economics, medicine, road safety, agriculture, business problems
Fuzzy Set Theory	**+**	**o**	**+**	**+**	Engineering, economics, environmental, management
Value Analysis	**-**	**+**	**o**	**o**	Engineering, economics, environmental, management
Simple Multi-Attribute Rating Technique	**-**	**+**	**-**	**-**	Environment, transportation and logistics, manufacturing and assembly problems
Goal Programming	**+**	**-**	**o**	**o**	Production planning, portfolio selection, distribution systems, energy planning
ELECTRE	**-**	**+**	**o**	**-**	Energy, economics, environment, transportation problems
PROMETHEE	**-**	**+**	**o**	**-**	Environmental, business and finance, logistics and transportation, manufacturing, assembly
Simple Additive Weighting	**-**	**+**	**+**	**-**	Business, water management, financial management
TOPSIS	**-**	**-**	**o**	**o**	Supply chain management, engineering, manufacturing systems, environment

of such a statement is: A runner runs *fast*. The linguistic expression *fast* must be transferred to a numerical scale of values. For this purpose, the linguistic variables are linked by a membership function μ_a that can map values between 0 (no membership) and 1 (full membership) [81, p. 6]. The value range of the membership functions is normalized, where $u(x) : x \rightarrow [0,1]$ applies. These membership functions are mostly modeled by triangle, ramp, or step functions, which represent the assignment of the value $\mu_A(x)$ to the output value $u(x)$. As a function with a computational efficiency [80, p. 229], figure 2.9 exemplarily visualizes a triangular function. Equation 2.4 gives the calculation rule. L or R membership functions are commonly used in addition to triangular membership functions to model a constant value of 1 for $x < A_2$ or $A_2 < x$ [81, p. 37].

$$\mu_A(x) = \begin{cases} 0 & \text{for } x < A_1 \\ \frac{x - A_1}{A_2 - A_1} & \text{for } A_1 \leq x \leq A_2 \\ \frac{A_3 - x}{A_3 - A_2} & \text{for } A_2 \leq x \leq A_3 \\ 0 & \text{for } x > A_3 \end{cases} \tag{2.4}$$

In general, membership functions are based on rules formulated by experts [80, pp. 185-188, 81, p. 3, 82, p. 87]. The membership function therefore represents a linguistic value range on a numerical scale [81, p. 9]. For example, an expert describes a production volume by the terms *low*, *medium*, and *high* while the membership functions are defined as visualized in figure 2.10. A sharp input of 500 pieces would then use both terms *low* and *medium*. In this example, the term *low* is given for 0.3, the term *medium* for 0.1 and high for 0.

The main linguistic operators to link fuzzy sets are *not, and, or* [81, p. 38]. These linguistic links must be expressed as mathematical operators in the fuzzy system, such as the maximum

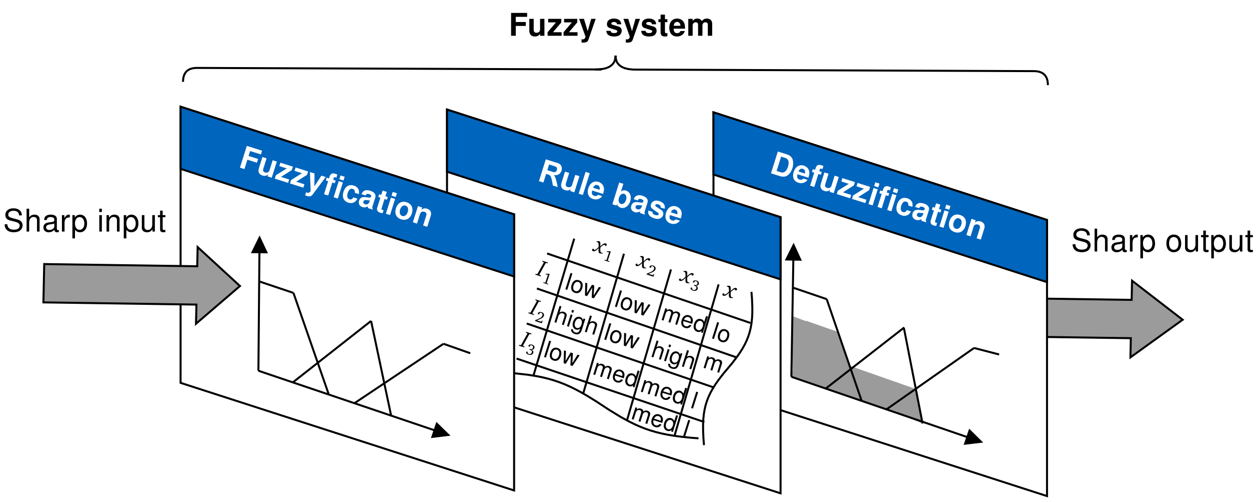


Figure 2.8: A fuzzy system with sharp input and output values according to Traeger [82, p. 79].

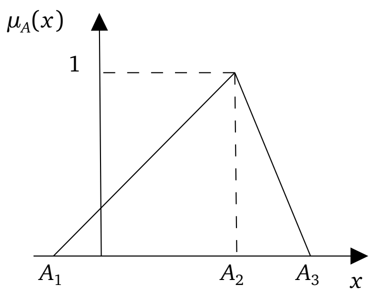


Figure 2.9: Exemplary triangular membership function.

operator, that outputs the maximum value of the systems to be linked [80, p. 232, 81, p. 38, 82, p. 89]. The equations for the maximum and minimum operator are:

$$\mu_{A\cup B}(X) = \max\left[\mu_A(x), \mu_B(x)\right] \tag{2.5}$$

$$\mu_{A\cup B}(X) = \min\left[\mu_A(x), \mu_B(x)\right] \tag{2.6}$$

For a detailed discussion on the operators, their selection, and application in fuzzy systems, refer to the fundamental works of Zimmermann [80], Bothe [81], and Traeger [82]. In practical applications, minimum operators have proven reliable for the *and* links and maximum operators for the *or* links due to their low computing effort [82, p. 89].

Lin et al. [83] demonstrate the applicability of Design Structure Matrix (DSM) for production decision-making using fuzzy logic. The DSM has the size $n \times n$ for n parameters. The dependency of the parameter x_i on the parameter x_j with $i, j \in \{1, ..., n\}$ is defined by the linguistic term $L_{x_j}^{x_i}$ (table 2.8).

After implementing a fuzzy system, its input signals, and the subsequent *fuzzyfication* with membership functions, the rules and their evaluation are defined. The choice of the *defuzzification* method then follows [80, p. 228, 82, pp. 102-111]. In this sense, three methods are presented. The Mean of Maximum method outputs the abscissa value below the middle of the maximum value of the result set as the initial value. The Center of Gravity method outputs the x-coordinate

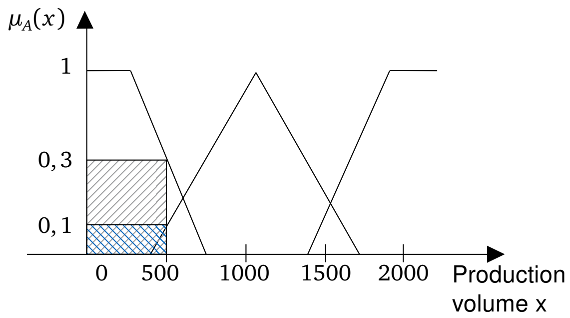


Figure 2.10: Three terms describing the linguistic variable production volumes. Low for less than 750 pieces, medium for 400 to 1 750 pieces and high for more than 1 400 pieces of production volume.

Table 2.8: DSM representation of fuzzy dependencies of *n* parameters [83].

	1	2	...	*n*
1	x	$L_{x_2}^{x_1}$	...	0
2	0	x	...	$L_{x_n}^{x_2}$
...	...	...	x	...
n	$L_{x_1}^{x_n}$	0	...	x

of the area's center of gravity [80, pp. 234-235, 81, pp. 12-13, 82, pp. 104-105]. In the case of singleton *defuzzification*, an individual line, the abscissa values of the lines are weighted and calculated with the respective degree of affiliation [82, pp. 107-108].

Influence of Surrounding Conditions on a Strategy

Companies have to take their specific environment into account when making decisions as highlighted in section 2.1. Especially the alignment of surrounding influences with company goals allow for competitive advantage [84] Thus, the knowledge of future dynamics of the surrounding conditions influences decision-making [53, 85]. Figure 2.11 summarizes the surrounding conditions of strategic planning. It does not show the inter-dependencies of the technological, legal, economic, ecological, and socio-cultural conditions, however. Nevertheless, the following explanation of the surrounding conditions draws from this visualization.

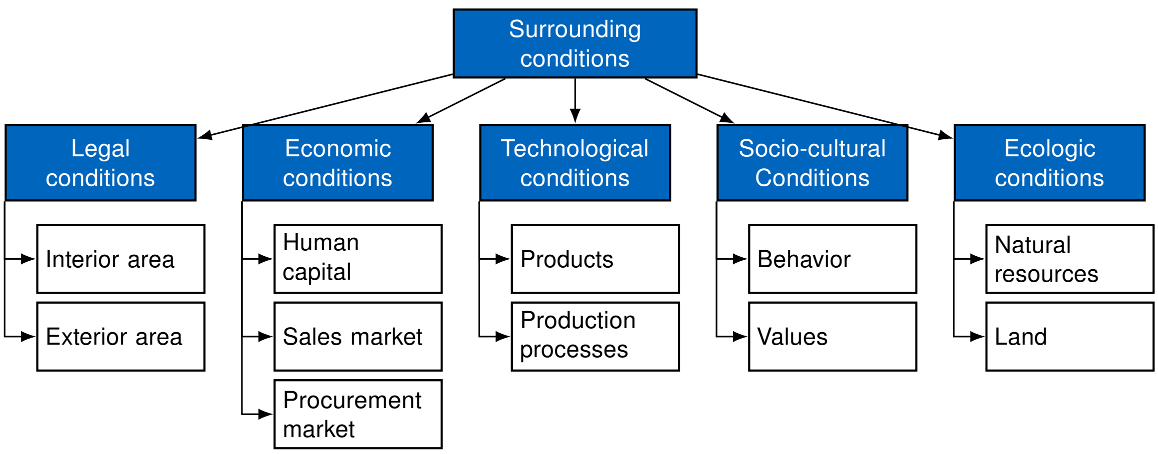


Figure 2.11: Essential surrounding conditions of a production site.

Legal conditions, for example, are specified by the state and are therefore binding for companies to comply with. These affect the internal and external domains of a company. Internally, companies must comply with company law, labor law, and labor contract law, and safety and testing regulations [57, p. 159, 60, pp. 41-42]. Externally, foreign trade legislation, patent protection legislation, and environmental protection legislation must be observed. Foreign trade legislation includes customs duties, export and import restrictions, free trade zones, and economic communities, which must be taken into account as boundary conditions in strategy development [60, pp. 41-42].

The overall economic development of industries, sectors, and markets are among the *economic conditions* of a country that influence production strategy planning. The sales market and its development reflect changes in customer behavior and provides information about necessary capabilities for strategy fulfillment [58, pp. 114-115, 84]. From here, conclusions can be drawn regarding criteria such as design, quality, delivery time, and flexibility, as well as price [58, p. 117, 70, p. 542]. These product requirements can be functional, such as quality features or functional dimensions, or constructive in character, such as design or material. Thus, product technology, geometry, dimensions, material, surface, and accuracy are modified [52, p. 99]. These product requirements impact production through the appropriate product design (figure 2.12). Further core criteria are market volume and potential, market growth, (target) market shares, and price and earnings conditions [52, p. 99, 60, p. 44]. On the procurement side, raw material markets, the labor market, and energy sources are strategically decisive [60, p. 45, 85]. Similarly, labor costs are crucial for specially skilled workers. Property costs, energy costs, and transport costs also influence the decision-making process. During transport, both delivery and transport of finished goods to the customer are decisive [57, p. 159]. The market also has requirements concerning ergonomics, introduction (e.g. expense of training staff), operation (safety, reliability, and environmental impact), and economics (purchase price, operating costs, and additional benefits) [52, p. 99].

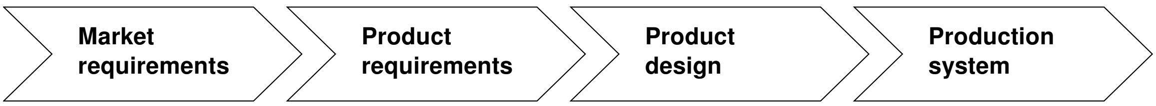


Figure 2.12: The product combines market requirements with strategic production system design adapted from Aldinger [52, p. 99].

Changes in production technology, mechanization or automation, changes in production materials, and new measuring or testing methods are described as influences from the *technological condition* [60, p. 45]. Innovations and decisions in this area influence the choice of production strategy.

The *socio-cultural condition* changes along with the social behavior of employees and values changes in the broader society. New leisure behavior, cultural norms, increased demands from employees, and work attitudes have a decisive influence on production. Political behavior also has a direct and dependent effect on strategic decisions [60, pp. 45-46]. Furthermore, workforce's skill level also influences the choice of strategy [57, p. 159].

Ecological conditions indirectly affect production development through existing standards and laws [60, p. 46]. Natural resources and land are relevant production factors defining a country's potentials [84]. Inter-dependencies between ecological conditions and socio-cultural and technological conditions also influence strategic decisions.

These external influences thus affect structural and infrastructural internal decision parameters [56, p. 37, p. 54]. Thus, it is the production strategy's obligation to streamline these external parameters with the internal possibilities for action and configurations to ensure the long-term success of a company.

2.2.3 Application of Production Strategies

This section presents a selection of strategies in developing economies described in the recent literature. According to Aboutalebi [86, p. 34], these can be categorized as off-shoring strategies with the aim of globalizing production by expanding production into remote countries. Automotive companies in particular are exposed to the opposing trends of globalization and localization of production [87, p. 38]. This section therefore presents different strategies known from the automotive industry to establish domestic value creation and supplier concept. Furthermore, trends in focal points of production strategies as well as the dependency between production and sustainability are presented within this section.

Developing Economies

Research on production in developing economies can be divided into two main categories. Firstly, research that addresses the market entry of a manufacturing company, and secondly, studies that address the manufacturing of products in these markets.

The literature describes a phased process for a Multi National Corporation (MNC) to enter new markets in developing economies. Leontiade's [88, p. 43] approach suggests, for example, planning local value creation depending on the market phase. As visualized in figure 2.13, the first market phase describes the pre-market, which is purely an import market where sales numbers are low. As demand increases, the pre-market evolves into a take-off-market, where products are assembled locally in small quantities. In the advanced early-mass-markets, large quantities are then produced locally. When the market develops into a mature mass-market, new technologies are also developed for and within the market itself. Xie [89] and Karabag et al. [90] describe similar approaches, evaluating the strategies for the applications of the color television industry in China and the automotive industry in Turkey.

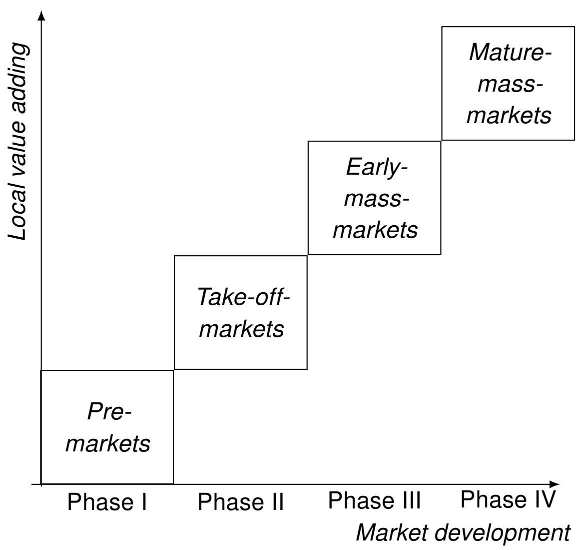


Figure 2.13: Company strategies on entering developing economies depending on the market phase adapted from Leontiade [88, p. 43].

These market entry strategies are derived from the overall global network strategy of MNC. Five of these global network strategies are described in the literature, whereby two focus on the local adaptation of products. These strategies differ significantly in economies of scale and scope achieved.

The first strategy, known as *local for local*, bases on the operation of production sites exclusively for the local market. The main advantages are high flexibility, short lead times, and local adjustments [14, p. 164, 33]. The *local for local* strategy is mainly used for market-specific products with either low-value density or strict and defined local requirements [14, p. 165].

The second strategy is known as *hub and spoke*. In this approach, cost or know-how-intensive core components are manufactured in one location, and simple assembly steps are carried out in another, close-to-market location. This strategy allows for economies of scale and market proximity to be used equally [14, p. 166].

In contrast to the market entry studies, Amoako-Gyampah and Boye [91, 92] as well as Ehie et al. [65] address companies already producing in Africa. In two publications, Amoako-Gyampah and Boye [91, 92] research manufacturing companies in Ghana. They cite the political conditions, market information, economic situation, and past sales as input of production development in Ghana [91]. This information is used for strategic decisions on equipment purchasing, facility planning, and budget planning, independent of company size [91]. With a second study on companies in Ghana and Singapore, Amoako-Gyampah and Boye [92] point out that production strategy in these countries depends on the prevailing boundary conditions. This study shows the influence that business costs, laboratory availability, and manufacturing practice have on the production targets of low cost, quality, flexibility, and delivery performance. Above all, the competitive environment influences decisions in the operations strategy of companies with a local production site. It is shown that competitive hostility has an influence on the strategic positioning with respect to low cost, quality, and flexibility. This effect is influenced by the company's ownership structure. According to this study, locally owned companies are even more influenced by competition. For example, competition influences decisions regarding delivery performance. Product quality, as another strategic priority, is influenced by the available labor force and company size. In small companies, in particular, the lack of skilled labor affects the ability to offer high-quality products [92]. By contrast, the competitive environment has an impact on costs, quality, and flexibility. For these results, the underlying study surveyed 58 companies in Ghana in 1998 [92].

Based on the Amoako-Gyampah and Boye [91, 92] studies, Ehie et. al [65] surveyed companies in Nigeria in regard to manufacturing strategies. They extend the observed influences to manufacturing practices and government policies. They also show that a competitive environment plays a decisive role in strategic decisions. Above all, the influence of government policies on low costs, flexibility, and delivery performance is rated as significantly negative. In summary, these studies show the dependency of production strategies on surrounding conditions for developing economies in Africa. In addition, they also show the complex networking of strategic positioning with regard to trade-off decisions, which is enhanced by the increasing dynamics of global competition [65].

Original Equipment Manufacturers in Developing Economies

For car manufacturers, production abroad offers the possibility of opening up new sales markets, as barriers to market entry are overcome [87, p. 241]. For other manufacturing industries too, market development is one of the main motives for shifting production [93, p. 14]. For OEMs, a production strategy adapted to the market status is necessary [87, p. 241]. Thus, production can, for example, be adapted to a large extent by in-house production share [40, p. III]. Especially for developing economies, more cost-effective models are promising and are therefore primarily an advantage for volume manufacturers [87, p. 241].

In the automotive industry, five production stages are commonly known for entering new markets and setting up production sites. These differ in the proportion of local value-added, the relocated processes, and the supplier strategy of the OEMs.

Following the Completely Build Up (CBU) and Fully Build Up (FBU) strategy, OEMs assemble vehicles at the main plant and ship them to the target market, so there is no local added value in the vehicle. This strategy is primarily applied in markets that do not levy customs duties on vehicle import. In countries that do apply duties on CBU vehicles, these range from 35 % in South America to up to 100 % in India [94]. The CBU strategy includes the establishment of distributor networks, marketing organizations, and a service network in the target country. The automotive industry traditionally uses the CBU strategy to enter new markets [95, pp. 204-205] because of the advantage of high scales in the central production plant [94].

Alternatively, the Semi Knocked Down (SKD) approach offers a higher proportion of local value-added. The vehicle components are produced, partly pre-assembled, and then delivered to the target market. There, the final assembly of the seats, engine, and other components takes place [96]. Two different approaches for SKD assembly are applied. With the first approach, the vehicles are completely assembled in the main factory and disassembled before shipping to the degree that lower or no import duties at all are levied. For the second approach, the painted body and components are shipped without prior assembly [95, pp. 204-206]. The advantage of the SKD strategy is the quick reaction to changes in demand, the flexibility in adjustments, and an early market presence [87, p. 176]. Disadvantages are higher logistics costs due to selection, packing, and shipping of individual parts [96].

The SKD strategy often represents a preliminary stage to Completely Knocked Down (CKD) assembly [87, p. 176] due to political restrictions by the local authorities. The standard is to allow SKD assembly for five years before CKD assembly is demanded [5, p. 11]. In this case, components are imported from the main factory into the target country, supplemented by locally supplied components [96]. The components are shipped including the necessary connectors, such as screws [97]. The local manufacturing process includes body construction, body shop, and assembly [96]. The CKD assembly is influenced by the chosen logistics concept, which, for example, specifies shipping as a kit or part-by-part [98]. A further prerequisite for CKD assembly is the local procurement of tools and staff training [87, p. 176].

Another concept is local production, optimized for small series and local value creation. Wells and Nieuwenhuis [99] propose micro-factory retailing for this purpose. Core components, such as engines, are produced or purchased centrally, while most of the components are purchased locally. Micro-factory retailing mainly performs assembly, sales, service, repair, retrofit, and upgrade. With this strategy, economies of scale are realized through centrally purchased or manufactured core components, and not through bodywork, as is the case with other strategies. For micro-factory production, the vehicle structure must be adapted accordingly. A possible example is a cost-effective space-frame construction for the frame [99]. The advantage of this strategy is low investment and fixed costs, which allows for an economic production of small quantities [100]. Economies of scale are achieved by the core components [99]. Local value creation dissolves the boundary between production and retailing [99, 100]. This kind of decentralized production requires adapted organizational structures in terms of flexibility and scaleability [101].

The OEMs strategies visualized in figure 2.14, show the trades involved in automobile production. These are the press shop that produces the body-shell, the body shop, the paint shop and the assembly [95, p. 151]. The illustration of the supplier components shows which strategies are

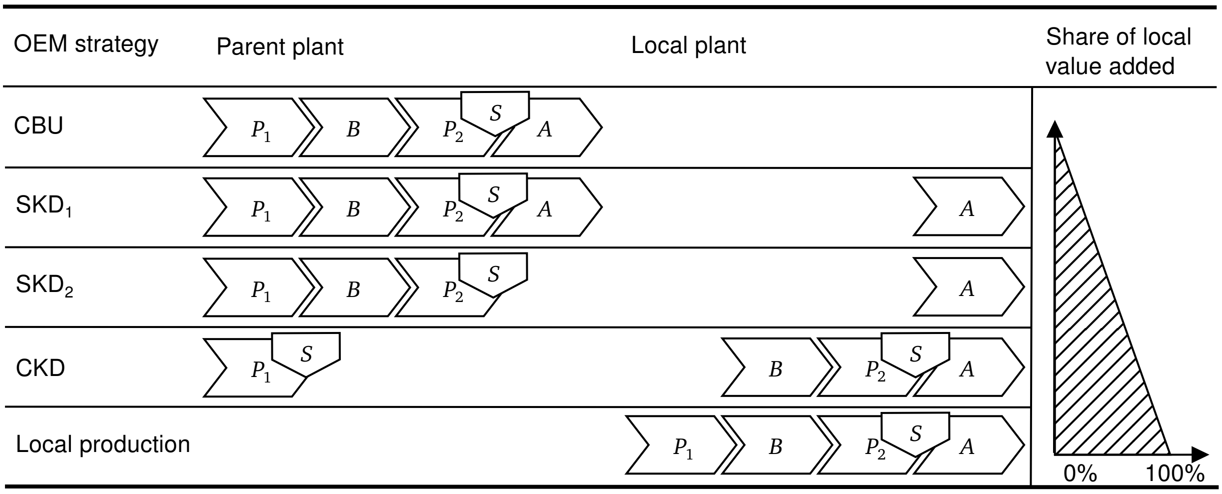


Figure 2.14: OEMs strategies and division of added value adapted from Göpfert et al. [95, p. 206], with P_1 for the press plant, B for bodywork, P_2 for paint shop, A for assembly and S for supply components.

based on local supply chains. Thus, the additional logistical effort of a CKD strategy described by Dombrowski et al. [98] becomes evident, as components are delivered to both the main plant and the local plant.

Table 2.9 displays exemplarily the Nigerian content definition of the different OEMs strategies. This definition is part of the Nigerian National Automotive Development Industry Plan, which began 2014 and runs out in 2024. Within this plan, the Nigerian government set the import duties for FBU vehicles at 35 %, which can only be reduced if the manufacturer also assembles vehicles locally. The rates for CKD (0 %), SKD 1 (5 %) and SKD 2 (10 %) are also defined and indicate the importance of local value-added [102, p. 11].

Trends in Production Strategy Priorities

A consortium of business schools and universities under the lead of Politecnico di Milano (Italy) is currently investigating trends in production strategy. This study surveys global companies from various industries, such as manufacturers of motor vehicles, trailers, and semi-trailers. In the latest survey of 2014, 931 manufacturing companies from 22 countries took part [103]. Netland and Frick [104, p. 9] derived trends in production strategy from this survey. Their first studies focused on cost, quality, dependability, speed, service, and flexibility. These were expanded to include the goals of innovation, sustainability, and responsibility. In this survey, sustainability refers to the goal of improving the ecological use of products and processes [104, p. 8]. With this study, it becomes clear that for European companies quality and dependability currently have the highest priority, and the standard deviation ranks lowest. Also, the production speed has a high priority with low deviation. Sustainability is considered a secondary objective, with relevance having slightly increased compared to the previous study. Netland and Frick [104, p. 14] conclude from this data set that sustainability and responsibility do not rank high enough in European companies' manufacturing strategies.

Pawellek [8, p. 6] also describes a change in current production strategies. He observes a shift in focus from capacity towards material flow, from operation-related to product-related, and from program-controlled to customer-order-related. In addition, continuous production with a minimum division of labor and batch size of one, as a guide value, is aimed at [8, p. 6].

Table 2.9: SKD and CKD equipment and process in Nigeria [102, pp. 21-22].

Phase	Definition by equipment	Process
SKD 2 (I)	Assembly line, miscellaneous tools	Vehicle cabin fully trimmed, painted and seats, dashboard, and accessories installed.
	Wheel alignment tester, turning radius tester, head light tester, side slip tester, speedometer tester, brake dynamometer, and shower testing	The other aggregates are loose and are assembled on chassis on assembly line.
SKD 2 (II)	Paint booth, oven & assembly line, conveyor line, miscellaneous tools	Car body is fully painted and glazed.
	Wheel alignment tester, turning radius tester, head light tester, side slip tester, speedometer tester, brake dynamometer and shower testing	The engine, gearbox, axles, suspension, drive-shaft, steering, seats, tyres, batteries, exhaust system, electrical, etc. are supplied as individual units for assembly in Nigeria.
SKD 1	Conveyors for paint line, oven & assembly line, conveyor line, miscellaneous tools	Car body is unpainted, but coated/phosphated.
	Wheel alignment tester, turning radius tester, head light tester, side slip tester, speedometer tester, brake dynamometer and shower testing	The engine, gearbox, axles, suspension, drive-shaft, steering, seats, tyres, batteries, exhaust system, electrical, etc. are supplied as individual units for assembly in Nigeria.
CKD	Welding guns, jigs, templates, metrology equipment (3-D measuring machines), etc.	Body sides, roof and floor pan are supplied loose for final welding and final assembly.
	Conveyors, paint tanks, paint both, drying oven, etc assembly line. Wheel alignment tester, turning radius tester, head light tester, side slip tester, speedometer tester, brake dynamometer and shower testing	The engine, gearbox, axles, suspension, drive-shaft, steering, seats, tyres, batteries, exhaust system, electrical, etc. are supplied as individual units for assembly in Nigeria.

In global production, the focus is on cost, quality, and time objectives [105, p. 1, p. 18]. MNC are planning local production sites in developing economies primarily to open up new markets and thereby increase their competitiveness [14, p. 2]. In addition to these goals, the local production site enables the promotion of increasingly focused sustainability. A study by the World Trade Organization [2, p. 48] demonstrates that, with rising demand for assembled products, demand for workers who manufacture them also rises, improving their wages locally. Saranga et al. [4] speak of the double helix effect triggered by the integration of local partners. This means that for global companies, costs are reduced, adaptation of products is simplified, and these can be delivered to the market faster. At the same time, domestic companies participate more in global value chains.

Within a pre-publication [3], two aspects of an automotive production site's sustainability are analyzed: economic sustainability for companies through new locations and customers, and social sustainability for the local society. Thus, the long-term impact of an automotive production site on the region is evaluated. By bench-marking, the changes of a region with an automotive production site against the nationwide changes e.g. in wages, health insurance, infrastructure, and education, a recommendation for future automotive production sites is derived.

Sustainability in the context of this work considers both securing economic advantages for the company and describing social sustainability in developing economies. This complies with London et al. [43], who demand to retain value-added locally, regarding workers and the population in developing regions, including job and income development, and educational opportunities. Furthermore, the development of infrastructure and reliable energy supply needs to be considered. Abele et al. [105, p. 1] indicate that positive effects can be achieved mainly through the long-term exchange of education and training. These are sustainable economic performance and growth at the national level, sustainable economic success at the organizational level, and job satisfaction with followed by better health at the individual level. Additionally, sustainability must be in focus within the target system of production design [70, p. 42, 105, p. 1, p. 18]. A holistic view on sustainability includes the economic success of the company and therefore aims at sustaining its competitive advantage [53]. Figure 2.15 summarizes the benefits for manufacturers, society, and consumers of locally produced goods. Nevertheless, the integration of sustainability goals in the automotive industry is still an unsolved challenge [106].

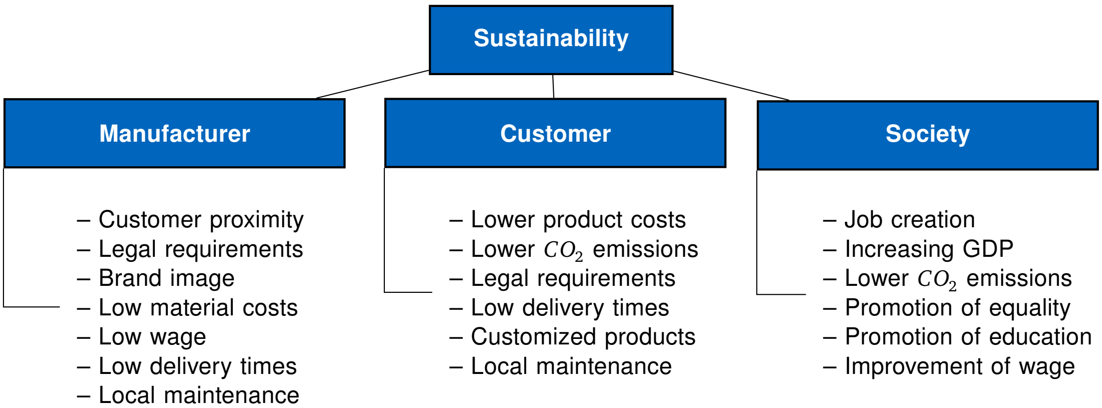


Figure 2.15: Sustainability benefits for manufacturer, customers, and the local society of a local production site.

2.3 Review of the State of the Art

The complexity of production strategy development in developing economies results from the previously described external influences in section 2.2.2, which must be brought in line with corporate and business strategic goals (section 2.2.1), a conflict visualized in figure 2.16.

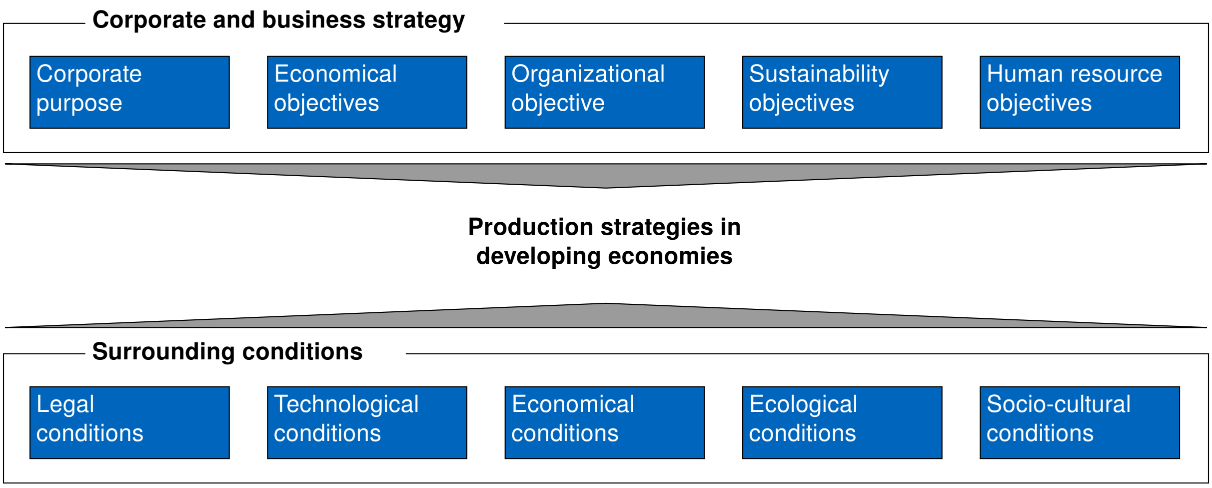


Figure 2.16: The conflict area of production strategy development for developing economies between surrounding conditions and corporate and business strategy.

The aim of a production strategy development method is to evaluate a set of options in order to give a recommendation on this basis (section 2.2.2), but a strategic decision rarely begins with a defined set of options [73]. Production strategy development therefore is a multi-criteria problem, and its set of options must be derived based on the respective surrounding conditions.

When analyzing manufacturing, operations, and production strategy, it is crucial to distinguish between the process of strategy development and the content of such a strategy [70, p. 76]. The process of strategy development describes the method used to develop a strategy, while the content defines the specific characteristics of an operation, like controls, procedures, and structures [58, p. 17]. To evaluate production strategy development methods for suitability, requirements known from the literature are:

1. Content of a production strategy
   (a) Integration of surrounding conditions into the strategic planning process [29, 60]
   (b) Definition of a set of options at the beginning of strategic decision-making [73]
   (c) Consideration of the turbulent conditions in developing economies [65, 92]
2. Development of a production strategy
   (a) Handling the lack of complete situation knowledge [29, p. 87, 60, p. 87]
   (b) Mapping of interrelationships of decisions [73]
   (c) Integration of corporate strategic goals into the decision process [55, 70]
   (d) Integration of interactions within the decision process [73]
   (e) Standardized and transparent strategy development [33]

The existing literature is evaluated according to following criteria, that are derived from the general recommendations above. These criteria (*C.1.-C.7.*) are divided into production strategy content and production strategy development.

1. Content of a production strategy
   C.1. Supported query of specific surrounding conditions
   C.2. Derivation of a production strategy parameter set
   C.3. Evaluation of production strategy parameters for developing economies
2. Development of a production strategy
   C.4. Linking of external factors to the parameters of the production system
   C.5. Mapping of internal cause-effect relationships of the decisions
   C.6. Integration of corporate strategic objectives into production strategy development
   C.7. Transferability and open-source capacity of the decision process

The selection of studies for the evaluation of production strategy content, and, thus, the parameters to be decided, follows the literature study by Deshmukh and Dangayach [68], who evaluated 260 studies on production strategy. Of these studies, 23 address the process of strategy development. The essential studies were evaluated for *C.1., C.2., C.3.*, supplemented by recent studies.

The ScienceDirect and Google Scholar databases were scanned for approaches that meet criteria *C.4.-C.7.* Therefore, the search terms "Production Strategy Development", "Operations Strategy Development" or "Manufacturing Strategy Development" were used. All results for ScienceDirect and the results of the first ten pages of GoogleScholar were evaluated, because GoogleScholar results are sorted by relevance.

2.3.1 Content of a Production Strategy

This section evaluates approaches to developing production strategy content, and especially their focus on the respective parameters of production development. Table 2.10 summarizes the literature review, whereby ○ means not mentioned, ◑ means described, and ● means systematically integrated.

Table 2.10: Evaluation of selected production strategy literature.

Criteria	[58]	[63]	[64]	[71]	[72]	[107]	[108]	[109]	[110]	[111]
C.1.	◑	◑	◑	◑	●	◑	◑	◑	◑	●
C.2.	◑	●	○	◑	◑	○	●	◑	◑	○
C.3.	○	○	○	●	○	○	◑	○	○	○

These approaches indicate that the surrounding conditions are used as input parameters for production strategy planning. However, only in Dombrowski et al. [72] and Ward and Duray [111], are the surrounding factors explicitly integrated into a content development process. Ward and Duray [111] remain on the top level in their method, since they only consider competitive priorities in interaction with the environment, and do not address detailed strategy parameters. In contrast, Dombrowski et al. [72] name specific factors of the surrounding that have an influence, but do not show how the strategy content adapts.

This results in the conclusion that the surrounding conditions are not used to satisfy *C.2.* and derive specific production strategy parameters. Apart from adapting the content based on the surrounding environment, Michaeli [63] shows how a strategy's content adapts to the application context, in his case, the aircraft engine industry. Dörrer [108] also adapts his strategy based on corporate strategic goals and the industrial context, the automotive industry.

So far, the least studied is the adaptation of the strategy content for developing economies (*C.3.*). Within the framework of the study done by Dörrer [108], developing economies are discussed as sales markets. Mefford and Bruun [71], with their approach, are the only ones who examine a specific adaptation of the strategy to developing economies. It remains to be criticized that their content is based on the sales market and the degree of value-added and leaves out other environmental factors.

Evaluating the approaches shows that the specific strategy content adapted for developing economies has not yet been sufficiently examined. This potential is also referred to in the literature. For example, Abele and Meyer [14, p. 142] highlight the importance of a production location strategy tailored to the company's location. In addition, factors such as company size are not sufficiently integrated into the inclusion of case-specific factors and offer research potential [68]. Ward and Duray [111] also come to this conclusion, as they point out that production strategy development is an inward-looking process: one's resources are rarely or not placed in the context of the environment or adapted based on this context.

Diaz et al. [112] conclude their literature research by identifying the need for research on development, implementation, and changes in operations strategy. They point out that generic parameters have been broadly studied, although the operations strategy is changing dynamically concerning competitive factors. Lanza et al. [33] conclude that there is a lack of management approaches in the production sector that combine strategy and local integration in global companies. The complexity results from a multitude of influencing factors in the respective markets and global supply networks [33, 71, 113]. Simultaneously, Lanza et al. [33] note that the focus on sustainability, which is a crucial factor in developing economies [3], should be more centrally integrated into decision-making processes. Therefore, the surroundings as well as the competitive and corporate strategy must be jointly considered for production strategies for developing economies. Thus far, the evaluation of external factors serves predominantly for comparison with competitors on the market [33, 111, 114].

2.3.2 Development of a Production Strategy

The research of approaches to select and evaluate production strategy parameters is pre-published in Brönner et al. [115], and table 2.11 lists the evaluation of the approaches.

Table 2.11: Evaluation of selected production strategy development literature.

Criteria	[55]	[58]	[71]	[108]	[116]	[117]	[118]	[119]	[120]	[121]
C.4.	◑	◑	◑	●	◑	◑	◑	◑	◑	◑
C.5.	○	◑	◑	●	○	◑	○	○	○	○
C.6.	●	●	◑	◑	◑	◑	◑	◑	○	◑
C.7.	○	◑	○	◑	●	●	○	○	●	○

It can be stated that the approaches [116, 117, 118, 122] partially integrate the external conditions (*C.4.*). Jia and Bai [117] concentrate on market-based requirements to judge the importance of different competitive factors. Crowe and Cheng [116] also use market conditions to evaluate the competitive environment to align the overall strategy with the production strategy. Likewise, Platts and Gregory [118] limit their assessment of the surroundings to the market requirements and competitors.

In contrast, the internal dependencies (*C.5.*) in production strategy development are only insufficiently addressed in [58, 71, 117]. Especially in the discussion on dependencies, the established authors [55, 58, 119, 121] use the selection as expert-based step-by-step processes. This greatly limits the replicability of the decision-making process. Dörrer's [108] complex system dynamics approach offers a solution to this issue. This approach allows for a comparison of different scenarios but requires appropriate knowledge of the system and its behavior.

The corporate goals (*C.6.*) are widely used by the authors [55, 58, 71, 116, 118, 119, 122] as input parameters in production strategy development. Authors such as Skinner [55], and Hill and Hill [58] demonstrate how to transform corporate strategic goals into production strategy goals on a generic level. Section 2.2.1 also addresses this issue.

For a decision process to be transferred to other application cases, the decision paths must be documented and adaptable at a manageable expense (*C.7.*). Within the generic procedure of Hill and Hill [58], some decision paths are documented. Hajirezaie and Husseini [120] choose a fuzzy method-based approach, which means that this method is in principle suitable for open-source publication. The same applies to the approaches of Crowe and Cheng [116] and Jia and Bai [117]. However, the rule base of the decisions is not available with this publication, which is why transferability cannot be further investigated. Examining these requirements shows that, with the approach of Dörrer [108], a promising development process exists for the development of production strategies. This process, however, requires profound prior knowledge to model the system and thus induce decisions. The application of this methodology, for example, relies on knowledge of an established OEMs. Therefore, the transferability of this method to new use cases must be criticized.

2.3.3 Research Demand

In conclusion, literature on current production strategy, such as [58, 63, 71, 72, 108], illustrates the dependency of strategic production decisions on the market environment, whereby decision-making mainly focuses on product sales. Due to the large heterogeneity of conditions in developing economies, e.g. in market size, population, development status, and infrastructure, it is however necessary to define localized production strategies [33]. This argument is also brought forward by Ferdows [113], who describes the challenge of detail and dynamics in global operations management. In particular, the detailed investigation of interactions between decisions within a factory, such as production volumes, flexibility, and make-or-buy decisions, and the corporate strategy is described as inadequate. This demand for detail is also reflected in current production strategy research, which identifies the integration of external environmental conditions and internal requirements as further research demand [72]. Research potentials mentioned in the literature illustrate the results of the evaluation of the previous chapter, i.e. that the content of a production strategy adapted to the surrounding factors of developing economies is not yet sufficiently available. Further criticism on existing methods are the large effort required and company-specific initialization [108, 116, 117].

This further complicates the already wide and uncertain solution space of strategic planning [45, p. 27]. This planning should evaluate those strategic options, that best meet the objectives, taking into account the surrounding and resources [118]. Simultaneously, there is demand for a fast and reliable development of a strategy adapted to a certain situation [52, p. 51]. Furthermore, Lanza et al. [33] indicate that the integration and coordination of strategic sub-tasks, such as the adaptation to local factors, are carried out as case-by-case planning in current strategy research and thus result in a large planning effort. This leads to the demand for a new method to systematically integrate local factors into the solution finding process.

Even the influences from the product, e.g. an electric vehicle, are not yet considered in the literature within decision categories. Following Mefford and Bruun's [71] argument, this is relevant, as the product has a significant influence on production system design and thus production strategy. Particularly when entering developing economies, a product that satisfies a need so far not or only insufficiently met, is the prerequisite for profit-based aid for this region [62].

In summary, current research lacks an analytical approach that integrates external influences in developing economies into the strategic decision-making of a production strategy. These boundary conditions are important in developing economies, whose surrounding conditions differ significantly from the familiar conditions in industrialized countries [123]. Furthermore, in accordance with the aCar project's research objectives, an open-source capable method should be designed. This means the resulting method of this thesis is intended to be applicable and adaptable for different companies and products. These arguments indicate the need for a practically applicable method within a suitable multi-criteria decision framework of strategy development based on an in-depth understanding of the prevailing conditions in developing economies.

Figure 2.17 defines the research questions and sub questions. Thereby, the first three questions focus on the development of the appropriate content of a production strategy. The last question addresses decision-making within strategy development.

Research Question

What content must a production strategy for developing economies contain, and how can company, country, and product specifics be integrated into strategic decision-making?

1. Which surrounding conditions in developing economies influence local production systems?
2. How to define requirements for the local production system based on surrounding conditions?
3. Which production strategy parameters are necessary based on the requirements?
4. How do new products, changing conditions, and consumer priorities affect the production strategy?

Figure 2.17: Summary of the research question and the four sub-questions.

3 Conception of the Method

The complexity of decision-making in production strategy development for a production location in developing economies stems from a variety of unknown influential factors on the production system and products. However, the effects between surrounding and production strategic decisions, in particular, are decisive for success in developing economies [4, 6, 14, p. 19, 65, 71]. Because of these effects, many companies and entrepreneurs hesitate to set up production facilities in developing economies [124]. To solve this problem, four sub-questions were set out in section 2.3. Based on the answers to these, a method is developed which allows companies to assess the situation in developing economies in relation to their product and to design an appropriate production strategy.

The following chapter is structured following the description of the research procedure, requirements on the method, and processing of the research question and sub-questions. Each subsection is structured by objective, research procedure, and methodical implementation. Finally, the results are summarized as modules of an overarching methodology. The section concludes with a description of the overarching method.

3.1 Research Procedure, Requirements and Limitations

A four-step research procedure is developed to address the research question (figure 3.1). Based on the prevailing surrounding conditions (*Module 1*) and the resulting requirements (*Module 2*), essential strategy parameters of a local production system in developing economies are presented (*Module 3*). With the knowledge of the strategy parameters, *Module 4* supports decision-making. The six studies published during this conception phase are presented in the following visualized process.

The overall objective of this research is to support production strategic decision-making in developing economies. Therefore, a knowledge repository for production strategy decisions should be created, which is intended to be based on expert knowledge. Using this knowledge repository, comparing scenarios and alternative decision paths is possible.

To fulfill the requirements for a sound scientific approach, the method should be transparent, both for the user and during the creation process. The applicability within the set target framework should be given, and the method and results should be valid in its entirety [125, p. 5]. Thus, the following requirements regarding the method to be developed:

Transparency: The process of strategy development should be transparent and comprehensible for the user.

Applicability: The overall method should be applicable within the scope. Therefore, the

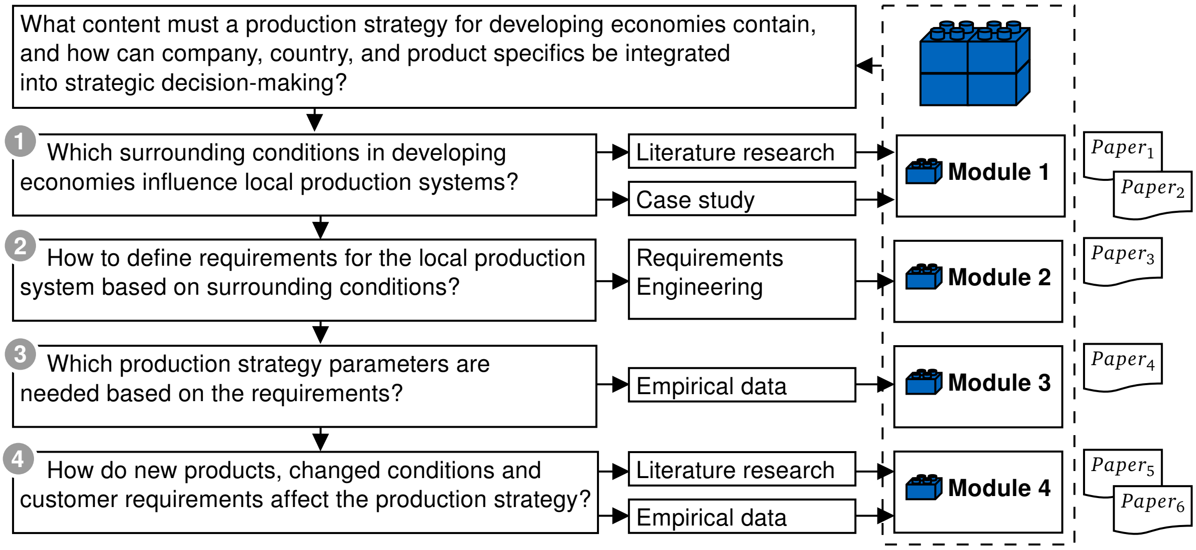


Figure 3.1: Overall research procedure including used method, implementation measures for the method and resulting publications.

influence of the framework conditions, which is initially unknown, should be integrated into the solution-finding process and thus, little prior knowledge of production strategy planning should be required.

Holistic: On the path towards solution-finding, no surrounding influences should be neglected in order to plan the production system in the long-term. For this purpose, the method must be designed for different countries, vehicle concepts, and corporate goals.

Expenditure: The method is intended to support multiple planning. As a result, the effort required to adapt to new application cases should be low, rather than the initialization effort. The method is intended to be applied by several companies, whereby adaptation and optimization should be made possible with little effort.

This work's focus is on the applicability for Small and Medium Enterprises (SME) manufacturers, as reliable information and expertise on production in developing economies for this group of companies is limited [14, p. 31, 126, p. 20]. Additionally, the scope is on automotive companies, since this industry is regarded as a core industry with its vertical and horizontal value chains [4, 7]. At the same time, this industry's product, the passenger or commercial vehicle, as a means of transport, offers further development potential for the local economy. Another scope of development is that the result of this concept is made available as an open-source publication, that can be applied by industry users and for further scientific development.

3.2 Discovery of Influential Factors

Influential factors on production depend on the company, market, and product, and determine the company's production strategy [93, p. 16, 23]. Pawellek [8, pp. 150-151] describes in particular the influence of the product, technology, organization, and production resources as key influential factors. Additionally, Lanza et al. [33] point to the influence of logistics, legal and political framework conditions, and society. Thus, the following subsections describe the objective of an influence factor analysis, the research procedure, and methodical implementation.

3.2.1 Objective

Anderson [127] points out that the lack of information about markets in Africa is a major obstacle in the internationalization of small and medium-sized enterprises. This is supported by Amoaka-Gyampah and Boye [91], who find that the challenge of gathering information applies to Ghana regardless of company size. Therefore, the objective is to identify the case, and company-specific information influencing the production location in developing markets. The influence of surroundings on the company strategy (section 2.2.2) on the production site and in particular on organization, technology, products, workforce, sales, and purchasing, as well as the society, is examined. For this purpose, a survey is developed to query the impact of surroundings as well as a company's abilities. This survey must be based on surrounding influences and their practical relevance known from the literature. The survey implementation should be online to make it expandable in the case of new findings.

3.2.2 Procedure

For a holistic analysis of the impact of surrounding conditions on production and products in developing economies, first, the literature was examined as proposed by Okoli and Schabram [128, p. 7]. This search was conducted using search field matrices, which link individual search terms using Boolean operators. To verify the practical relevance of the results identified in the literature, the case study research method was applied since case studies allow examining a situation in depth in the real-world context [129, p. 15].

For the literature review, the databases of ScienceDirect, a platform for peer-reviewed inter-disciplinary literature, and Scopus, an abstract and citation database for peer-reviewed books, journals and proceedings, were searched using a search matrix (table 3.1). The matrix includes synonyms for the terms "local production", "developing countries"—as their developing economies are interrelated with domestic production [130, p. 4]—and "process design".

Table 3.1: Research with Boolean Operators. Columns are connected by the *or*-Operator and rows by the *and*-Operator. Quotation marks define the relationship of the term.

	AND		
OR	"Local Production" "Local Manufacturing" "Local Assembly"	"Developing Countries" Africa India	"Product Design" "Process Design" "Product Development" "Process Development"

This literature review identified 174 relevant publications in the categories of world development, production, production economics, international business, technological forecast, and social science. After having reviewed the titles and abstracts, 73 papers were selected for the final study. Therefore, literature which is not related to physical products, was excluded. In an iterative step, research papers, books, reviews, and studies cited in the findings or related to the research field of process and know-how transfer were included. The publication period ranges from 1970 to 2018, with an increasing number after 2010 (29 publications, 40 % of the literature findings) with 11 publications dating 2017 and 2018 (15 % of the literature findings). The research was conducted in the period between 2018/08 and 2018/10, and the results are summarized in appendix A.2.1.

Research Results

Within the research of production-related influences in developing countries, six main categories were identified. These are organization and management, technology and processes, products, employees, sales and procurement, and society and politics in developing countries. The following section presents the results of the literature review and is structured by this categorization. The results of this literature research are pre-published in Brönner et al. [131].

Organization and Management in Developing Economies

According to Bullinger et al. [132, pp. 10-11], company organization, and management are significantly influenced by external influences. These are, in particular, the internationalization of markets, associated trade relations, and investments. Business investments depend both, on local financing possibilities [133, 134] and foreign direct investments [30, 135]. These are summarized as the investment climate, which is influenced by market size and stability. Furthermore, political restrictions on local financing also affect the investment climate [134, 136, 137]. Financing decisions are in turn influenced by low expected margins in developing economies, therefore companies face low profits and thus longer maturities until the location investment returns profits [7, 138, 139]. Not to be underestimated is the financial expenditure for the adaptation of products and processes to the local environment, purchasing power, and legal conditions [140, 141].

Besides the monetary aspect, the adaption of corporate culture to the surrounding conditions influences the company. The challenge is therefore to acquire local competence [141, 142, 143], e.g. through local management [144] or partners [145, 146]. According to Lund et al. [147], this facilitates compliance with local standards and regulations and the assessment of local competitors.

The surrounding conditions also have a considerable influence on corporate strategic decisions such as the time to market [148, 149] and the launch strategy for new products [14, pp. 41-42, 150]. This planning is complicated by forecasting demand and the right choice of production volume. However, an accurate forecast of sales figures is essential due to the low margins in these price-sensitive markets [145, 151]. Likewise, the aforementioned assessment of local competition has a significant influence in this regard, since the luxury market in developing economies is nowadays predominantly occupied by foreign products and the low-cost market by domestic products [152]. Table 3.2 summarizes an extract of factors influencing the organization and management of production sites.

Table 3.2: Organizational influences and challenges.

Organization & management 🏛		
Investment • Difficult investment climate • Difficult calculation of appropriate profits • No availability of FDI • Long ROI because of small margins	**Corporate culture** • Existing psychological fear • Availability of local corporate management • Distance to main plant • Availability of local partnerships • Lack of local labor standards • Lack of after-sales processes	**Strategy** • Assessment of local competitors • Duration of time to market & market entry • Uncertainty of demand • Cannibalism effect at the home market • Lack of intellectual property rights • Emergence of spin-offs

Technologies and Processes in Developing Economies

In addition to influences on corporate organization and management, the environment also poses challenges for the technologies and processes used. Due to the difficult financing conditions, and therefore often low investment volumes [146, 153], the processes and technologies must be designed adequately, i.e. rapidly and with little effort [154, 155].

In addition, they should be designed simply and support the employees in their work tasks [14, p. 194]. Developing economies often have no standards in measurement technology and process execution [156, 157]. As a result, the boundary conditions have a direct influence on quality tests, which should be avoided if possible [158]. Therefore, processes must be designed according to local requirements and standards, e.g. concerning waste [145, 154]. This is particularly demanding if no norms and standards are established in the country [154]. The output of processes is determined by employee skills and local technological capabilities [159, 160], and, due to high uncertainty in demand, the processes must be flexible, which also affects the technologies in use. According to Chang and Park [161] and Alcorta [162], the requirement for flexibility relates to the number of units, product mix, and production speed.

The influence of environmental conditions, such as local humidity, temperature, and air quality, influences the production process [163]. Robust processes should therefore be used to be adaptable to any environmental condition. The developed and implemented processes should also meet the requirement of sustainability, which relates to, among other things, the energy consumption of processes and technologies [164].

Furthermore, productivity and performance are cited as presenting great challenges in developing economies [7, 14, p. 35]. These result from high scrap rates, high production times, and lack of resource and process utilization [162]. Additionally, constant process improvement is described to be difficult for companies in developing economies [30, 148]. Also, processes and technologies must be efficient and economical even for small quantities [159]. Table 3.3 shows a selection of influential factors on the choice of process and technology.

Table 3.3: Technological influences and challenges.

Technology & process			
Investment	**Process**	**Environment**	**Productivity**
• Low initial investment • Need for economic efficiency for small-scales	• Complexity and effort of development • Output depends on employee skill level • Lack of process and measurement standardization • Lack of local norms e.g. in waste reduction • Lack of reliable energy infrastructure	• Robustness against environmental influences • Sustainability of technologies and processes	• Low effectiveness and performance • High scrap rates • Lack of capacity utilization • No continuous improvement

Products in Developing Economies

A product, in this case, the vehicle, is the output of the production system. As presented in section 2.2.2, the surrounding conditions, especially the consumer market, impact product design and subsequent production processes. The product design must, therefore, be suitable in price, function, and quality for the area of application and the consumers [100, 151]. Consequently, the number of components should be reduced and standardized [154, 165]. This standardization is essential due to the supply situation in new markets in developing countries [165].

Since the market demands low sales prices, material costs are a key factor [145]. This is particularly critical as companies are forced by local competitors to offer competitive prices [166]. Similarly, the demanding environmental conditions are an extra burden for the vehicle, highlighting the importance of quality assurance [4, 14, p. 214]. Table 3.4 summarizes selected influential factors on product design for e.g. African markets.

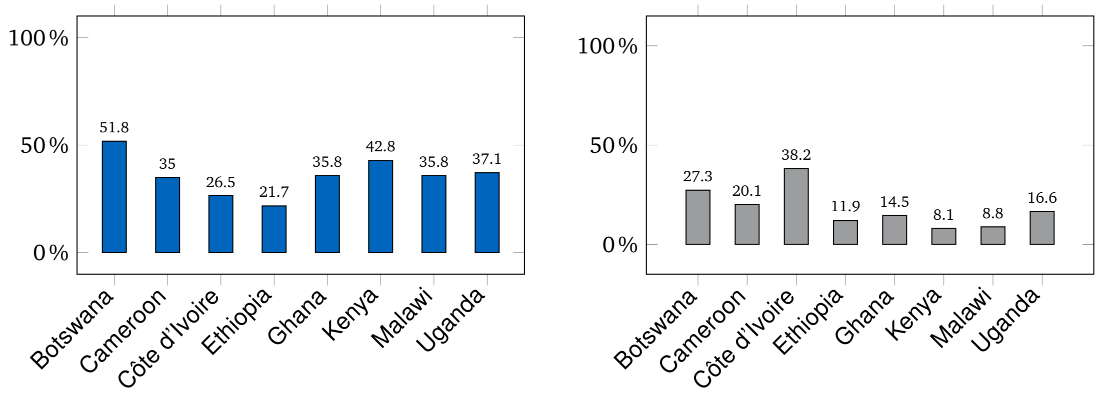
Table 3.4: Product-related influences and challenges.

Product	
Components • Cost, quality and function adapted to surroundings • Number of components adapted to production processes • Lack of standardized components • Availability of resources • Need for involvement of local population • Consideration of life-cycle including reuse • Lack of maintenance processes and spare parts availability	**Costs** • Demand for competitive value • Demand for low material costs • Need for low break-even points • Difficulty realizing economies of scale and scope

Workforce in Developing Economies

One of the decisive production factors in developing countries is the available labor force. Formal education and technical training of the local workforce influence the choice of processes and technologies. The literature especially points to the lack of qualified labor as a challenge in developing regions [14, pp. 38-39, 146, 167]. Likewise, implicit knowledge about complex products is often not yet available [140]. According to Baptist and Teal [136], these and the simultaneously very different qualification and educational standards in developing countries must be taken into account in designing production systems, especially in Africa. This highlights the need to attract skilled workers for employment. Even once employees are trained for their tasks, difficulties remain, as turnover of skilled workforce is a problem that companies must address [168, 169]. It is therefore important for companies to build long-term relationships and trust towards their employees [133, 139]. This long-term success can only be achieved if the local culture and language are integrated into the company [154, 170]. Many companies in Africa have recognized this problem and focus on the qualification of employees, as data from the World Bank's Enterprise Survey shows (figure 3.2).

Thus, in deciding on a know-how transfer process and its development, successful qualification of workers must be planned [170, 172]. A substantial part in this is the age of the technology to be transferred [170, 173]. Table 3.5 shows the influence of skills and choice of technologies with regard to the local workforce.



(a) Percentage of firms offering formal training.

(b) Percentage of firms identifying an inadequately educated workforce as a major constraint.

Figure 3.2: Comparison of the percentage of companies that offer formal training and the percentage of companies that mention workforce education as a constraint in representative African countries. Data source [171].

Table 3.5: Employee-related influences and challenges.

Employee & workforce	
Skill and qualification	**Technologies and Processes**
• Lack of skilled employees	• Choice of know-how-transfer process
• Need for the integration of local culture and language	• Need for an appropriate know-how-transmitter
• Country-specific education level	• Influence of technology age
• Turnover of trained employees	• Appropriate codifiability of work tasks
• Difficulty attracting top talents and managers	
• Need for long-term relationships	

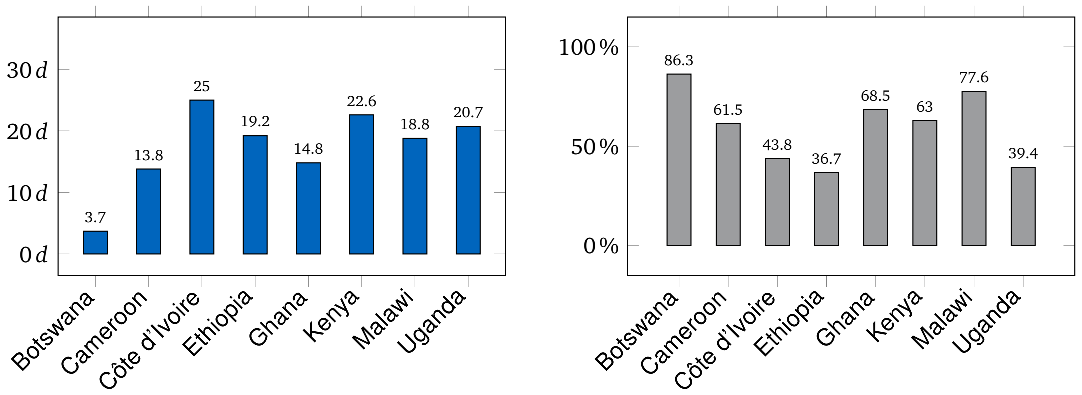
Sales and Procurement in Developing Economies

According to Thomas and Wind [166], it is necessary to integrate local suppliers, both for cost and political reasons. Nevertheless, the required quality and compliance by suppliers is a challenge for multinational corporations [174]. Also, compliance with delivery times and costly communication with suppliers increases complexity [175]. It is therefore essential to aim for long-term partnerships with suppliers, and, at the same time, focus on their continuous development [140, 176]. This will open up opportunities for suppliers to be integrated into the companies' global supply chain. Furthermore, suppliers can also make a valuable contribution to product design through their knowledge of the region [166].

Expensive to transport product modules, such as seats in the automotive sector, should be sourced locally [140]. It is essential to find suppliers who meet the required standards, such as environmental standards [174]. Moreover, it is advised to use standardized off-the-shelf items in the products, since these can often be sourced locally [177].

Especially the infrastructure in developing economies is a challenge for purchasing and sales departments due to high distribution costs and uncertainties. This makes reliable supply chain planning a complex task. This is also referred to in the literature as an underdeveloped business ecosystem [178, p. 10]. To manage this, Gastrow [140] as well as Humphrey and Schmitz [179] propose forming clusters in developing regions as a potential measure.

The World Bank's Enterprise Survey reveals that, in various African countries, for example, Botswana, Ghana, or Malawi, more than two-thirds of the companies depend on foreign materials for further processing (figure 3.3). It is precisely for this reason that the duration of customs clearance must be integrated into time planning. The duration of the import process varies by country and takes up to 25 days on average. This contrasts with the usual processes in the automotive industry, which, according to Göpfert et al. [95, p. 9], attach great importance to reliable just-in-time delivery. Table 3.6 lists influential factors on purchasing and sales processes.



(a) Days to clear imports from customs for manufacturing firms.

(b) Percentage of manufacturing firms using material inputs and/or supplies of foreign origin.

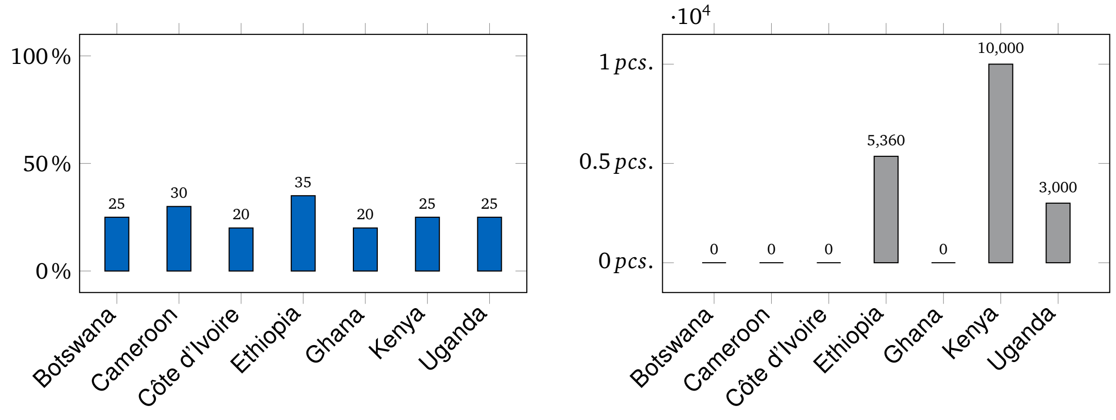
Figure 3.3: Comparison of African countries in days to clear imports from customs, and percentage of companies supplied from outside the country. Data source [171].

Table 3.6: Influences and challenges for sales & procurement

Sales & procurement $			
Supplier	**Product**	**Infrastructure**	**Technology**
• Required local suppliers by authorities • Existing quality issues • Unreliability and inflexibility of suppliers • Need for supplier training • Need for a collaborative partnership • Possible integration into global network	• Demand for established modules • Need for global standardized suppliers	• High logistic and distribution costs • Underdeveloped business ecosystem • No existing clusters • Lack of reliable infrastructure	• Available capability of supplier

Society and Politics in Developing Economies

On the one hand, local policy promotes industry, on the other hand, it is also obliged to define regulations, for example with regard to safety or product recycling [154, 180]. To prevent companies from following purely import-oriented strategies, governments set up guidelines, import duties, requirements for local content, or other tariff and non-tariff restrictions in developing countries [14, p. 12, p. 39, p. 169, 162]. However, there are no uniform regulations for import duties in African countries (figure 3.4). Thus, this poses a challenge for comparable production system planning. Furthermore, in the countries under consideration, import tariffs range from 20 % to 35 % of the vehicle value. Also, e.g. in Ghana, an age limit of ten years for imported vehicles is enforced. In comparison, the imported vehicle's maximum age is eight years in Kenya. But despite high import duties, local car production figures are very low [5, pp. 12-16].



(a) Percentage of import tariffs on vehicles.

(b) Domestically produced vehicles (CKD, SKD and local production).

Figure 3.4: Comparison of African countries in vehicle import tariffs and local value adding. Data source [5, p. 12-16].

The political leadership in developing economies often demands social obligations from companies, for example, a target number of jobs created [14, p. 79, 139]. In some countries, political leadership is committed; in other countries, however, political support for multinational enterprises is either missing or characterized by political uncertainties [14, p. 59, 174]. Moreover, in various countries, companies struggle with corruption and theft [139, 180]. In combination with high employee turnover, this reinforces the challenges of missing reliable intellectual property rights [139, 180].

Conclusion of the Literature Research

In conclusion, the literature research identified influential factors on production design and operation in developing economies. The number of references given in appendix A.2.1 depends on the authors' focus on a region or an influential factor, not on their claim to present them holistically. By comparing influential factors in countries such as Botswana, Cameroon, and Ghana, it becomes apparent, that these factors are not homogeneous, but rather illustrate the heterogeneity of African developing economies. Knowing these influential factors, the question remains whether these are topical and industry-specific.

Case Study

In order to clarify the topicality and appearance of the influential factors in the automotive industry, the case study research method following Yin [129] was applied. This method is acknowledged in the discipline of case research, applied for example by Rosca et al. [145], Mengel [181, p. 7], and London et al. [43]. The case study is pre-published in Brönner et al. [131] and Salah [182, pp. xi-xxvi]. Appendix A.2.2 summarizes the case description and the interview transcript. The following is a summary of the results of the study on the challenges as well as the solution approaches of the examined case.

The vehicle of the examined company, Wallys, was developed locally and customization is done individually according to customer requirements. Individualization for the customer was thus provided from the very beginning of the vehicle development process. The vehicle itself is robust and designed for demanding use. The company offers a basic vehicle type with fiberglass bodywork which makes low investment costs and a low price possible. Due to the low technological requirements compared to deep-drawn components, the bodywork can be supplied locally. Another decision based on the capabilities of the local suppliers is to use straight glass, as no local supplier in Tunisia has the technological capabilities to produce curved glass. The process decisions in the manufacturing and final assembly were made in such a way, that no large investments in automation were necessary, and the processes can be operated manually. To reduce production complexity, the chassis, bodywork, and wheels are standardized. Particularly challenging for Wallys are the lack of product knowledge among new employees and the skilled and trained staff turnover, which is approximately 30 % per year. Due to the lack of knowledge of technical processes, Wallys focuses on intensive in-house training to qualify new employees. Besides training them for their work tasks, the aim is to bring them closer to the company culture, including the necessary time for training and learning. This culture includes continuous improvement, which is exemplarily explained in the interview along with the example of the vehicle doors. Within the improvement process, the gap between door and frame was reduced in many iterations, and the processes were adjusted to smaller tolerances. Another challenge during vehicle development was the local homologation, as local requirements were not specified and communicated. Wallys's solution was to homologate their vehicle in Europe. In a supply chain, quality, reliability, and delivery time of local suppliers are unpredictable. Therefore, Wallys relies on selected, long-term suppliers who have been integrated at an early development stage. Additionally, a full-time employee from quality management for suppliers ensures reliability, and several sources are used for core components to avoid bottlenecks in the supply chain. In the sales sector, after-sales management is challenging because of the widely spread customer base. Wallys's solution to this was to design vehicles in a way that repairs can be carried out by customers themselves or by suppliers like the PSA Group.

The outcome of the study reveals that the influential factors of the surrounding conditions are acute and relevant in the studied case of Wallys. Simultaneously, the study indicates that monetary expenditures are not the decisive factor for the successful solution of influential factors in developing countries, but rather adaptation to local conditions (table 3.7). Both, research and case studies, demonstrate the relevance of different influential factors on production sites described above in section 2.2.2.

Table 3.7: Selected surrounding challenges and solutions [131].

Influential factor	**Solution**
Product	
Reduction of complexity	Straight windshields, fiberglass bodywork
Reduction of components and resources	Continuous improvement
Lack of local requirements	Homologation in Europe
Standardization	Standard components like the drivetrain
Employees / workforce	
Lack of qualified workers	Intensive in-house training, manual work tasks
High fluctuation of qualified employees	Company culture, intensive in-house training
Technological challenges	
Low process complexity	Concentration on assembly
Low investments	No automation
Manual work tasks	Components especially designed for manual assembly
Sales and procurement	
Local suppliers	Building and maintaining a local supplier base
Collaborative relationship	Early integration of suppliers
Unreliable suppliers	Supplier quality management

3.2.3 Implementation as Module 1

The application of the literature research answers the question which factors influence a local production system in developing economies. Thereby, the summary of influential factors on a production site in developing regions reveals that these are complex and interact with each other. A large share has no direct influence on strategic planning of the production system, but rather affects planning and decision-making indirectly, via upstream or downstream processes and higher-level corporate strategic decisions. For this reason, in order to assess the impact on production strategy for a certain location, the effects on the remaining company divisions must also be evaluated. In order to evaluate a company's readiness for production in developing economies, the factors identified by the literature research were integrated into a questionnaire, that is the central element of *Module 1*. This questionnaire was implemented in LimeSurvey [183], a survey development and assessment tool. Due to the number of influential factors, so-called conditional branching questions were used to cluster the expert knowledge [184, p. 31]. This structured branching allows for an easy implementation of context-sensitivity, as follow-up questions can be formulated based on earlier responses [185]. This enables further question levels, which are only pursued if the first question level is applicable or relevant. Thus, the effort for self-assessment is limited. Consequently, the occurrence of an environment-related influence can be queried on the first question level, and the probability of occurrence or accuracy can be evaluated on the second question level (figure 3.5). To identify the internal and external experts necessary to answer the questionnaire, the procedure proposed by Müller et al. [186, p. 93], which is described in appendix A.1.3, is suggested.

Level 1

Are local suppliers able to supply the required quality?

○ Yes ○ No

Level 2

Suppliers can be trained to ensure the required quality. Choose on of the following answers.

○ Absolutely correct
○ More likely correct
○ Not likely correct
○ Absolutely not correct

Figure 3.5: Exemplary conditional questions on level 1 and 2. If the user answers the first question-level negatively, the second question-level follows.

3.3 Definition of Requirements

Requirements specify the relevant capabilities and limitations of a system [187, p. 37, 188, pp. 107-108] and are based on external and internal influences [187, p. 88]. Requirements are defined in the early planning phase of projects and support consensus-building between the stakeholders involved in planning [187, p. 37, 189, p. 1]. The objective of a requirements process, stakeholders, the process, and the implementation are described hereafter.

3.3.1 Objective

Knowing the influential factors for a production site, e.g., in sub-Saharan Africa, internal requirements then have to be clarified. The approach, resulting in the requirements, must be transparent and methodical, especially if production site planning is not an individual case. Additionally, internal stakeholders essential to planning new production sites must be identified. For this reason, the process of requirements engineering [187, pp. 99-106] needs to be adapted to support systematic requirements development.

3.3.2 Procedure

According to ISO/IEC/IEEE 29148:2011 [190, p. 5] a requirement is defined as a "statement which translates or expresses a need and its associated constraints and conditions" and "exists at different tiers and expresses the need in high-level form". A requirements process minimizes the development effort, provides a basis for cost estimation and the preparation of the time schedule. Simultaneously, a requirements claim must be correct, unambiguous, complete, and consistent [191, pp. iii-4]. To ensure this it is necessary to identify the relevant stakeholders inside and outside the company. This identification is particularly important in global organizations, due to the heterogeneity and decentralization [188, p. 72]. A process is then necessary to systematically record the requirements of the stakeholders and store them for further processing. Hence, the following paragraphs describe on the one hand groups of internal stakeholders and on the other hand the process of developing requirements.

Identification of Stakeholders

Stakeholders are persons who directly or indirectly influence a system through their requirements [189], and may vary from project to project [190, p. 8]. Two generally valid groups are internal stakeholders and regulatory authorities. Internal stakeholders for production design are those who are integrated or affected into the product creation. According to Ehrlenspiel and Meerkamm [192, p. 163], these are, on the one hand, marketing and product planning, research and development, materials management and logistics, and manufacturing and assembly planning. On the other hand, there are those involved in manufacturing, such as component manufacturing, assembly and testing, and stakeholders who are responsible for sales, shipping, commissioning, and maintenance. Additionally, management and controlling are involved in the development of internal requirements. Within this process of stakeholder selection, involvement of the various stakeholder groups is necessary, as they have different operational objectives [70, p. 43]. Table 3.8 summarizes the stakeholders and their role in defining the requirements for a production site.

Development of Requirements

Due to this heterogeneity of stakeholders, developing requirements for the strategic orientation of a production site in developing economies requires a methodical process. This demand is reinforced by the rapidly changing conditions in developing economies. A process for the integration of various stakeholder groups and conditions into the requirements development is known from software engineering: the requirements engineering process [187, pp. 99-106, 189]. Based on Sommerville's [187, pp. 99-106] approach, the requirements engineering process for production site planning in developing economies is derived. The proposed process consists of four phases: requirements discovery (1), clustering (2), prioritization (3), and specification (4) (figure 3.6).

Table 3.8: Stakeholders within requirements development based on Ehrlenspiel and Meerkam [192, p. 163].

Role of the stakeholder	Description
Management	Group of clients and decision-makers who ensure that the project is carried out in line with the company's objectives and strategy. Checking consistency with corporate philosophy.
Controlling	Define the project's financial framework.
Component manufacturing and assembly	Responsible for technical goals of the production strategy and the definition of requirements.
Maintenance	Formulate the goals and requirements regarding maintenance, reliability, and recoverability of the equipment.
Shipping and order picking	Defines transport-related requirements.
Manufacturing and assembly planning	Define the requirements for personnel qualification, training documentation, and operating instructions as well as process improvement, workplace design and workplace safety.
Materials management and logistics	Define requirements regarding material supply, procurement, and storage as well as distribution and procurement logistics.
Marketing and product planning	Represent the company and product in the destination country.
Research and development	Defines requirements regarding the development process, product and technologies, and manufacturing processes.
Testing	Define the requirements regarding the quality to be aimed for in coordination with the company goals and external requirements.
Regulatory authority and society	Provide the legal framework and social acceptance.

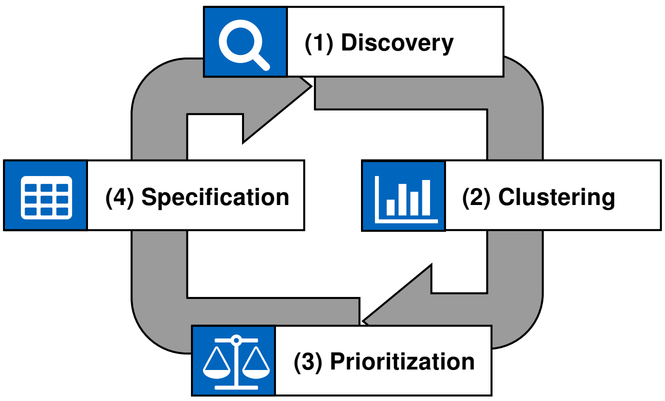


Figure 3.6: Process of the requirements engineering according to Sommerville [187, pp. 99-106].

(1) Requirements Discovery

It is necessary to consider the surrounding conditions to determine the requirements. This can be done, for example, through the questionnaire of *Module 1*. This questionnaire, on the one hand, allows for the allocation of questions to stakeholders. On the other hand, it connects questions by conditional branching, and allows for context-sensitivity [185]. Thus, a positive answer, which corresponds to a surrounding influence, is followed by a question on the secondary level. Based on this, a rough requirement can be formulated. Further procedures to determine requirements include interviews, technical documentation reviews, and simulations. A detailed description can be found in Sommerville [187] or ISO/IEC/IEEE 29148 [190].

(2) Requirements Clustering

The production requirements are clustered into the levels of organizational environment, corporate strategy, and production system (figure 3.7) [193]. For example, requirements resulting from the organizational environment level are influenced by market trends, laws and standards, and available workforce. The corporate strategy level addresses strategic and operational objectives, as well as corporate principles that influence production system design, as described in section

2.2.1. The production system forms the lowest level of requirements. The requirements on each respective level are divided into the organization, product, processes, and resources. This is useful to consider the heterogeneity and decentralization of the knowledge carriers and requirement makers [188, pp. 70-71]. The division in this requirements process is named following the planning fields of the production strategy presented in section 2.2.1, which are employees, technology & processes, product, location & operating material, organization.

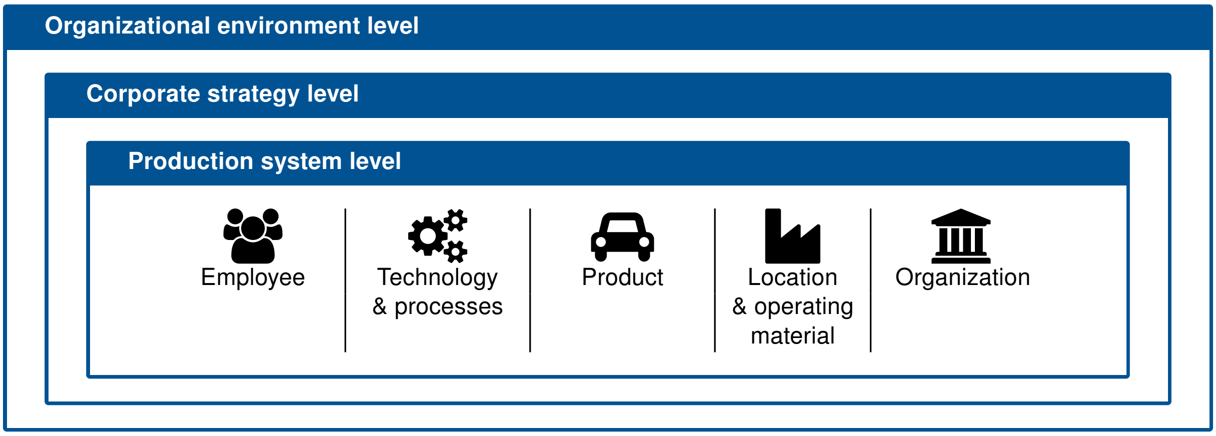


Figure 3.7: Levels super-ordinate to the production system, which can introduce requirements for the production strategy.

(3) Requirements Prioritization

After identifying and clustering requirements, both interrelations and contradictions in the requirements can be analyzed, which allows for prioritization of requirements. Further ranking methods are the House of Quality, evaluation according to effort or costs, which demands an objectification of requirements, and proceeding from the outside to the inside. Hereby, beginning with the environmental requirements, the production requirements are then processed. This process, ranking the system's requirements from the outside to the inside, benefits from known external influences before internal levels are processed.

(4) Requirements Specification

Finally, after the ranking, the requirements are specified. Therefore, the IEEE Std 830-1998 [191, p. 15] suggests uniquely identifiable and maximum readable requirements. To document and specify the requirements uniformly, a template is introduced, which is visualized in figure 3.8. The template shows the linkage of a system component with a descriptive word like must, shall, or should. This procedure simplifies the requirement creation for users, since they can define requirements in natural language [194, p. 62].

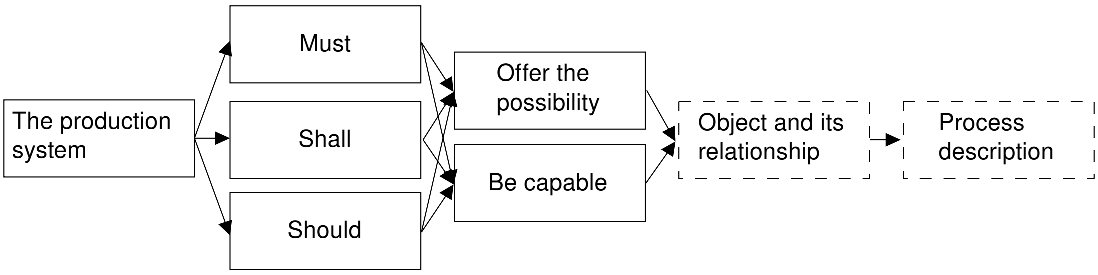


Figure 3.8: Requirements template adapted from Eigner [194, p. 62].

3.3.3 Implementation as Module 2

Module 2 answers the question "How to define requirements based on surrounding conditions?". Thus, the following procedure is proposed for practical implementation:

1. Input of a set of applicable influential factors.
2. Execution of the requirements process to define the requirements.

After *Module 2* is carried out, a defined list of requirements should be available, considering country-specific influential factors. If experts are available for internationalization, either the stakeholder query of the requirements can be omitted, or this group of experts can be additionally involved in the process. The requirements can be supplemented by other known production requirements at this point so that they can be integrated into the further process. If no experts have been selected yet, refer to appendix A.1.3, which introduces a process for selecting experts.

The added value of this approach is the targeted query based on influential factors from the stakeholders, which enables a holistic collection of requirements as requested at the beginning of the section (figure 3.9). Thus, the requirements determine the future capabilities of the planned production site. The approach of requirements engineering allows for systematic development of relevant requirements, and documentation of the stakeholders' needs [189]. An integration of the questions in dependent surveys enables an efficient stakeholder integration if requirements for different use cases have to be queried.

3.4 Development of a Parameter Set for the Production Strategy

Within a production strategy, a production system's configuration is defined. A production strategy parameter describes the structuring elements of production in interaction with the product's essential characteristics [26, 87, p. 6]. Therefore, decision-making based on production parameters not only has to consider operating costs, but also synergies between product development and production [14, p. 113]. Hereafter, the objective of this subsection, the procedure to achieve it, and its implementation are presented.

3.4.1 Objective

The objective of *Module 3* is to derive and confirm an appropriate production strategy parameter set for developing economies, extending and selecting the production strategy parameters of section 2.2.1. The resulting parameter set should specify the production system and summarize the decisions to be taken. Each parameter must be assigned to a decision scope, in which the decision must be made (section 2.2.2). The goal is not to exclude any solution option through dependencies or earlier decisions. The procedure is pre-published in Brönner et al. [195].

3.4.2 Procedure

The process of defining the content of the production strategy for developing regions, i.e. the corresponding parameters, consists of two steps. First, the parameters are derived in order to test them in a second step.

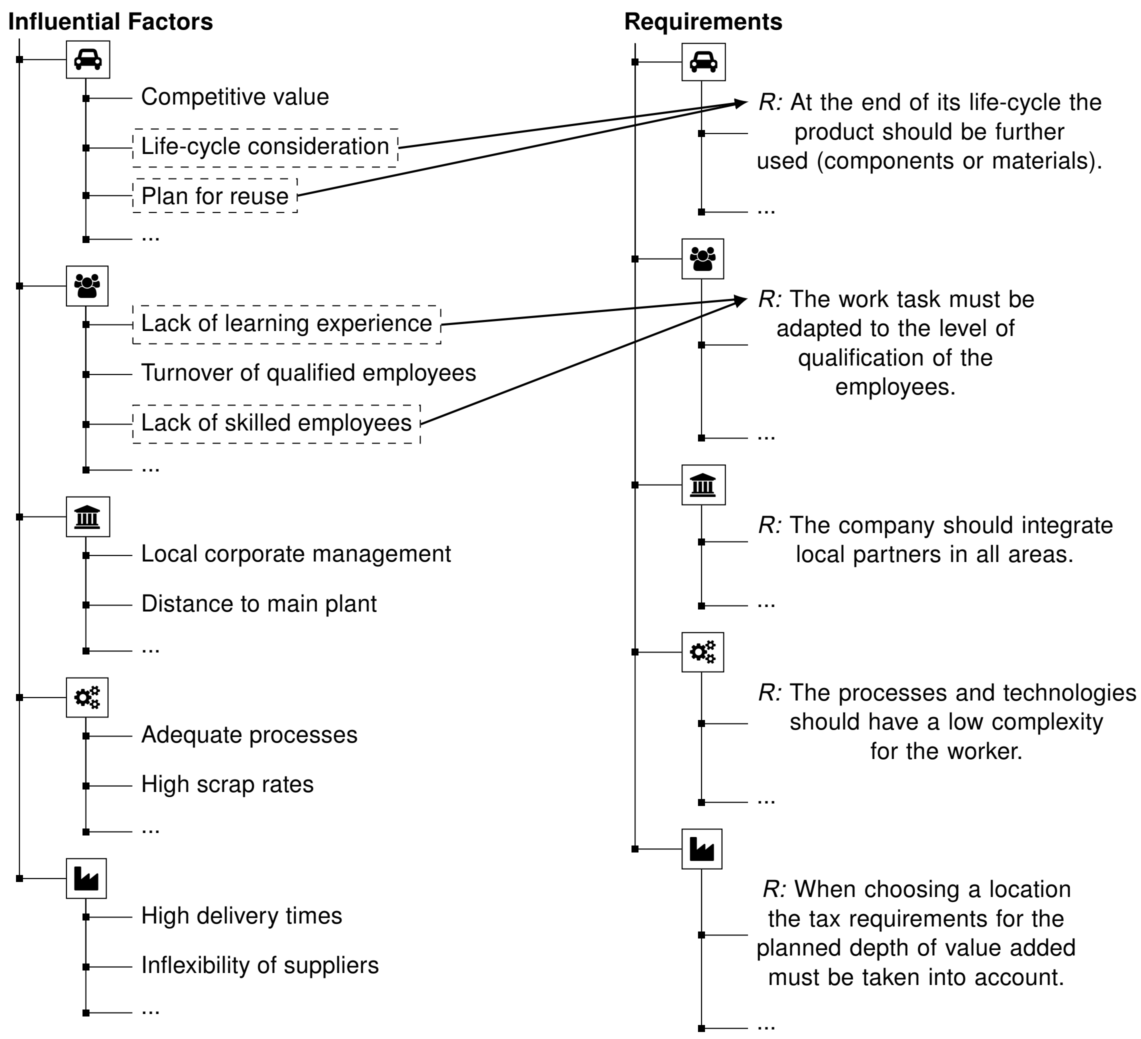


Figure 3.9: Transformation of influential factors (resulting from *Module 1*) into requirements (*Module 2*). Note: *R* = Requirement, the arrows represent the process of *Module 2*.

Derivation of Production Strategy Parameter Set

Using the developed requirements, the set of production strategy parameters and their decision scope are derived, following the logic that, based on local boundary conditions and requirements, the production system design varies. A production system planner has a choice between strategic options to solve the requirements set previously. The developed step-wise process allows for mapping influential factors to specific requirements, and subsequently to the solution space. Here the solution space is defined by the logical argumentation chain of users of the method and participating experts. Figure 3.10 visualizes the transformation of requirements into the solution space. This visualization supports the comparability of requirements with strategic decision parameters, as demanded by Abele and Meyer [14, p. 116]. The solution space of strategy parameters corresponds to the trade-off decisions described in section 2.2.2. With this module, the strategy parameters known from the literature are checked for relevance to the application and, if necessary, extended. The decision scope of the parameter, is to be specifically defined for each company and industry. Within a comparable framework, such as similar products or markets, these production strategy parameters and their decision scope may be consistent.

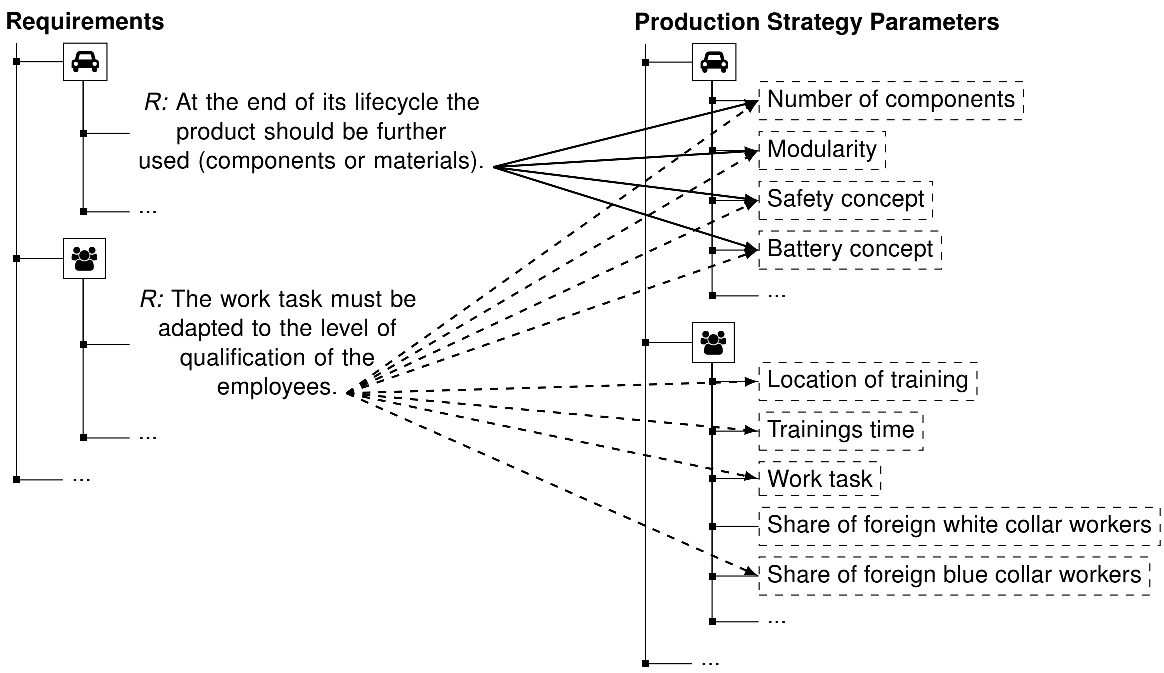


Figure 3.10: Mapping requirements to production strategy parameters. Note: *R* = Requirement, the arrows represent the process of *Module 3*.

Confirmation of Production Strategy Parameters

The ISO/IEC/IEEE 29148 [190, p. 7] describes validation in a system life-cycle context as a set of measures to ensure that a system is capable of achieving its intended purpose, objectives, and targets. To validate the requirements, Sommerville [187, p. 111] suggests multiple experts check for errors and inconsistencies. Thus, the validation of the derived parameters should be carried out through expert interviews. Also, for the selection of these experts, the procedure described in appendix A.1.3 is suggested.

For these interviews, closed questions are suitable [187, p. 104], in which the interviewer records the respondent's answer. According to Döring and Bortz [196, p. 359], this procedure is a quantitative data collection technique. Thus, the validation interview design can be designed as a survey interview. The closed questions of the survey are then formulated as hypotheses since hypotheses are theories that have so far not been proven. The hypotheses are expressed according to the principles of empirical research defined by Döring and Bortz [196, pp. 56-57]. Thus, the formulation of hypotheses is oriented towards their falsifiability, which presupposes the measurability of variables and associated reproducibility of cause-effect relationships.

3.4.3 Implementation as Module 3

The underlying question in *Module 3* is which production strategy parameters are necessary due to the requirements. As described previously, *Module 3* consists of two major steps. First, the set of parameters must be defined, and second, these parameters must be validated.

1. Definition of production strategy parameter set

A parameter set is derived based on the defined requirements for the production site. These parameters describe the solution space for a production site configuration. Thus, this selection of parameters is decisive for the further course of production strategy development. It is recommended to supplement the parameters drawn from the literature review, as summarized in table 2.2. Thus, the specific production strategic parameters for developing economies supplement those for conventional production strategy planning.

2. Confirmation

This summary of production strategy parameters and their decision scope should be confirmed by independent experts (for a procedure to identify experts refer to appendix A.1.3). Hereby, external consultants with expertise in local conditions and internal production planners are suitable. This confirmation can take place through closed surveys with the formulation of a hypothesis. Figure 3.11 shows an example of survey implementation. The first hypothesis tests the developed parameter, and the second hypothesis tests the derived decision scope.

Worker training concept

(1)	Hypothesis:	The worker training concept is an essential production strategy parameter.
	Answer:	○ I agree ○ I disagree ○ I cannot or do not wish to give an answer
(2)	Hypothesis:	The decision scope is between on-the-job and off-the-job training.
	Answer:	○ I agree ○ I disagree ○ I cannot or do not wish to give an answer

Figure 3.11: Example for parameter and decision scope confirmation.

3.5 Decision Support in Production Strategy Development

After having defined the respective production strategy parameters and their scope, decision-making is the next step. The goal of strategic decision-making is assessing alternatives, picking the best alternative, and deriving recommendations for management [29, p. 133]. With the basics from section 2.2.2, the objective for decision support is defined, the procedure for developing the methodical support, and the implementation is presented subsequently.

3.5.1 Objective

A decision support procedure links management input to operational options. Therefore, an evaluation of the production strategy should be based on country-specific conditions as well as corporate strategic goals. This means linking corporate strategy and strategic production parameters within one framework. This further means including the surrounding conditions of the developing economy in focus into the decision-making process. The decision-support model incorporates expert knowledge about interrelations between production strategy, corporate strategy, and environment. To apply to a multitude of SME, the model must be extendable for each company and the model's results should be comprehensible and replicable. To ensure that this decision-making is comprehensible and can be stored for future decisions, it should be made available in a knowledge repository. In summary, the following requirements must be met:

(1) Linking corporate strategy and production strategy parameters

(2) Including production location surrounding

(3) Use of expert knowledge

(4) Replicable results

3.5.2 Procedure

As argued by Lanza et al. [33], qualitative, empirical methods for decision support offer a promising approach, but have so far only been investigated through case studies as decision support in production strategy development. Section 2.2.2 depicts that fuzzy logic is suitable for multi-criteria evaluation in strategy decisions. This suitability is based on the possibility to use qualitative expert knowledge in building a mathematically logical model [81, p. 4]. Fuzzy logic does not require the system to be completely known [78, p. 4], but allows for an iterative adjustment of the model with further knowledge gain [75, 197, p. 17].

With the selection of a fuzzy logic-based model for solving the strategic planning task, a generic framework for the strategy development systems is designed to meet the requirements (1) - (4). This framework forms the basis for the simulation model for production strategy development for developing economies.

Framework

Strategic decisions depend on external influences, such as market volume or higher-level corporate strategic decisions [58, p. 39, 70, p. 81]. At the production level, trade-off decisions must be made as described in section 2.2.2. Following Schotter et al. [85], evaluating external and internal boundaries in global organizations is crucial for long-term success (figure 3.12).

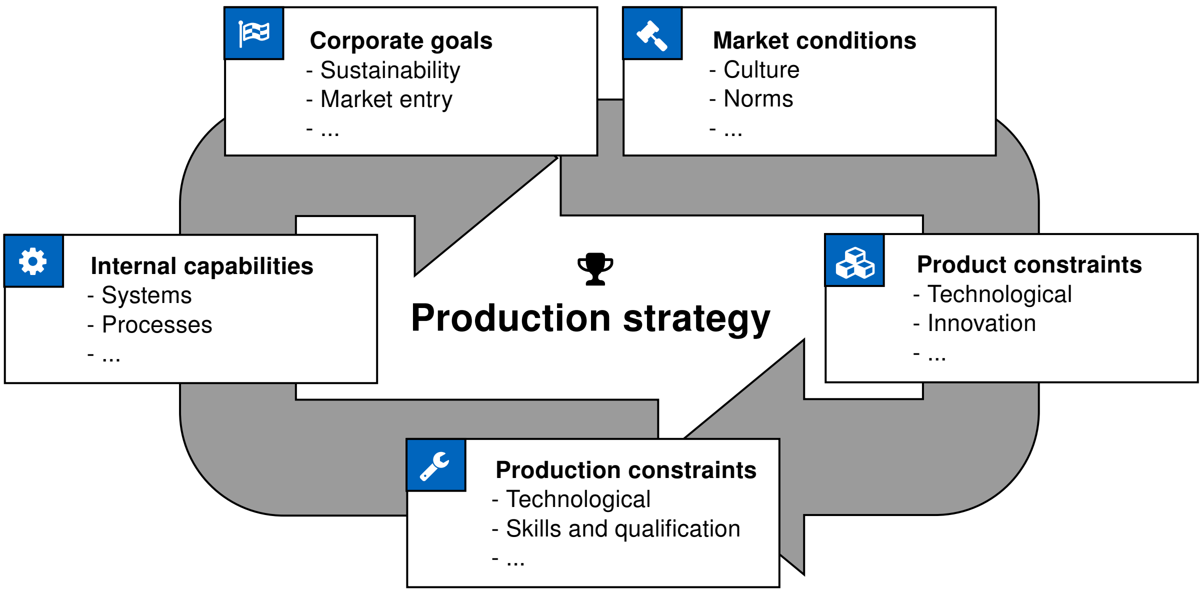
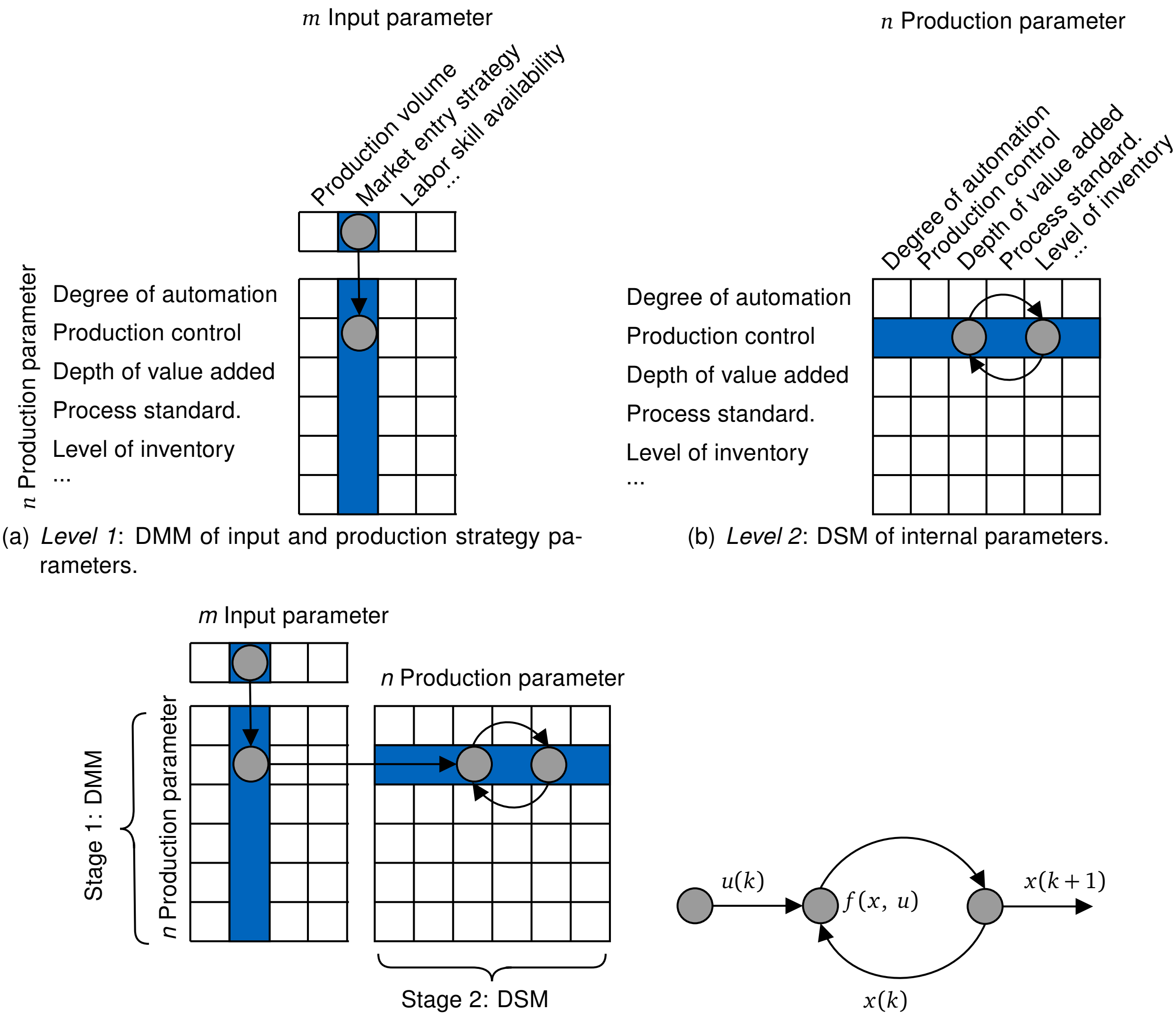


Figure 3.12: Dependence of influences on a production strategy in developing economies.

Thus, a two-step procedure is proposed to incorporate external as well as internal trade-off decisions. On *Level 1*, the external and company strategy influences on the production strategy parameters—developed in *Module 3*—must be mapped out. On *Level 2*, the internal interactions of production planning are considered, as demanded by Dombowski et al. [72]. The corresponding framework is based on the logic of DSM and Domain Mapping Matrix (DMM), whose usefulness has been proven in complex systems of information visualization [198, 199]. According to Danilovic and Sandkull [198], this method's advantage is the visualization of simulation-specific information for all project participants and thus reduce project-specific uncertainty. The DSM captures internal interactions of items of a certain domain by a value entered in a square matrix ($n \times n$). If the direction of action is not relevant, filling in the DSM can be reduced to an upper-triangle matrix [200, p. 260]. The rectangular DMM $n \times m$ allows a connection of several domains (represented by DSM of different dimensions: e.g. $n \times n$ and $m \times m$) [199, 200, p. 260]. This allows to connect an input vector of the dimension $1 \times m$ with the help of a DMM ($m \times n$) with a $n \times n$ DSM. Figure 3.13 (a)-(c) shows the processing of an input vector using DMM and a DSM. To extend this approach of the *Level 1* dependencies—connected via DMM—by the *Level 2* (DSM), a recurrent fuzzy system is proposed (figure 3.13 (d)), as a recurrent system is particularly suitable for building expert systems with a step-wise dependency.



(a) *Level 1*: DMM of input and production strategy parameters.

(b) *Level 2*: DSM of internal parameters.

(c) Procedure for processing the input values.

(d) Schematic of a recurrent fuzzy system.

Figure 3.13: Structure of the two-level approach linking $1 \times m$ inputs with $n \times n$ production parameters as well as the recurrence of production parameter dependency.

After the structure of the framework is determined, the parameters must be defined. The production parameters are taken over from those developed in *Module 3*. The input parameters are based on Porter's [84] diamond or national advantage:

- Corporate goals
- Market conditions
- Internal and external resources
- Pre-defined production strategy parameters

The connection between input and output (*Level 1*), as well as internal dependencies (*Level 2*), are formulated linguistically. An example of such *Level 1* connection is *"labor skill availability"* which is related to *"worker training concept"*. On *Level 2*, the *"worker training concept"* must be fitted with the decision on the *"degree of automation"*. These dependencies are described using the so-called *IF...THEN...*-rules, which form the basis of a fuzzy system. Membership functions connect input and output with *IF...THEN...*-rule. The mathematical evaluation of these rules is called interference [197, p. 7]. For the description of dependencies of *Level 2*, the internal production options, the DSM is used.

The rules of a recurrent fuzzy system are defined as follows [201, 202, pp. 261-264, 203]:

$$\begin{aligned} \text{If } x_1(k) = L_{j_1}^{x_1} \text{ and ... and } x_n(k) = L_{j_n}^{x_n} \\ \text{and } u_1(k) = L_{q_1}^{u_1} \text{ and ... and } u_m(k) = L_{q_m}^{u_m} \\ \text{then } x_1(k+1) = L_{w_1(j,q)}^{x_1} \text{ and ... and } x_n(k+1) = L_{w_n(j,q)}^{x_n}. \end{aligned} \tag{3.1}$$

With equation 3.1, a linguistic vector $\boldsymbol{L_j^x}$ at time k is mapped to a vector $\boldsymbol{L_w^x}$ at time $k+1$ depending on a vector $\boldsymbol{L_q^u}$ [202, p. 266]. Thereby, for each component x_i of the start vector $\boldsymbol{x}$ and component u_i of the vector $\boldsymbol{u}$, a linguistic variable $L_{j_i}^{x_i}$ or $L_{q_i}^{u_i}$ must be defined. It follows, that each rule describes the combination of index vectors by $\boldsymbol{j} = (j_1, ...j_n)$ and $\boldsymbol{q} = (q_1, ...q_n)$ results in $L_{w(j,q)}^x$. The vector $\boldsymbol{w}$ represents a trace from $\boldsymbol{j}, \boldsymbol{q}$ to a specific conclusion. The linguistic variables are extended by weights $g_{L_w(j,q)}$. The weights enable a transparent adjustment of the system dynamics and increase the sensitivity of the input variables [203]. For weighting the following rating is suggested: 1 is very important, 0.6 relatively important, and 0.2 less important.

In the case of a two-level planning system, the pre-publication [115] shows the suitability of a weighted recurrent fuzzy system for the simulation of external-internal as well as internal-internal dependencies. For this system, in line with Schwung [197, p. 16], a Mamdani fuzzy system based on causal knowledge is used. Moreover, minimum or maximum operators are used as operators for interference, and the membership functions are modeled as triangle or trapezium functions [197, p. 10]. For this model, following the example of Stahl et al. [203] as well as Adamy and Kempf [202], triangular membership functions are set up, and the center of sums method as the defuzzification method is chosen for this recurrent system. As recommended by Mencar et al. [204, p. 26], three to five triangular functions are implemented. Following Lee [205, pp. 266-267], the product operator for AND-operations and the maximum operator for OR-operations are chosen for this expert system.

Basic Model

Based on the structure described above, a basic model was developed, which, on the one hand, is intended to demonstrate the applicability of the method, and, on the other hand, provides the basis for its application by companies. This allows companies to begin with a simple initial partitioning and add their parameters and membership functions as required, thereby refining the model to suit the specific company and situation. Systematic procedures for such an adaptation are described in Schwung [197, pp. 17-18]. The model was built in MATLAB 2019a using the Fuzzy Logic Toolbox and App Designer. The rule base and model in use are pre-published in Brönner et al. [115] and made available open-source on GitHub [206]. This basic model was implemented in such a way that it allows less experienced users to evaluate strategies using this solution. An Excel interface for simplified data entry and extraction was also implemented. Figure 3.14 schematically illustrates the function of the basic model. The input values, such as the corporate objectives, are inserted either according to the calculation rule or based on expert assessment and then transformed to the value range of the model. These normalized values are then simulated and, based on the simulation results, recommendations can be made.

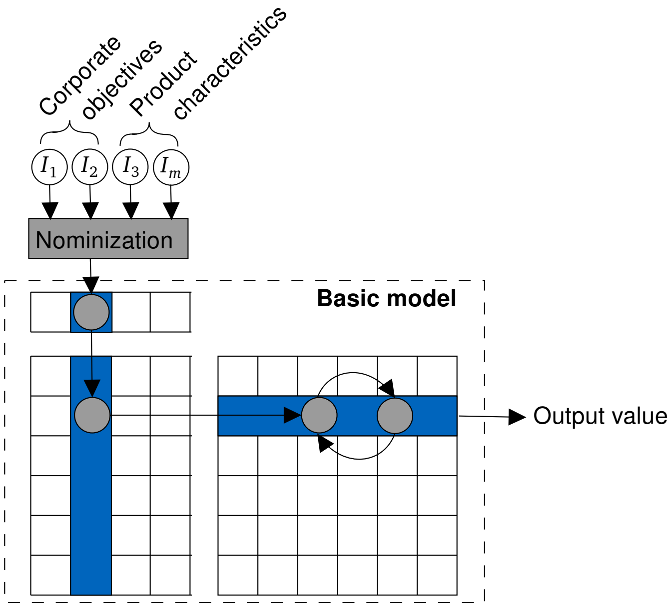


Figure 3.14: Basic model with the interface for entering the normalized input values.

The model design followed the procedure (1) definition of parameters and their value range, (2) construction of relations, generation of rules and weights, (3) test of the features of the basic model, (4) verification and validation.

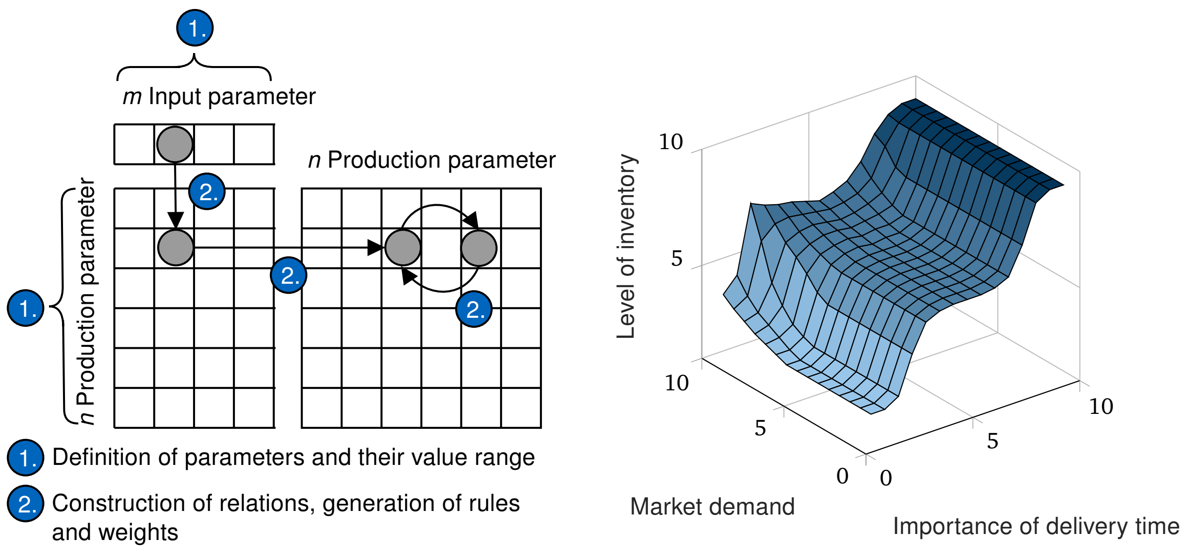
(1) Definition of parameters and their value range: Initially, the production parameters required for strategic planning were defined together with their associated decision scope. For the basic model, in line with section 3.5.2, company-specific goals, market conditions, and internal resources were chosen as input variables. A distinction has been made between input values based on an expert assessment and those based on country-specific factors. An example of such input is production volume. Its description of the input production volume is presented along with the exemplary output degree of automation in table 3.9. The entire model parameters are described in appendix A.2 (input parameter) and A.3 (output parameter).

Table 3.9: Example of parameters and its description.

Input	Description
Production volume	The production volume is a market-specific input factor, since it depends on the size of the sales market. In Africa, the market is usually small, so that products and processes must be adapted to a smaller production volume [144]. The volume has an influence on the degree of automation [207], the selection of operating resources [70], and on the production and assembly line's structure [58].

Output	Description
Degree of automation	The degree of automation, the distribution of physical and cognitive tasks between humans and technology, is described as a continuum ranging from completely manual to fully automatic [208]. A low degree of automation allows for a high degree of flexibility and low fixed machine costs. In contrast, a high degree of automation has the advantage of economies of scale and a lower share of labor costs [14].

(2) Construction of relations, generation of rules and weights: As suggested by Zimmermann [80, p. 211], as well as Al-Najjar and Alsyouf [209], the input parameters were evaluated on a 10-point scale. The remaining value ranges of input variables too, were transformed, as suggested by Kahlert [210, p. 90], into a uniform value range $[1, 10]$. Examples of expert-assessment using the 10-point scale are the importance of delivery time or product cost, where a value of 1 means that the expert rates this parameter as very low, and a value of 10 means that this parameter has a very high priority. Values that are country-specific can be transformed into the value range [1,10] using given calculation rules. This applies, for example, to the availability of local workers, which can be transferred to the value range $[1, 10]$ using the employment-to-population ratio of the International Labor Organization (ILO) database [211]. Appendix A.3.2 summarizes the input parameters and their operationalized value ranges. The corresponding membership functions were implemented as triangular functions following Michaeli [63], Lin et al. [83], and Stahl et al. [203]. Due to the large number of input and output variables, three functions were set up in the basic model, as implemented by Stahl et al. [203]. After the choice of three triangular functions, the expert knowledge, also referred to as tacit knowledge [212, p. 397], was transferred into a knowledge base. For this purpose, the literature proposes expert interviews, expert observation, process data analysis, a generalization of known rules, and automatic knowledge acquisition [210, pp. 87-88, 212, p. 394, 213, p. 165]. In this case, due to the large number of input and output parameters, the first universal rules derived from the literature were generalized, analyzed, extended, and weighted by experts. In total, nine experts were involved in creating and weighting the rule base of 144 rules. Since this model serves as a basis for more detailed models, the rule base must be adapted by company internal experts to meet specific industry and company requirements. Figure 3.15 shows the procedure for generating the weighted rule base and an exemplary rule surface.



(a) Generation of the weighted rule base. (b) Example of a resulting rule surface.

Figure 3.15: Development of the basic model.

When a simulation is complete, the model outputs a sharp value in the continuous value range $[1, 10]$ for each of the selected output parameters. To generate a statement regarding production strategy, these value ranges are assigned to a recommendation. For example, the value range for process choice can be divided into the recommendations "project", "job shop", "batch", "line flow", and "continuous flow". For the basic model, table 3.10 summarizes the assignment of value ranges to recommendations with the respective valuation bases of the classification.

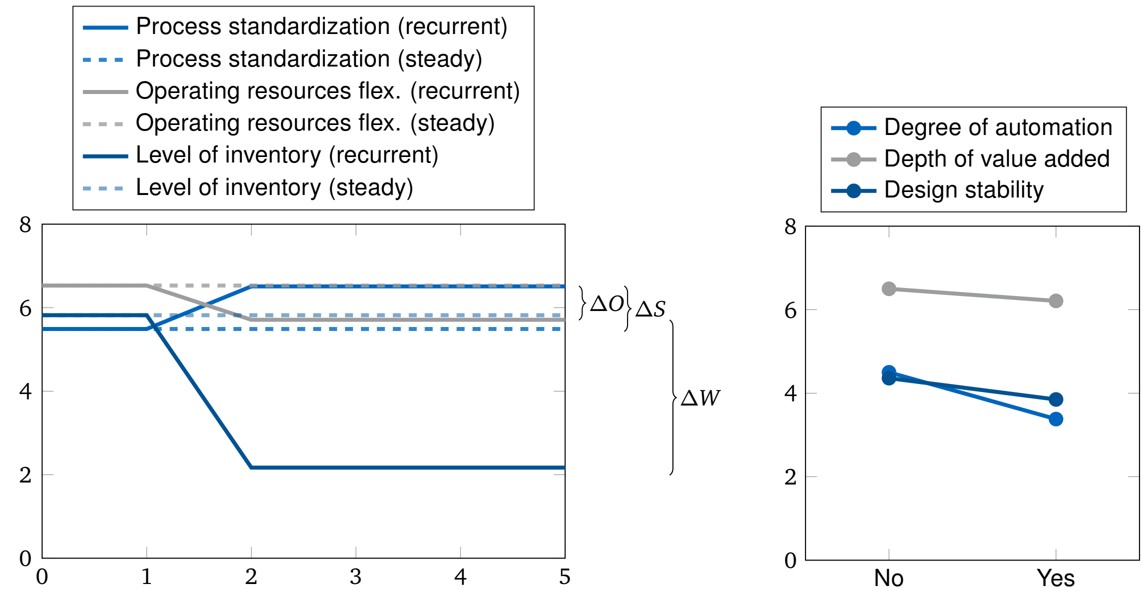
Table 3.10: Output parameters and exemplary interpretation of the simulation values.

$x(k+1)$	1	2	3	4	5	6	7	8	9	10	Additional information
Degree of automation	Manual processes			Hybrid processes				Automated processes			[40, p. 106, p. 193]
Production control	Central control			Hybrid control				Decentral control			[58, p. 326, 214]
Depth of value-added	External production			Differentiated decision				In-house production			[215, p. 34]
Production choice	Project		Job shop		Batch		Line flow		Continuous flow		[58, p. 161, 70, p. 190, 216, p. 240]
Process standardization*	Individual					→				Highly standardized	[14, pp. 204-205, 70, p. 187]
Process coupling*	Intermittent					→				Continuous	[70, p. 190]
Operating resources flexibility	Special resources			Depending on process				Multi-functional resources			[58, p. 162]
Operating resources life-cycle	<7 years operating time			7-14 years operating time				>14 years operating time			[217, p. 121]
Production technology	Low-tech			Medium-tech			High-tech		Super-high-tech		[70, pp. 652-653]
Production network	World factory				Hub and spoke			Local for local			[14, pp. 164-168, 18, 33]
Process scaleability	Local/small			Regional/medium				Global/huge			[70, pp. 260-261, 218]
Level of inventory*	No inventory					→				High inventory	[14, p. 291, 58, p. 163]
Quality control	No control			Statistical control				Continuous control			[40, p. 16]
Design stability	Frozen design			Adaptable design				Continuous improvement			[14, p. 204]
Worker training	On-the-job training			Instruction and training				Off-the-job training			[105, pp. 68-73]
Integration of society*	No integration					→				High integration	
Staffing strategy	Local staffing			Cross-country staffing			Expatriate staffing				[14, pp. 249-251]
Incentives for employees	No incentives			Non-monetary incentives			Financial Incentive				[14, p. 259, 95, p. 165]

*Continuous output value

(3) Test of the features of the basic model: Figure 3.16 (a) illustrates the effects of integrating internal dependencies using a recurrent feedback system, as discussed in Brönner et al. [115]. For example, an inventory concept with high stock levels would be simulated due to external inputs (*Level 1*) if internal dependencies (*Level 2*) are considered. With this two-level approach, the output value is adjusted by ΔW through the connection of level of inventory and production control, degree of automation, and product type. Thus, this system adds product design as a significant influence, which is in line with Morton [219]. Although the inventory level largely depends on demand and its fluctuation [70, p. 366], the relevance of internal connections of a production location in developing countries is emphasized by Abele and Meyer [14, p. 62] as well as Mefford and Bruun [71, 123]. In the example, process standardization and resource flexibility are also significantly altered by integrating internal dependencies (ΔS and ΔO). The adaption of process standardization on product characteristics is always associated with financial expenditure and, concurrently, process standardization allows for a more appropriate adaptation of production to the workforce's education and qualification level [14, p. 33, 65, 71].

Weighting the dependencies rule base allows for optimization, as the importance of rules is adjusted [80, p. 248]. Moreover, complexity in the rule base generation by experts is reduced as weights are added in a later step. As no additional rules are required, the rule base complexity does not increase, allowing for a better model interpretability [203]. Figure 3.16 (b) illustrates how the degree of automation output is reduced by 25 % in the weighting process. This is based on weighting the rules of dependency between production volume, flexibility, worker training, and standardization. Improving output quality is crucial, as, for example, the degree of automation is essential for unit cost calculation [14].



(a) The impact of recurrence on the output value. Five iterations are visualized.

(b) The impact of weights on the output value.

Figure 3.16: The impact of recurrency and weighting on selected outputs of the basic model [115].

(4) Verification and validation: Prior to applying the basic model, its validity was tested. According to Adriaenssens et al. [220], a valid fuzzy model for decision support is measured by the value it provides to its users. The complexity of validating an expert system, however, becomes evident through the fact that its result represents only a recommendation, and is therefore difficult to determine as right or wrong [221]. On the contrary, one advantage of a fuzzy system is the interpretability and thus the possibility to verify results by the user [197, p. 177].

Studies summarizing validation procedures discuss both the verification of a model and its validation. On the one hand, it is necessary to verify a model, i.e. to correctly design the model structure, and, on the other hand, to validate the model, i.e. to ensure the quality of decisions [222, 223, 224]. The verification of the model structure, the implementation of the rules, and the recurrence are explained in Brönner et al. [115], so that, in the following, the validity of the model must be proven. For the validation of expert systems, a multitude of procedures have been suggested in the literature [222, 223, 225, 226, 227], which are covered by the overarching concepts of component validation, overall system validation, and statistical methods. Proposed methods of component validation include rule validation, heuristics, and meta-models. Test cases, Turing tests, control groups, and sensitivity analyses are used for overall system validation. The statistical methods use the classification of experts into categories to confirm the hypotheses made based on model validity [222, 223, 227]. In the following, two procedures for expert validation and analysis of sensitivities are applied.

For expert validation, test cases were defined, which were then solved by both, the model and experts [222, 223]. As suggested by Suen [226], the test cases were based on real situations. The evaluation by experts was done in a survey, as this format can be processed quickly and accurately. The purpose of the survey was to assess whether the experts trust the model results [226, 228]. This was implemented by confirming or rejecting the simulated results as hypotheses. Due to the complexity of the rule base, the background information to this hypothesis was described as a simplified dependency (meta-model), as suggested by O'Keefe [222, 223]. Lavoie and Daim [229] give threshold values between 67 %, and 75 % for acceptance by experts.

Two cases were defined and tested with two procedures to validate the basic model. Within one procedure, the experts themselves assessed the output values for the production strategy parameters. A 10-item Likert scale was therefore used for the expert assessment to ensure comparability with the basic model's outcome. In the other procedure, the simulated results of the model were presented to the experts based on hypotheses. The hypotheses described the outcome of the simulation and could be confirmed, rejected, or not answered by the experts. To fulfill the requirement of fast processability and to prevent preconditioning of the experts, the experts were randomly assigned to two groups. Each group evaluated the hypotheses for one test case and assessed the production strategy parameters of the other test case. Table 3.11 shows the two groups of experts, their assignment, and test procedures. To ensure the functionality of the study, a pre-test was conducted with n = 5 persons, the results of which are included in the overall evaluation.

Table 3.11: Dividing the experts into two randomized groups to process the survey. Number of participants after exclusion of participants with below average knowledge.

Procedure	Test case 1	Test case 2	Description
1. Evaluation	Group 1 (n = 14)	Group 2 (n = 8)	Evaluation of the hypotheses based on the simulation results by the experts.
2. Assessment	Group 2 (n = 8)	Group 1 (n = 14)	Assessment of the production strategy parameters by the experts.

As suggested by Suen [226], the experts were invited from different geographical regions (Germany, Sweden, Austria, Ghana, South Africa), based on their knowledge of production and operation execution as well as management, and knowledge of automotive production in developing economies. For example, the survey was distributed to members of the African Association of Automotive Manufacturers (AAAM), an association of automotive manufacturers, suppliers, and consultants to create an environment for automotive industrialization[1]. The statistical data on the experts are given in appendix A.4.4. Survey participants whose self-assessment values indicated below-average experience in the mean value in the subject areas of production development, production strategy development, developing economies, or the automotive industry were excluded from the study. This reduced the number of experts from n = 27 participants to n = 22 experts for validation.

The result of the expert evaluation of the hypotheses reveals that, with an acceptance rate above 75 %, 13 of 18 results are confirmed. With the lower criterion of 67 % acceptance rate, 16 of 18 results are accepted (appendix A.4.4). The hypotheses on the quality control receive 66 %, and the design stability receives 65 % agreement.

These results correspond to the expert assessment, where the average deviation of the assessment is 25 % (quality control), and 27 % (design stability). For this reason, these two parameters are critically reviewed in the further course of the validation. Comparing the deviation of the mean value of the expert assessment to the simulated value, 15 of 18 results deviate by a maximum of 25 % and only one result (number of expatriates with 36 %) deviates more than 33 % (appendix A.4.4). In general, the self-assessment of the experts must be critically reviewed based on their previous knowledge, organizational roles, or bias concerning the topic [223, 224], since "[v]alidation is a critical factor in a field where subjectivity tends to override other considerations" [227]. This also applies if the model is supposed to perform better than an expert [222], as inputs and outcomes may be difficult to be evaluated separately [224].

To further test the developed basic model, a sensitivity analysis was carried out, as it allows for validation of the model's feasibility and robustness [14, 220, 222, 224, 227]. A sensitivity analysis allows to transparently present the dependencies of an expert model [222] and to test the impact of different surrounding influences [226]. A validity check through a sensitivity analysis is performed examining outputs concerning the input values and their expected change with new inputs [221, 224, 227].

In the following analysis, the input factors are therefore examined to determine importance based on this basic rule base. For this reason, the screening method designed by Morris [230], which allows for examination of model parameters utilizing a grid search, was applied. This screening method reveals more and less important input parameters affecting the output parameters [231, p. 22, 232, p. 91]. The Morris method varies a factor per time step and outputs two sensitivity measures. μ indicates the overall effect on an output and σ the secondary or higher value effect [232, pp. 92-93]. Campolongo et al. [233] extend the μ effect to μ^*, which indicates the mean value of the distribution of the absolute values of the elementary effects (EE) [233] and improves avoiding incorrect classifications (i.e., classification of relevant parameters as irrelevant) [231, p. 36]. These elementary effects are a central component to the Morris method, and the elementary effect of the *i*th input factor is defined as [232, pp. 94-95, 234, pp. 35-36]:

$$EE_i = \frac{[y(x_1, ..., x_{i-1}, x_i + \Delta, x_{i+1} ..., x_k) - y(x)]}{\Delta}. \tag{3.2}$$

In this case, the function y depends on k parameters, and $\boldsymbol{x} = (x_1, x_2, ...x_k)$ represent the values of the test area. Δ is a value in $(\frac{1}{p-1}, \frac{2}{p-1}, ..., 1 - \frac{1}{p-1})$, where p describes the number of levels [231, p. 23]. This results in μ, μ^* and σ:

[1] AAAM, founded in 2015, is an association of African automotive manufacturers focusing on the expansion of the automotive industry in Africa (https://aaam.africa/).

$$\mu_i = \frac{1}{r}\sum_{j=1}^{r} EE_{i,j}, \tag{3.3}$$

$$\mu_i^* = \frac{1}{r}\sum_{j=1}^{r} |EE_{i,j}|, \tag{3.4}$$

$$\sigma_i^2 = \frac{1}{r-1}\sum_{j=1}^{r} (EE_{i,j} - \mu_1)^2. \tag{3.5}$$

Saltelli [232, pp. 94-108] provides a more detailed description of the application. This work applies the implementation in Matlab [235], including the method's extension by Sohier and Piet-Lahanier [236]. Small σ and μ^* values, in this analysis, have a low overall influence and are almost independent, whereas high values indicate high importance of these values due to their dependency [232, p. 96, p. 107]. Figure 3.17 shows the results of the Morris analysis, and, in the following, parameters with large influence and a high standard deviation (highlighted with focus) as well as noticeable parameters of expert validation (number of expatriates (), quality control (), design stability ()) are discussed.

The Morris sensitivity analysis of the model illustrates that the labor skill availability (3) on incentives for employees ($) has the highest standard deviation. This dependency is expected since considerable efforts in worker training ($\triangle$) must be undertaken when facing low qualifications. It is therefore essential to secure these workers by providing additional incentives [14, pp. 196-197, 95, p. 165]. The high standard deviation σ means that the secondary effects of this input factor on other output variables, too, are high [237]. Overall, three of the four highest mean values result for the qualification level of employees, which is following Abele et al. [14, p. 147], "an important indicator of a location". This statement is supported by Göpfert et al. [95, p. 175], who claim that production should be adapted to the level of training of regional workers. The employee influences described in section 2.2.2 also refer primarily to their skill and vocational training level. For the production network (), the analysis highlights the dependency of production volume (1), delivery time (5), and flexibility (8). A dependency between the production network and production volume is expected, as these decisions are crucial in designing the production network [14, pp. 164-168, 33]. This essential correlation is also mentioned by Black et al. [5, p. 14] in their investigation of African countries' suitability for automobile manufacturing. Likewise, the connection between network structures and delivery time and flexibility is shown by Matt et al. [101] and Rauch et al. [100] in connection with production in developing economies.

The expert assessment on the number of expatriates for production in developing economies was divided, which is why their dependencies are examined in detail below. The sensitivity analysis shows that the number of expatriates () is dependent on the availability of employees (18), the skill level of the employees (3), and their behavior concerning employee turnover (19). According to Abele et al. [14, p. 56, pp. 97-98], a statement about the number of expatriates depends on the country and company's staffing strategy and particularly depends on the training of the available workforce. This is also in line with the observation of Midler [21, p. 21] at the Renault plant in India. Mefford and Bruun [71] report on successful projects by Japanese companies that have deployed a large number of expatriates in developing economies and Lanza et al. [33] note the

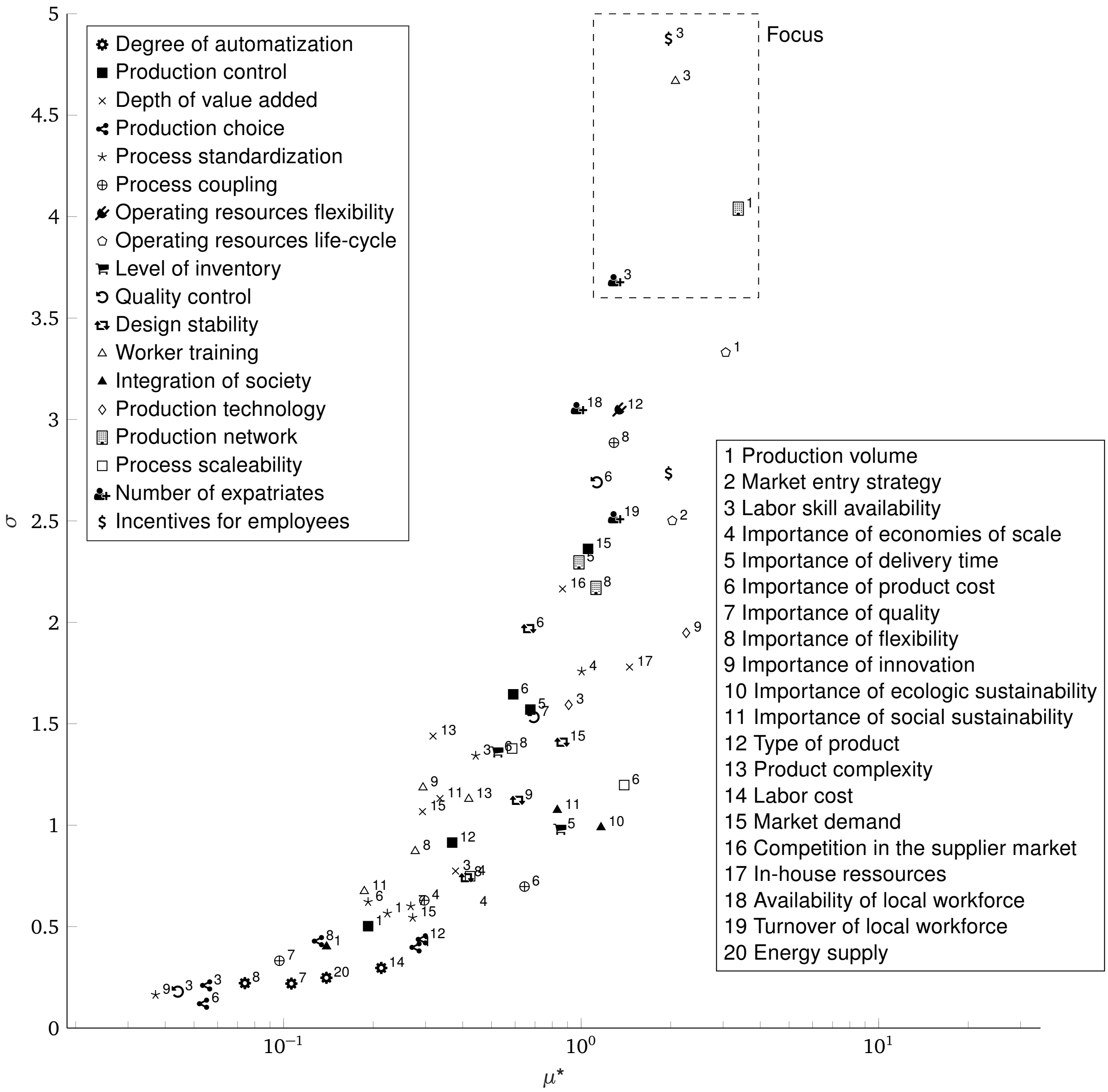


Figure 3.17: Morris sensitivity analysis: Impact of the model inputs (1-20) onto the model outputs (marks). Highlighted are outcomes with high standard deviation and high distribution of elementary effects. The plot shows the importance of labor skill availability onto these outcomes.

dependency of staff turnover, differing qualification levels, and temporary expatriates in global production networks. Wang et al. [238], in their study on expatriates and knowledge transfer in China, too, show the relevance of expatriates for building up local management skills and illustrate the dependency of qualifications on local employees. Due to the low expert confirmation for the parameter "number of expatriates", it is changed into the parameter "staffing strategy", as the relevance of the "staffing strategy" is exposed in the literature. Thus, in the following, staffing strategy is defined as the ratio of local to expatriate workers.

For quality control (↺), the sensitivity analysis shows the influences of the input values importance of product cost (6) and the importance of quality (7). The correlation of an investment in quality control on product quality and unit costs in manufacturing is confirmed as significant by a study of manufacturing companies in Ghana [91]. Additionally, the importance of quality and costs as part of a production strategy decision in Ghana is confirmed in a further study.

Hereby, companies are particularly concerned with meeting the increasing quality standards of their customers and focus, for example, on reducing defective rates and implementing quality control circles [92]. Since these dependencies correspond to the expectations from the literature, the parameter is retained in the model.

The connection between adapted product design (🔁) and increasing product specialization in the new market is described in Abele and Mayer [14, p. 205, p. 214]. Furthermore, in their study of local production facilities, Brand and Thun [239] show that increasing competitive pressure is leading to local adjustments in product design. This competitive pressure of design changes can be attributed to cost pressure in the low-end segment and to technological innovation in higher-end segments. Design changes are also often made by companies to generate a new sales market in other segments. Domestic firms tend to expand from the low-end segment into the mid-range segment, while foreign firms are moving from the high-end segment into the mid-range segment [152, 239]. Local adaptations enable companies like Hyundai in India, with low-powered, fuel-efficient engines, tropical air conditioning, and higher vehicle clearance, to secure a large market share [14, pp. 18-19]. Since these dependencies correspond to the expectations from the literature, the parameter is retained in the model.

In summary, the experts confirmed the model's results and a comparison with their assessment shows the added value of the simulation, due to the small deviations of the mean value of the expert estimate with simultaneous deviations in the individual assessments. The output values not explicitly confirmed by the experts were further investigated using sensitivity analysis. Overall, the discussion of the sensitivity analysis results indicates that the changes are to be expected and that the model is therefore operationally valid according to O'Keefe et al. [222], Sojda [224] as well as Saaty and Ergu [227]. Nevertheless, validation is only a snapshot [222] and must, therefore, be carried out anew with every adaptation of the model.

3.5.3 Implementation as Module 4

The decisive production strategy parameters are derived from the preceding *Module 1, Module 2* and *Module 3*. This means that the decision scope is determined before *Module 4* is proceeded. Figure 3.18 shows the procedure of *Module 4*, which is explained in the following paragraphs.

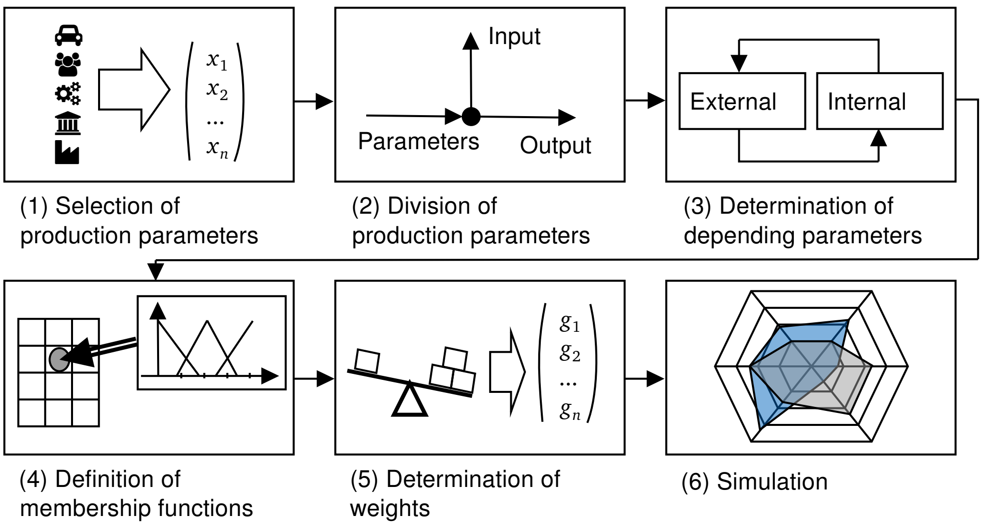


Figure 3.18: Procedure for parameter setting and simulation. The procedure is based on conventional procedures for creating fuzzy systems. In addition, the focus is on the decision between already defined company-specific input parameters (e.g. type of product) and the output parameters to be determined (e.g. degree of automation).

To develop the simulation model, the parameters to be evaluated must first be selected (1). It is advisable to select the essential production parameters for the further steps at this point to reduce complexity. Then, (2) the production parameters must be subdivided into those to be specified (outputs) and those already specified (inputs). Subsequently, the DSM and DMM matrices must be filled (3), the membership functions defined (4), and weighted (5) by experts (experts may be selected as described in appendix A.1.3). Figure 3.19 shows a template for the matrices and visualizes how the internal dependencies form a triangular matrix.

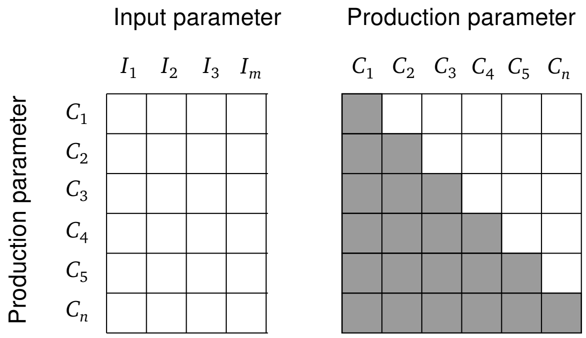


Figure 3.19: Template of dependency matrices. At least one dependency for each of the *m* inputs must be defined in the m x n matrix. If no rule in the *m x n* matrix affects a production parameter *C*, a rule must be defined in the *n x n* matrix. Otherwise, this parameter does not affect the system and can be discarded.

The rules and weightings can either be determined directly by experts or set up in a two-step procedure. The latter consists of a collection of known rules, e.g. from the literature or the subsequent evaluation of suitability by experts [115]. It is suggested to use the information known from the requirement definition to determine weightings. Finally, the results are simulated and defuzzified (6). To simplify the application of the basic model, the procedure summarized in appendix A.3.4 is recommended.

In order to evaluate decision alternatives, the economic impact of the production strategy on unit costs must be assessed. For this purpose, the cost of goods sold should be assessed on the basis of local material costs, production costs and development, sales, and distribution overheads. This monetary valuation can be done by experts or integrated in the model, as shown in Pelka [240].

3.6 Summary of the Method for Production Strategic Decision-Making

Previously in section 3.1, the method's goals, and requirements were defined. The method is required to be transparent, holistic, and applicable with little effort within the defined application framework. Furthermore, the method intended to be specifically applicable to developing economies and SME. For this reason, the method is composed of four individual modules that can be applied independently (figure 3.20). Following, the modules are described for an overview.

Module 1 forms the baseline of the overall methodology, in which the willingness to manufacture in developing economies is tested on a company and product-specific basis. To support this, a conditional questionnaire is designed, which is available open-source. The basis of the questionnaire is the literature and practical research described in section 3.2. The results of the

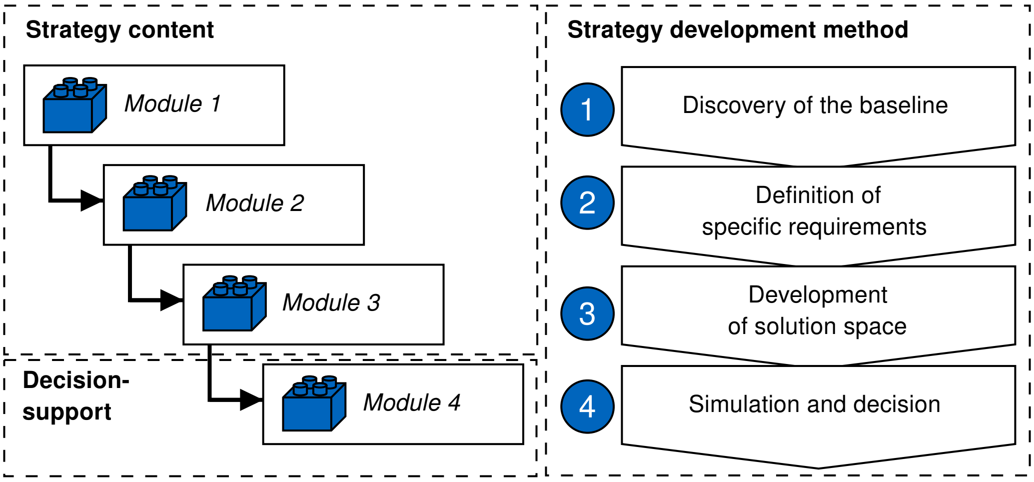


Figure 3.20: Modules to define the strategy content and support decision-making along with the four-step strategy development method.

questionnaire sensitize for the further course of strategy development because it queries the prevailing conditions and their effects in a condensed form. In addition, it queries the responsibilities of the respective planning tasks based on company departments and stakeholders.

Module 2 determines the requirements for a production facility and its development in developing economies. Structuring by organizational level, business operation level, and production level, as well as the stakeholders involved (table 3.8), is proposed to reduce the complexity of the planning task. The procedure is based on the requirements engineering process following the steps requirements discovery, requirements clustering, requirements prioritization, and requirements specification. The requirements should follow the form of the requirements template (figure 3.8) to ensure consistency.

Module 3 derives parameters of a production system, which represent the solution space for the set requirements. These parameters must be confirmed by experts and, if necessary, supplemented or, in the case of already defined parameters, reduced at this point. It is advisable at this point to also integrate external experts, if possible with local knowledge, into the confirmation process.

Based on the solution parameters, a recommendation regarding the production strategy must be developed. For this reason, *Module 4* provides a procedure for transferring this decision process into a fuzzy expert system that can map both internal and external-internal relationships. By applying this model, for example, scenarios in the development of markets or for comparing different countries or regions can be simulated (figure 3.21). This opportunity considers the dynamics of the surrounding factors' influence and company strategy for a long-term orientation of the production system. Thus, well-founded recommendations regarding the strategy are developed. To reduce the effort, or if the previous steps have not been completed, a basic model is developed, which links corporate strategic objectives, product characteristics, and country specifics with conventional production strategy parameters. This model is available open-source and users may extend the model company, and industry-specific. To assist the interpretation of the simulated output values, specific information is summarized in table 3.12. If the simulated results are not satisfactory, an iteration of the overall process is recommended, to further specify the parameters and rules of the simulation model.

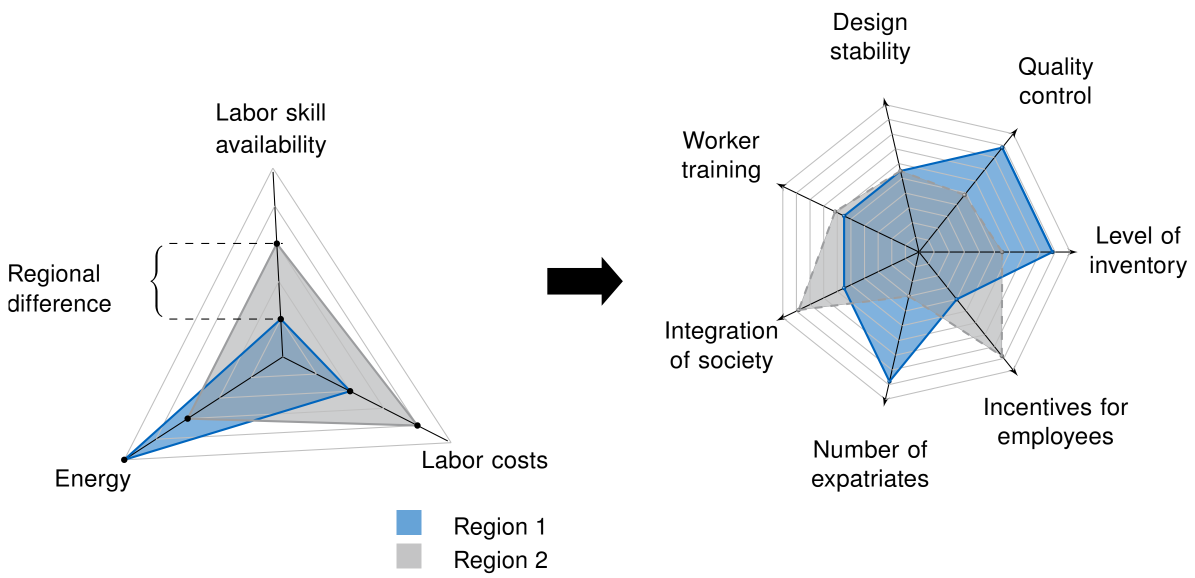


Figure 3.21: The impact of regional differences onto the output variance.

Table 3.12: Output parameters and respective additional information.

Output	Additional information	Source
Degree of automation	▸ Automated and hybrid assembly systems	[40, p. 106]
	▸ Fields of application of assembly systems	[40, p. 193]
	▸ Assembly technology for electric vehicles	[216, pp. 254-263]
	▸ Differences between assembly and manufacturing	[58, pp. 172-174]
	▸ Ramp up of hybrid manufacturing systems	[241]
	▸ Dependency of volume and automation	[14, pp. 198-199]
Production control	▸ Comparison of production control strategies	[214]
	▸ Integrated push-pull strategy and decoupling points	[242]
	▸ Trade-off between push and pull strategies	[243]
	▸ Bottleneck resources	[70, p. 691]
Depth of value-added	▸ Concentration on core components	[93, pp. 430-434]
	▸ Supply chain position and core components	[215, pp. 28-35]
	▸ Supplier integration in developing economies	[21, pp. 53-60]
Production choice	▸ Production choice depending on volume (automotive)	[216, p. 240]
	▸ Production choice depending on volume and task	[58, p. 161]
	▸ Dependency of process task, flow, variety and volume	[57, pp. 94-102]
Process standardization	▸ Production complexity and process standardization	[57, p. 129]
	▸ Choice of production technology and product design	[14, pp. 204-205]
	▸ Standardization of links	[216, p. 106]
Process coupling	▸ Coupling of technology	[57, pp. 240-241]
	▸ Coupling and automation	[14, pp. 219-220]
	▸ Workplace design and flow assembly	[40, pp. 157-170]
Operating resources flexibility	▸ Capacity flexibility	[40, pp. 98-100]
	▸ Approaches for a flexible assembly	[244, pp. 6-7]
	▸ Change of requirements in developing economies	[144]
Operating resources life-cycle	▸ Life-cycle of operating resources	[217, p. 121]
	▸ Product life-cycle and operating resources life-cycle	[40, p. 517]
Production technology	▸ Optimized production technology	[57, pp. 456-457]
	▸ Production technology and economies of scale	[14, pp. 67-70]
	▸ Production technology for developing economies	[144]
Production network	▸ Production networks, economies of scale and scope	[14, pp. 164-168]
	▸ Design and operation of global production networks	[33]
	▸ Local content, CKD and automotive production network	[18]

Continued on next page

Table 3.12 – continued from previous page

Output	Additional information	Source
Process scaleability	▸ Geographic technology scale	[218]
	▸ Scale of technology	[57, p. 240]
	▸ Serial processes and distribution of value-added	[216, p. 35]
Level of inventory	▸ Inventory, delivery volume and service requirements	[14, p. 158, p. 291]
	▸ Logistic and level of inventory	[95, p. 157]
	▸ Inventory management	[245]
Quality control	▸ Quality control and product design	[14, pp. 213-214]
	▸ Management and quality	[246, p. 186]
	▸ Quality control and standards in developing economies	[65]
Design stability	▸ Product design and local adaption	[14, p. 204]
	▸ Local adaption: Renault Kwid	[21, pp. 39-41]
	▸ Customization and core competence	[93, pp. 433-434]
Worker training	▸ Worker training and human resource management	[105, pp. 247-252]
	▸ High voltage safety	[216, pp. 32-34]
	▸ Training and education in developing economies	[247]
Integration of society	▸ Technology and society	[247]
	▸ Inclusive markets in developing economies	[248]
	▸ Society and multi national corporations	[123]
Staffing strategy	▸ Local staffing, executive staffing, know-how transfer	[14, pp. 249-251]
	▸ Expatriates in developing economies	[71]
Incentives for employees	▸ Incentive systems in production	[95, p. 165]
	▸ Staffing in developing economies: Hero Honda	[14, p. 259]

4 Results

After having presented the process of method development in the previous section, in the following section, the approach is applied, and the results of this application are presented. The results are divided into the description of the case study, the application of the method, the simulation of scenarios, and the implementation recommendation for the aCar Mobility project.

4.1 Application: aCar Project

The methodology was applied within the aCar project (section 1.1). A start-up emerged from this project in 2017, aiming to commercialize the aCar and internationalize its production. The start-up's headquarter is located in Munich and the company started the ramp-up of a small-scale series for Germany in 2020. Following the start of series production, international production locations are planned. These are preferably to be located in developing economies to promote sustainable development. Thus, to achieve long-term economic sustainability for the company and social and environmental sustainability progress on-site, the impact of changing surrounding conditions on the production location concept is investigated. This process is intended, on the one hand, to reduce the effort when planning several production sites in various countries, and, on the other hand, to reduce uncertainties regarding future market developments. Due to the company's current size and therefore limited financial resources, there is no possibility of applying a conventional entry strategy with a shared value-added at the home plant.

The aCar is a cost-effective passenger and commercial vehicle reduced to essential vehicle components. The most important competitive priority in current planning are the costs in the sub-Saharan region. The focus of vehicle development is, therefore, on simplicity, functionality, and robustness. So far, there is no competitive situation in the developing economies with regard to low-cost electro-mobility, and the market for vehicles specifically adapted to rural environments has not been occupied by major manufacturers yet.

Based on this situation, a production strategy was developed for the first international production site in Ghana. The effects of future market changes, such as increasing demand, changing customer requirements, and competition, are integrated into this development, as is the transferability to other African countries. For this reason the scenarios

1. *changing competitive priorities*,
2. *increasing demand*,
3. *different countries*, and
4. *different vehicles*

are simulated for the production strategy.

4.1.1 Module 1 to Module 4

With the knowledge of the environment-specific situation in developing economies already available and since the internal stakeholders were aware of the research project, its results, and the conditional questionnaire, the application of the method started with *Module 2*. Internal stakeholders involved in the method application were responsible for corporate management, business development, and production planning. The resulting requirements of *Module 2* were assigned to the categories of employees, organization and management, location, technology and process, and product (appendix A.4.2). This procedure resulted in 12 requirements for the employee category, 19 requirements for the product (the aCar) category, 23 requirements for the area of technology and process, and 7 requirements for the location. In total, 39 requirements were defined for the organization.

These requirements formed the basis to define the production strategy parameters and their decision scopes according to *Module 3*. It should be emphasized that requirements from the employee category, such as the high turnover of qualified employees, can also be met by parameters from the process category, such as process complexity and standardization. This highlights the complexity of strategic location concept decision-making. Within the methodology, a confirmation of the developed parameters by both internal and external local experts is proposed. For this reason, seven experts were interviewed within the application. This team of experts consisted of project staff from the start-up, as well as entrepreneurs, vocational training staff, and scientists from Accra and Kumasi (Ghana). Among the participants, two experts stated experience in corporate, business, or production strategy, four experts reported experience in production, manufacturing, and assembly, two experts stated experience in qualification and training, and one expert in engineering. Throughout these interviews, attendees validated the parameters, whereby at least six experts agreed for each parameter, with 85.5 % of parameters approved by all experts. Appendix A.4.6 summarizes the interview results.

Within the application of *Module 4*, non-relevant parameters, that were already defined, were excluded. Moreover, it was found that the parameters specified in the base model are sufficient for the use case. For this reason, the implemented parameters of the model are utilized for simulation, and results are transferred based on table 4.1 into use case-specific recommendations.

4.1.2 Simulation

With the initialized model, the scenarios described in section 4.1 were tackled, and, as a common reference for the scenarios, the strategy for the local production of an aCar in Ghana was simulated. The following section first describes the scenarios and then presents the results of the simulations. The scenarios are described partly in Brönner et al. [250] and the input data is summarized in appendix A.14. Finally, the scenario's simulation results are compared, and a recommendation for the implementation in Ghana is derived.

Scenario 1 - Changing competitive priorities: As the markets develop, consumer priorities change. This is currently the case in India, where, for example, the customer focus for vehicles is shifting from price orientation to price-performance orientation [6]. A successful vehicle developed in response to this change is the Renault KWID, which is developed and produced in India [4, 21]. This scenario, therefore, examines the impact of changing competitive priorities. Simulation competitive priorities 1 examines a shift from pure costs to quality, innovation and sustainability. This shift in customer focus is reinforced in the simulation competitive priorities 2.

Table 4.1: aCar project specific conversion of the simulation results into recommendations. A description of the categories is summarized in Heinke [249, pp. 45-61].

Production parameter	1	2	3	4	5	6	7	8	9	10
Degree of automation	Manual	Static hand tools		Flex. hand tools	Auto. hand tools	Static work stations		Flexible work stations	Fully automated	
Production control	Make-to-stock		Configure-to-order	Assemble-to-order		Manufacture-to-order		Engineer-to-order		
Depth of value-added	Incl. production of components		Incl. production of systems		Incl. production of modules			Final assembly of vehicles		
Production choice	Workshop production		Group production			Flow production				
Process standardization	Low standardization			Medium standardization			High standardization			
Process coupling	Interrupted processes				→					Connected processes
Operating resource flex.	Special operating material			Both depending on process			Multifunctional operating material			
Operating resource l.-c.	<7 years operating time			7-14 years operating time			>14 years operating time			
Production technology	Conventional			Case depending			Innovative			
Production network	World factory			National			Local for local			
Process scale-ability	Local/small			Regional/medium			Global/huge			
Level of inventory	No inventory				→					High inventory
Quality control	No control	Final control	Final and incoming control		Statistical control			Continuous control		
Design stability	Design freeze		Critical changes allowed			Versioning of the vehicles			Cont. improvement	
Worker training	None	Into the job				On, along, near the job			Off the job/home-based	
Integration of society	No integration				→					Integration in every decision
Staffing strategy	Local staffing (1-5 Expatriates)			Cross-country staffing (5-15 Expatriates)			Expatriate staffing (15-30 Expatriates)			
Incentives for employees	No incentives			Non-monetary incentives			Financial Incentive			

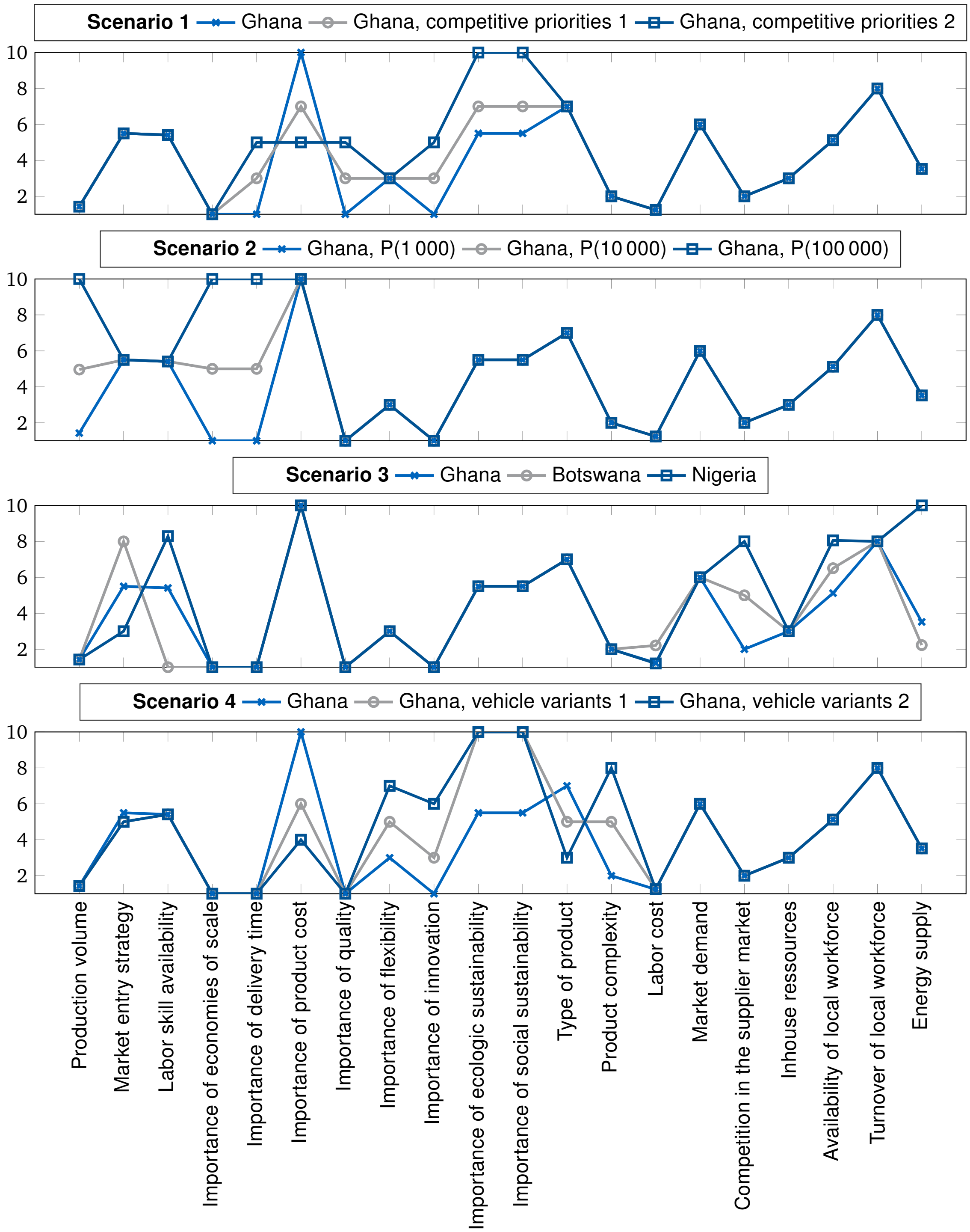


Figure 4.1: Input values of the four scenarios in reference to Ghana.

Scenario 2 - Increasing demand: Entering new, closed markets is often the primary objective of local assembly or production facilities in the automotive industry [87, p. 48, 108, p. 34]. Thus, market development and, consequently, increasing sales figures must be integrated into the strategic decision of the production configuration [108, p. 37]. Especially in developing markets, a great dynamic in the growth of sales figures is expected [251]. The Ghana P(10 000) simulation, therefore, examines the increase in production volume from 1 000 to 10 000 units, changes in delivery times and the priorities of economies of scale. A further increase to 100 000 units is considered with the second simulation Ghana P(100 000).

Scenario 3 - Different countries: Even if product requirements remain unchanged, adapting production to a new location is a financial challenge [14, p. 205]. Especially countries in Africa differ significantly in market size and thus sales volume. In addition, the supplier market and the available quality differ. Moreover, the availability of trained workers is also heterogeneous [5, pp. 6-8]. Thus, this scenario investigates the extent to which different country-specifics have an impact on the simulated results. For this reason, the inputs for Botswana, as an African upper-middle-income country, and Nigeria, as another lower-middle-income country, are simulated.

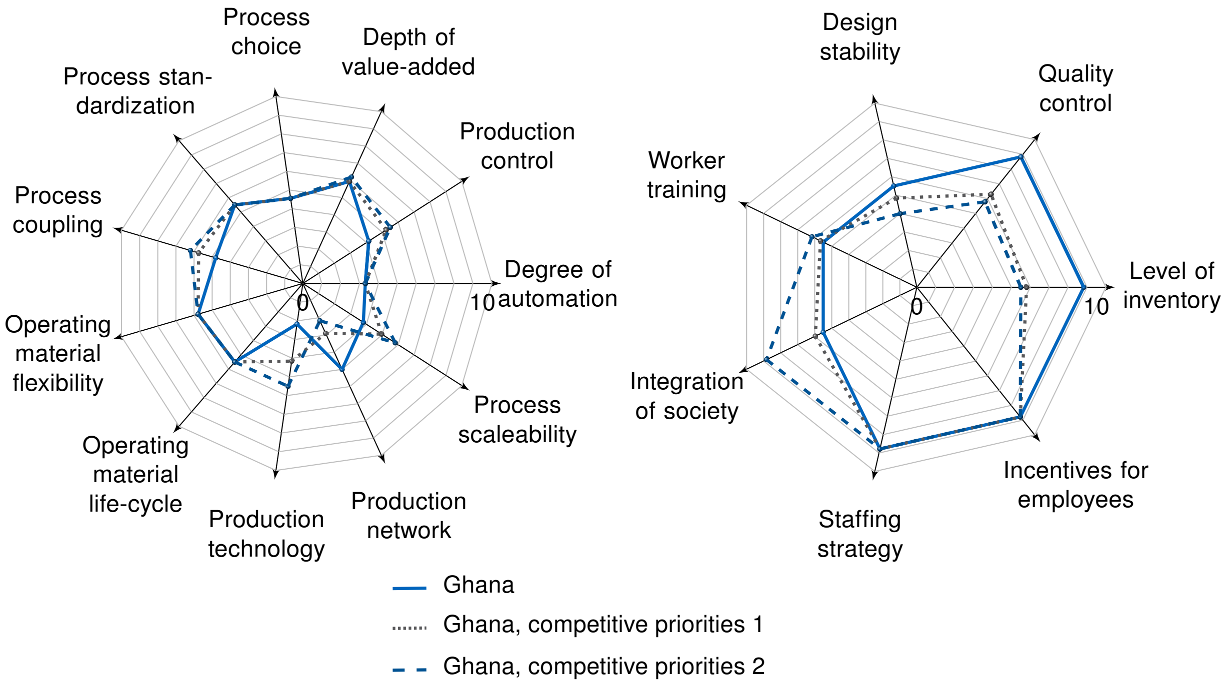
Scenario 4 - Vehicle variants: Especially in developing markets, consumer requirements are constantly changing [65] and customer-specification of the developed vehicles is increasingly important [6]. Therefore, the assembly of several vehicle variants on-site to address different customer groups becomes of interest. In this scenario, the changes caused by new vehicle variants are evaluated. Thus, the two simulations of different vehicle models 1 and 2 simulate, on the one hand, the change in priorities and, on the other hand, changes in the product type and its complexity.

In summary, the four scenarios include changes in customer priorities and demand (figure 4.1). Furthermore, the differences in environmental conditions are worked out along the example of two other African countries. The fourth scenario simulates an expansion of product range with additional vehicle variants.

The results reveal differences and similarities of production strategy directions for various scenarios. With emerging markets, consumer priorities and their product requirements change, as simulated in *Scenario 1*. While simulating changing priorities, it becomes evident that, the technological capabilities of the production system, like the production technology, scaleability and its control procedure, have to be adjusted (figure 4.2). Additionally, the inventory level needs to be adapted to lower levels due to an increasing priority on shorter delivery times. Consequently, the production control tilts slightly towards more pull processes. Due to the changed customer priorities in, for example, delivery time, the quality control in both simulated cases has to be reduced compared to the reference simulation. The simulation indicates no effects on the depth of added value, operating material (life-cycle and flexibility), worker training, and the staffing strategy. As the company demands for social commitment increase, so do the requirements for integrating the local community.

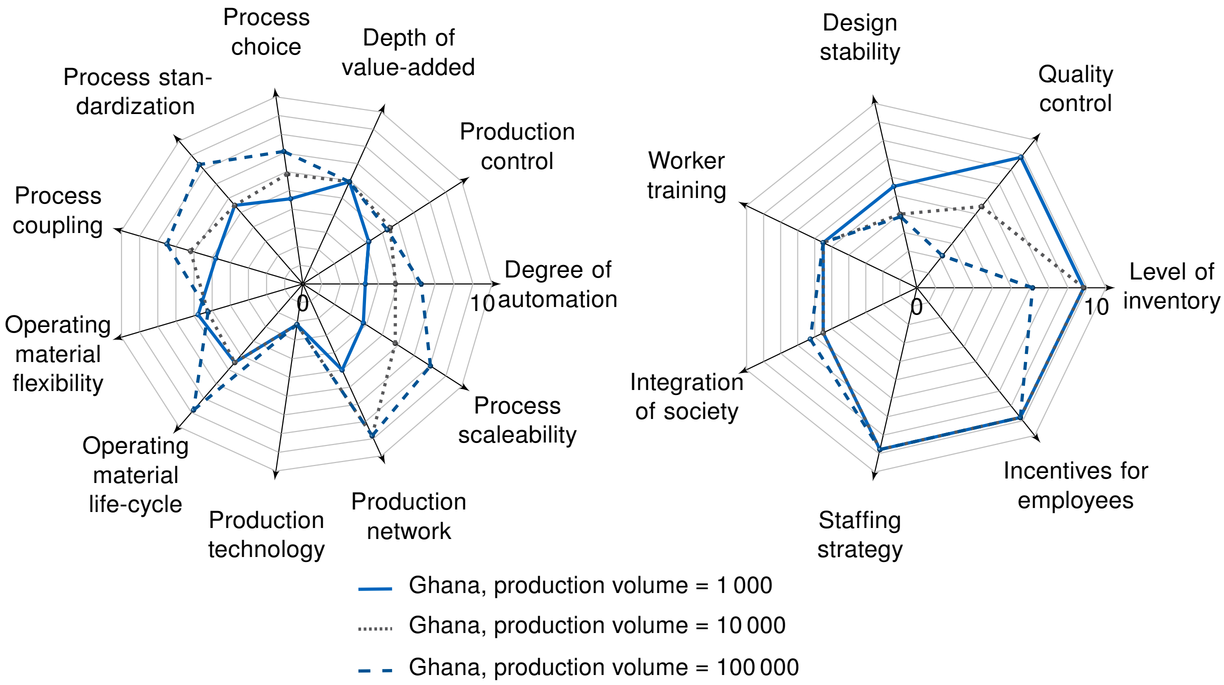
Simulating increasing production volumes (*Scenario 2*) reveals significant changes in the production structure (figure 4.3). As volumes increase from 10 000 to 100 000, for example, the standardization of processes becomes significantly important, as well as process coupling and planned automation. The planned operating material life-cycle and the scaleability of processes also move further into focus. The orientation of the production network shifts from a local-for-local approach for a small volume towards integration into a global network for higher volumes. On the infrastructural side, quality control output, and the level of inventory output decreases with increasing production volume. By contrast, recommendations regarding the depth of value-added, the flexibility of operating resources, or the staffing strategy does not change within these simulations. Constant input values regarding skills and worker availability and worker turnover result in constant values regarding incentives and worker training.

The countries Botswana and Nigeria (*Scenario 3*) have no influence on the degree of automation, flexibility of the operating material, or production network in comparison to Ghana (figure 4.4). With better supply capabilities in Botswana and Nigeria in comparison to Ghana, the depth of value-added increases. Regarding the structural strategy parameters, it becomes evident that



(a) Structural production parameters.　(b) Infrastructural production parameters.

Figure 4.2: Scenario 1 - Changing competitive priorities.

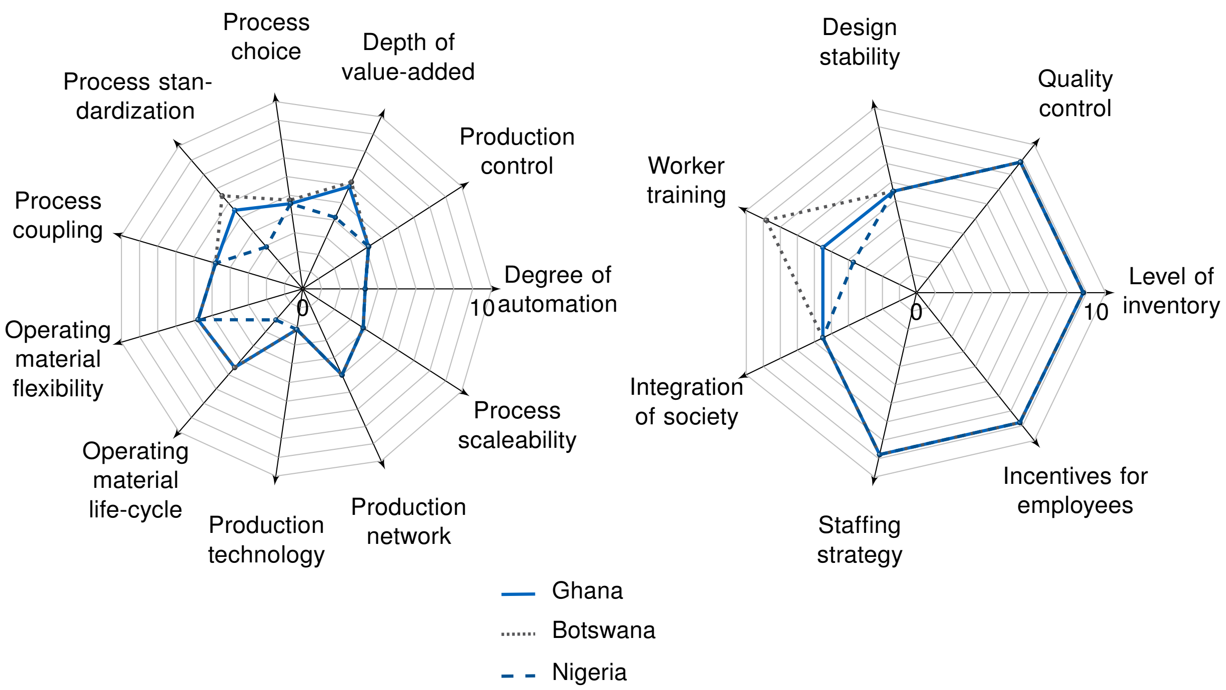


(a) Structural production parameters.　(b) Infrastructural production parameters.

Figure 4.3: Scenario 2 - Increasing demand.

despite Nigeria and Ghana being among the lower-middle-income countries in Africa [171, 252], the simulated results indicate more differences than between Botswana, which is among the upper-middle-income countries and Ghana. The infrastructural strategy parameters only indicate changes in worker training expenses, as these are reduced by changing abilities of qualified workers.

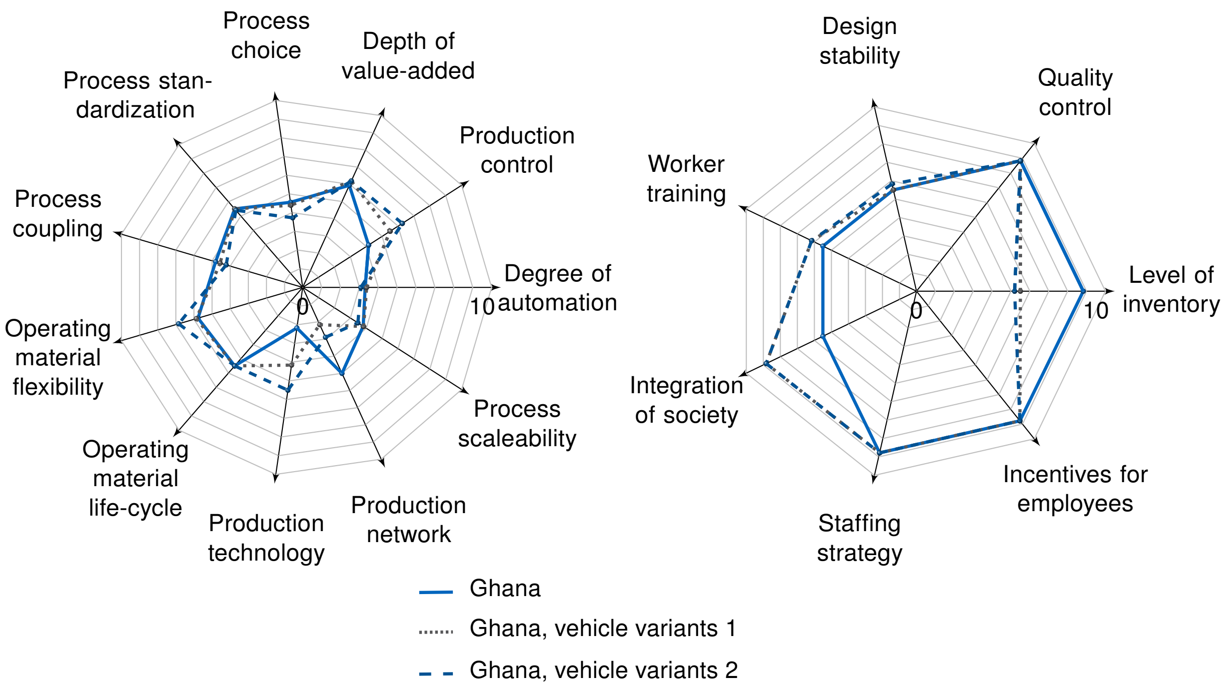
The simulation of different vehicle variants (*Scenario 4*) reveals the change in technology of



(a) Structural production parameters. (b) Infrastructural production parameters.

Figure 4.4: Scenario 3 - Ghana, Botswana and Nigeria.

the processes, and increasing requirements on inventory planning, production control, and technology (figure 4.5). Zero or only small impact is indicated through this simulation in, e.g., worker training, integration of local authorities, or staffing strategy oriented towards expatriates.

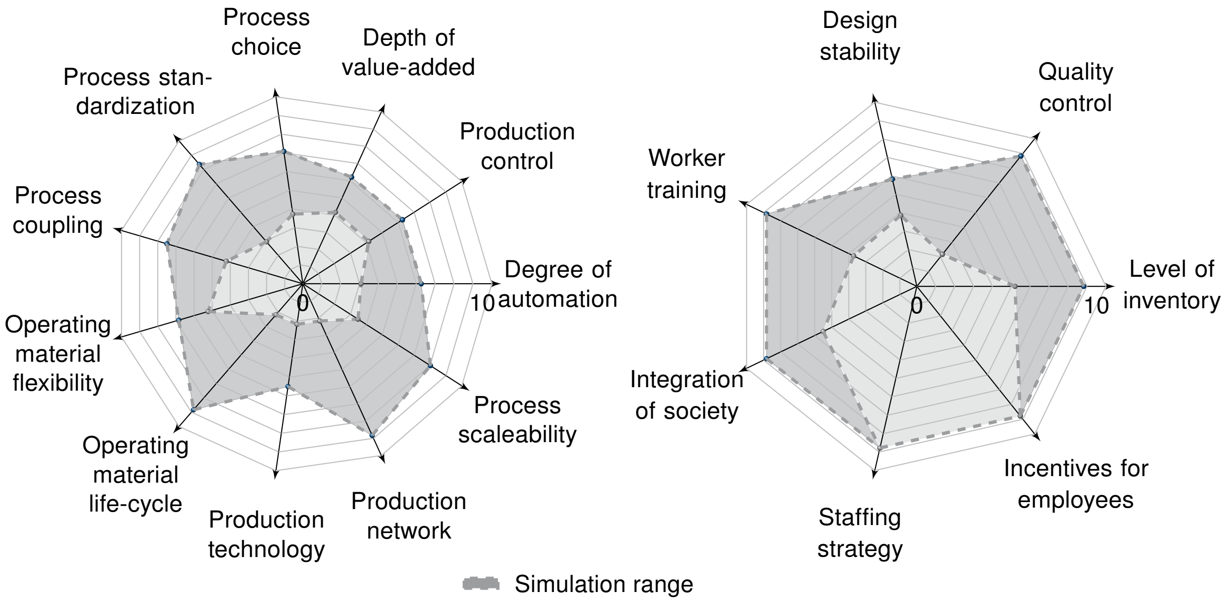


(a) Structural production parameters. (b) Infrastructural production parameters.

Figure 4.5: Scenario 4 - Different vehicle models.

4.1.3 Summary of the Simulations

Figure 4.6 summarizes the minimum and maximum values of the scenarios, and the findings highlight the following: Within the structural parameters, the degree of automation, process choice, operating material life-cycle, process scaleability, and production network decision are mainly altered by increasing production volume (*Scenario 2*). On the contrary, production control mainly changes when multiple variants are planned (*Scenario 4*), whereby the depth of value-added mainly depends on supplier capabilities (*Scenario 3*). Standardization gains importance alongside an increasing production volume and varying country capabilities (*Scenario 2, 3*).



(a) Structural production parameters. (b) Infrastructural production parameters.

Figure 4.6: Comparison of minimum and maximum simulation results. The simulated results indicate that production strategies in developing economies are case-specific.

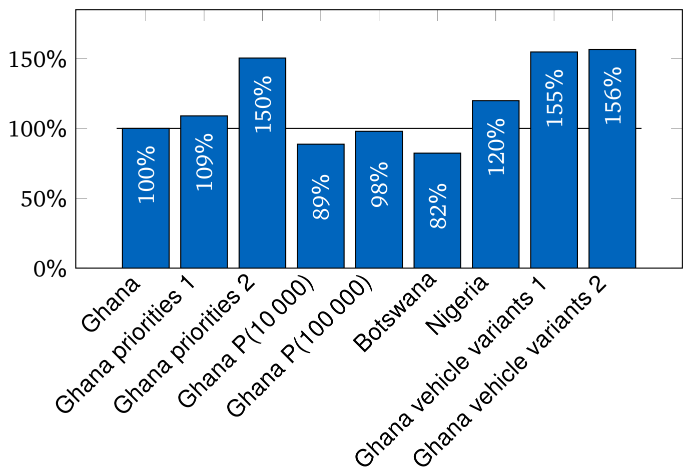
The infrastructural parameters are scenario sensitive. For example, the importance of worker training decreases with increasing skills of the local population in *Scenario 3*, but must still be planned intensively. On the contrary, an expatriate oriented staffing and an incentive system are indispensable. Both the competitive priorities and planned production volume influence the design stability *Scenario 2, 3*. Fewer quality controls need to be enabled when the planned production volume increases (*Scenario 2*). Both the increasing volume and shorter delivery times or complexity due to multiple variants influence the planning of the inventory concept. This is independent as long as only country-specific input changes are simulated (*Scenario 3*).

When comparing the extreme values of these scenarios, it becomes evident that a constant production strategy is not reasonable. In particular, varying production volume impacts production design. Nevertheless, commonalities for a strategic recommendation are identified. For example, the depth of value-added is in the middle range between make-and-buy in the scenarios, with a slight tendency towards buy. Production control and standardization (of process and product design) also show no significant changes.

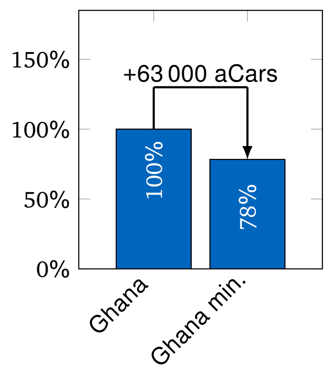
4.1.4 Unit Cost Calculation based on the Scenarios

If cost trends are assigned to the outputs and combined with individual company costs for material procurement, development, and training, the simulation allows for a statement about the unit costs in the scenarios. Figure 4.7 (a) shows the, to Ghana, normalized monetary estimation of unit costs based on the assessment of Pelka [240] using aCar specific data. Unit costs increase when competitive priority changes because, in particular, material costs and direct production costs affect the cost price. Lower costs are achieved by increasing the number of units produced, since an increase to 10 000 vehicles produced per year enables lower purchasing costs and a reduction in production costs per unit. A further tenfold increase in production quantity results in lower material costs, which are offset by rising production and distribution costs. Comparing Ghana, Botswana, and Nigeria, manufacturing costs vary, with 18 % lower costs in Botswana, while production in Nigeria means a 20 % increase in the unit cost of goods manufactured. Comparing these countries, the main cost drivers are the existing energy infrastructure and import duties on components and assemblies. For example, Nigeria charges between 5 %, and 10 % import duty on components such as steering wheels, propulsion parts, and clutches, whereby Botswana has no import duties on clutches and propulsion parts [253]. These cost drivers outweigh the different labor costs, which are 73 % lower in Nigeria than in Botswana. Simulating different vehicle models shows that this variation significantly increases unit costs (> 55 %), whereas the differences in the two simulations are small (1 %).

Figure 4.7 (b) visualizes that in Ghana, with constant customer priorities, the minimum unit costs are achieved when producing approximately 64 000 vehicles per year. This number of units thus represents the trade-off between the main cost drivers economies of scale in purchasing, distribution costs and production costs. A local minimum cost price is achieved between 10 000 and 19 000 vehicles. In this range the cost price is approximately 93 % of the cost of 1 000 vehicles.



(a) Comparison of the cost price of the scenarios.

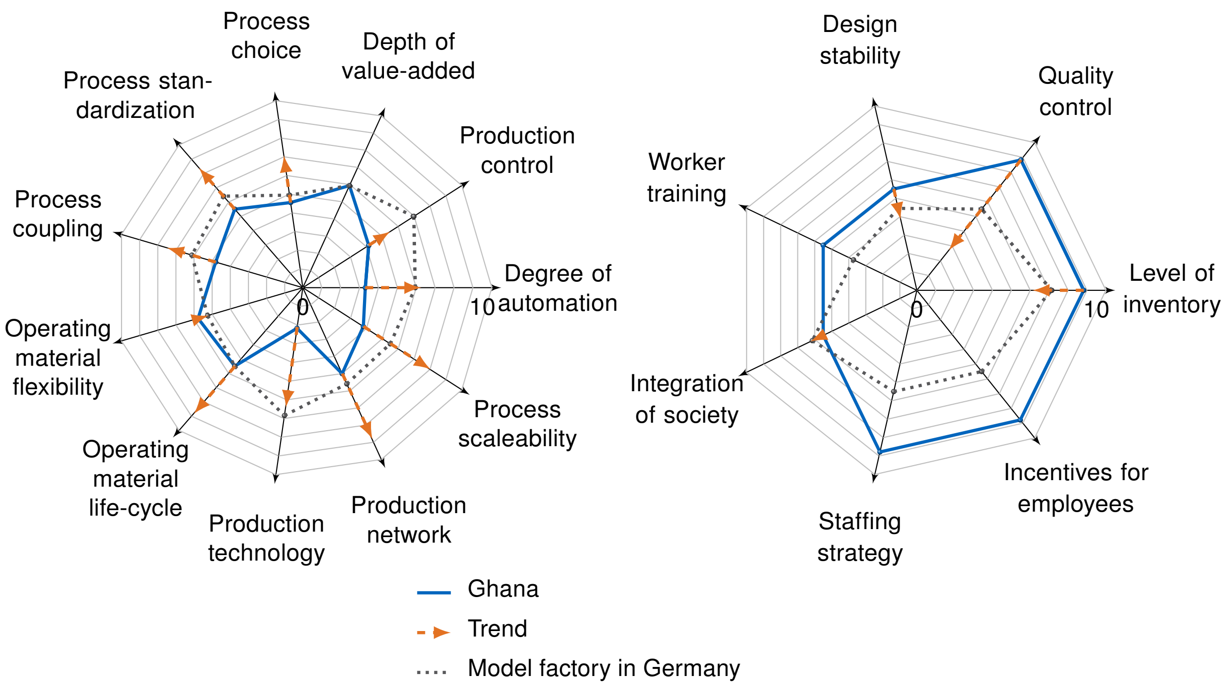


(b) Dependence of quantity and minimum cost price.

Figure 4.7: Comparison of the cost price based on the cost classification of Pelka [240]. Note: The cost price of the aCar is the sum of direct material costs, material overheads, direct production costs, machine running time, production wages as well as development, administration, and sales overheads.

4.2 Transfer into a Production Strategy

A strategy is not a snapshot but a long-term plan that incorporates external changes. Based on the assumption that a quantity in the amount of the cost-optimal number of units can be sold in Ghana in the future, a strategy is formulated for a market entry with a production volume of 1 000 vehicles moving towards the production volume with minimum unit costs. Furthermore, it is assumed that only one variant of the vehicle will be offered for the planning period due to the development costs. The strategic trends resulting from this assumption are visualized as arrows (-►) in figure 4.8. Considering this change of production volume, an appropriate flexibility of the production system needs to be planned for when implementing the strategy. To translate the sharp output values into use case-specific recommendations, table 4.1 is used. These recommendations build on the results of Heinke [249], Fahn [254], Jovanovic [255], and Keuthen [256]. The following description is divided into structural (section 4.2.1) and infrastructural results (section 4.2.2), whereby the parameters are presented counterclockwise.



(a) Structural production parameters.

(b) Infrastructural production parameters.

Figure 4.8: Transfer into a strategy for a production site in Ghana. The trend arrow indicates the extent to which an increasing quantity towards the quantity of minimum cost price changes the result. The output values of the factory in Germany are visualized for reference and highlight similarities and differences to Ghana.

4.2.1 Structural Production Parameters

The simulated value for the *degree of automation* of operating resources in Ghana indicates the use of static hand tools in the application case. These include, for example, screwdrivers, hammers, open-ended wrenches, and saws with which the manufacturing and assembly processes are carried out. These tools can be used for the initially low production volume. The trend arrow, however, shows that electrically or pneumatically operated hand tools, such as pneumatic torque screwdrivers and riveting machines, are necessary for fastening in higher volumes. In an extension of assembly with increasing production volumes, static work stations such as bearing presses, lifting platforms, filling stations, and assembly cranes or manipulators can be added.

This type of workstation still allows process variations and requires human workforce to execute, support, and monitor the operation.

These manufacturing and assembly processes are to be triggered by customer demand. An assemble-to-order *production control*, therefore, provides for order-related assembly of both, modules and the entire vehicle, as well as customer-anonymous production of components. As the trend simulation shows, this type of production control will also be able to cope with an increasing number of units.

In contrast to the previous parameters, the simulated *depth of value-added* is constant even when production volumes increase, meaning that the recommendation for final assembly of vehicle and production of core modules remains unchanged. In conjunction with an assemble-to-order control, the assembly of core modules is thus triggered by the receipt of a sales order. High-tech components such as the electric motor, power electronics, and battery are sourced from global suppliers. Furthermore, with a globally centralized purchasing, economies of scale for these components are achieved. Nevertheless, to establish a local network, the remaining vehicle components need to be sourced locally. Cooperation with local suppliers is useful not exclusively for socio-economic reasons, since local suppliers are familiar with local standards, working methods, and environmental influences. However, measures are required to support local manufacturers to supply the ordered quality and to comply with agreed delivery times. In the aCar case, add-on components, axle systems, power-train, energy storage, and control units are supply components that are recommended to be assembled locally. A summary of the make-and-buy components, assigned to their assembly is visualized in figure 4.9. The figure highlights that interior, exterior, and frame are designed and optimized for local production.

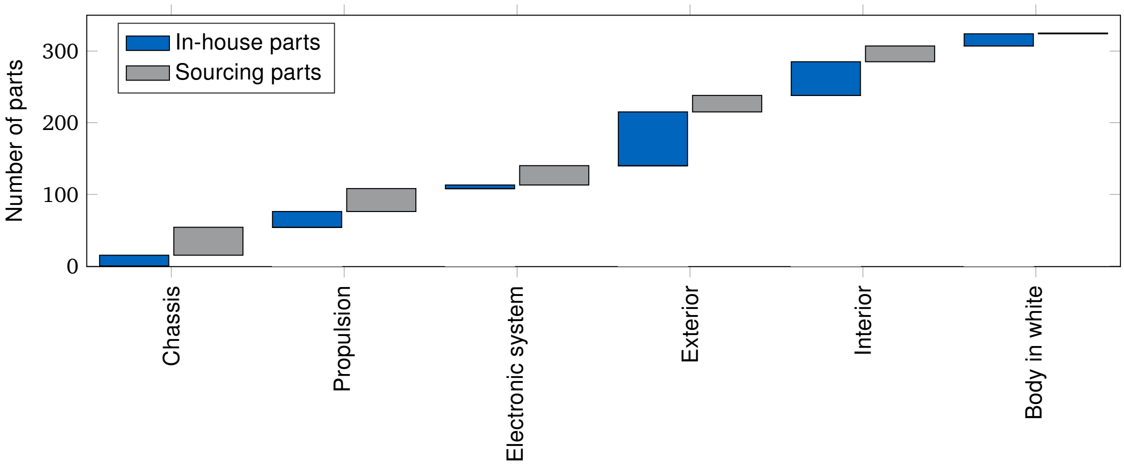
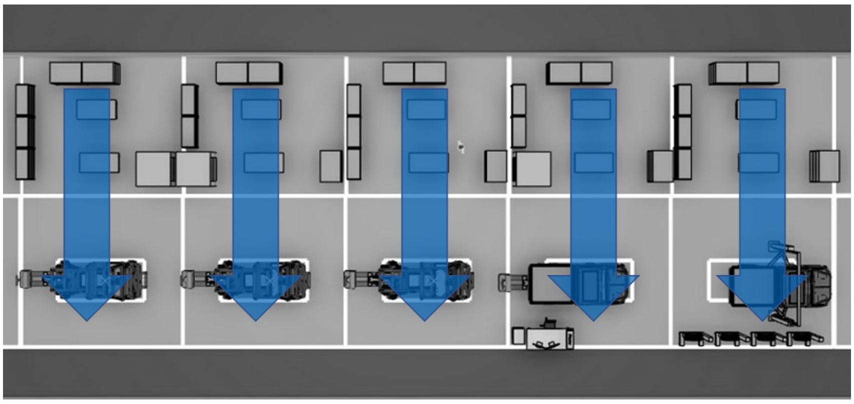
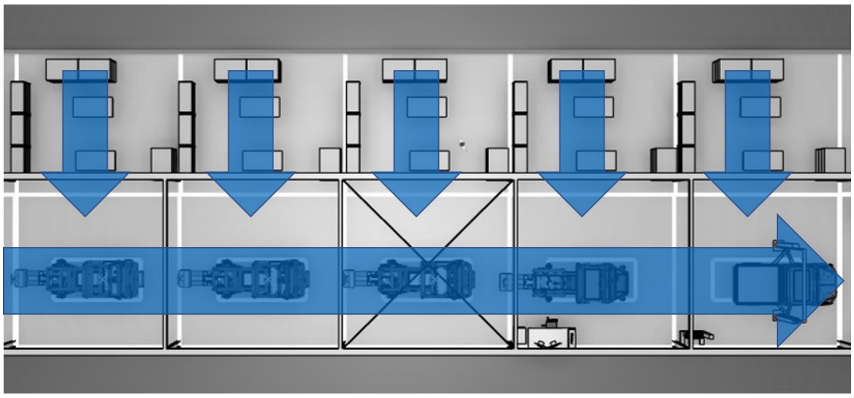


Figure 4.9: In-house and sourcing parts of the aCar divided into assemblies. The focus of in-house competence is on parts of the exterior, interior and body in white.

A low production volume at the time of market entry results in the arrangement of the production processes as a group production (*process choice*). However, as production volume increases, the assembly processes should be arranged as flow-assembly, as is common in the automotive industry. This change in the arrangement of processes is incremental and must be considered when planning the shop floor and purchasing the operating equipment. In flow-production, the operating resources are arranged in the assembly sequence of the vehicle. The warehouses are located near the installation site and components flow through the pre-assembly process to the final assembly line as required. Figure 4.10 shows two exemplary expansion stages of flow-production, illustrating the required adaption with increasing production volumes. In the first stage, flow production and pre-assembly is carried out with static or flexible hand tools, which are supplemented in the second stage by automated hand tools in addition to static work stations such as assembly cranes and lifting platforms. The supply of material is carried out manually in the first stage and is extended by milk runs in the expansion stage.



(a) Arrangement of the processes in the assembly hall at market entry.



(b) Extension of the assembly hall with increasing quantities.

Figure 4.10: Visualization of an exemplary concept of a flow production with the assembly line, pre-assemblies and logistics areas.

The simulation highlights the relevance of *process standardization* with increasing quantities, that is expressed by possible cost savings and simplified quality assurance. Nevertheless, local adjustments to processes are necessary at the start of production, that are later established as standard with increasing quantities. However, the tools (e.g. screwdrivers), measuring equipment, and joining processes should be standardized at the start of production. In logistics, standardized means of transport (e.g. for transporting batteries) should likewise be used from the outset to avoid expensive adjustments as quantities increase.

Like the simulation of process standardization, the output value for *process coupling* depends on the quantities. Consequently, work in progress or buffers may be useful at the start of production but must be reduced over time to reduce lead time and inventory levels. This is achieved through the systemic linking of processes, such as production with pre-assembly and pre-assembly with final assembly. Reducing work in progress, as well as buffers in production, enables production planning to lower lead times, quality control, and reduce tied capital. Furthermore, the coupling of assembly processes with material supply is useful to reduce inventories. However, coupling assembly processes requires a corresponding level of delivery reliability on the part of the suppliers, that cannot be expected in Ghana when production starts.

In addition to the already described automation of operating resources, its flexibility and duration of use (life-cycle) are simulated. The recommendation regarding *operating material flexibility* varies depending on the processes. For example, flexible equipment such as lifting platforms, screwdrivers, assembly cranes, or test benches is to be used in the final assembly line. Special equipment is suitable for component transport and assembly fixtures. To consider uncertainties in the *operating material life-cycle* regarding product adaptations and increasing volumes, a medium-term period of between 7 and 14 years should be provided for, that, according to Fisel [217, p. 212], corresponds to one to two product life-cycles of an electric vehicle.

The *production technology* to be used in Ghana is classified as conventional. For example, in the manufacturing of component cutting machines, bending machines, manual welding equipment (figure 4.11) and lifting platforms, manual filling stations, and forklift trucks. Compared to innovative technologies, these conventional technologies are often associated with a higher manual workload, which means that lower fixed costs can be realized. For the aCar production in Ghana, for example, the vehicle frame has edged sheet metal sections, that are bolted and welded. The concept of a driver's cabin with glued cast nodes implemented in the prototype, however, does not meet the recommendation to use conventional production technologies and is therefore revised and, as a result, implemented as a welded construction. Figure 4.12 shows the frame of the vehicle, the construction with glued cabin, and the adapted welded cabin.

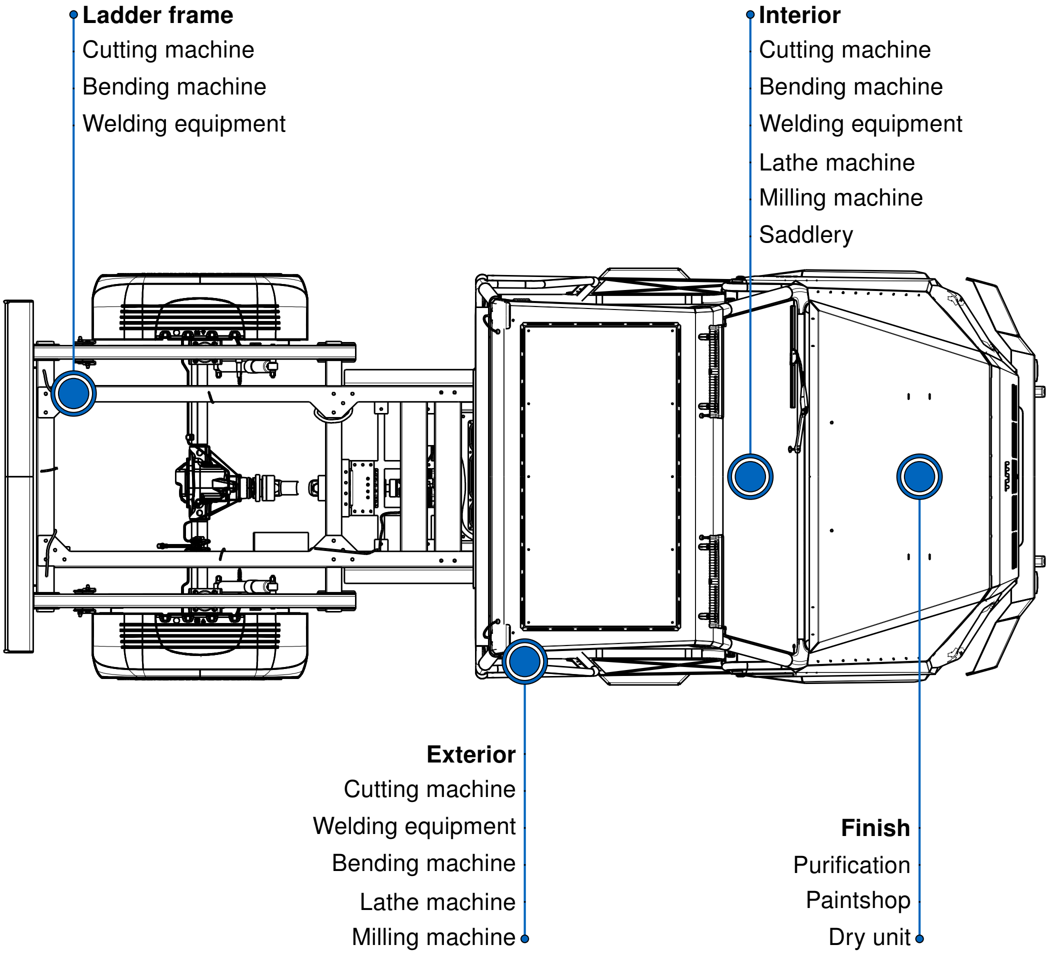
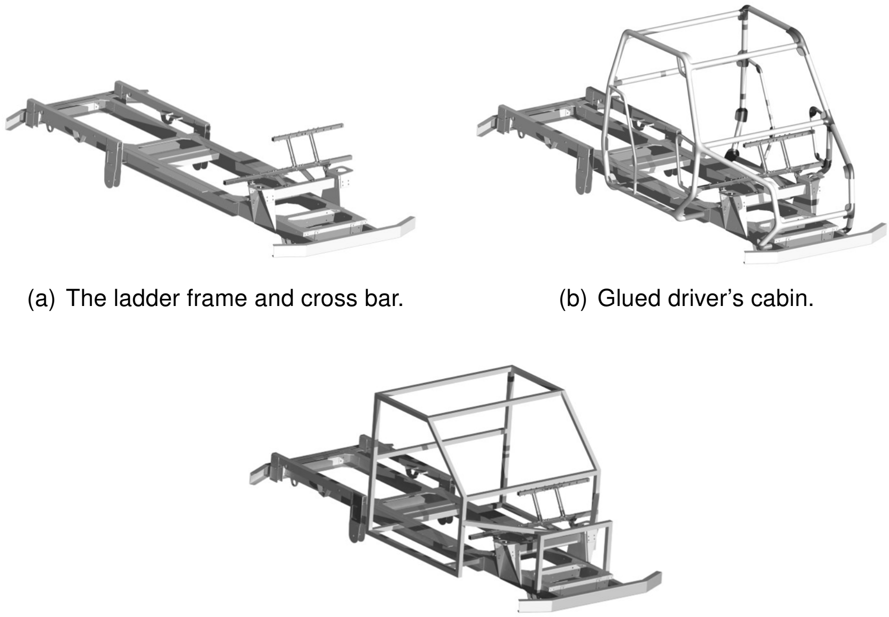


Figure 4.11: Assemblies and operating material for local production of the aCar.

The *production network* is sensitive to the number of pieces and customer requirements regarding delivery time and required flexibility (figure 3.17). Assuming a corresponding volume can be sold on the local market in the long-term, a local-for-local concept is recommended. This allows for a more sustainable change in the region and enables shorter delivery times, lower delivery costs, and customized products.



(a) The ladder frame and cross bar. (b) Glued driver's cabin.

(c) Welded driver's cabin.

Figure 4.12: Frame assemblies of the aCar to be produced locally.

Process scaleability is to be planned on a medium level, with adaption towards larger units in the case of increasing production volume, since large economies of scale are achieved with large-scale technologies. Investing in large process units, however, is associated with higher risks, as the capital cost is higher. In return, the capital cost per capacity unit is lower. Additionally, installation costs, service costs, and operating costs per unit produced are lower. Medium scaleability is reflected in medium operating time of the equipment, low level of automation and the recommended flexibility of the operating resources. To increase future scaleability the individual functions of an aCar could be used in derivatives.

4.2.2 Infrastructural Production Parameters

A minimum *level of inventory* ensures continued production, even in the event of quality or delivery failures by a supplier, and maintains the ability to deliver in an emergency, which is particularly necessary for developing economies. Accordingly, high stock level is recommended for the start of small series production. With increasing success and thus increasing volume, reduction of inventories becomes necessary to reduce tied capital. Due to a long delivery time, special challenges arise for the storage of lithium-ion batteries in the case of aCar production. Therefore, batteries must be packed to be protected against mechanical damage and environmental influences during transport, handling, and storage. Besides, container material and construction must prevent electrical contact, corrosion of connections and short circuits, and, moreover, batteries should be stored in a cool, dry room without significant temperature fluctuations and protected from environmental influences. When purchasing core components globally, direct shipment of batteries should be provided to reduce transportation time and tied up capital. Components with a constant consumption and shorter delivery times, e.g. the chassis, are procured according to the minimum inventory strategy, which allows the inventory level to be kept at a defined quantity. This procurement strategy also applies, for example, to external components, which do not deviate between vehicles. The level of stock thus determines the procurement strategy, which in turn depends on the supplier relationships and processes.

For *quality control*, the use of manually performed quality checks in combination with supporting measures such as Poka-Yoke has proven successful in companies producing in low-wage countries to ensure a high-quality standard. Therefore, it is recommended to apply Poka-Yoke principles and, if not viable, to rely on labor-intensive test routines to avoid purchasing expensive, automatic test equipment for quality control. Therefore, in the beginning, continuous quality controls, e.g. in incoming goods inspection, should be implemented, upgrading to statistical controls alongside increasing volume and worker capabilities. With the necessary control of the incoming goods, the need for a common quality policy with suppliers, described by Reinhart et al. [257, p. 13], becomes apparent. Moreover, assembly times are to be planned in such a way that workers have sufficient time within their work steps to carry out the assembly task with the required quality and to control it themselves. An end-of-line acceptance of the vehicles, as usual in automobile production, and a rework station ensures vehicle quality before delivery.

For the vehicle *design stability*, the procedure used by Renault India and described by Midler et al. [21, pp. 39-41]—an early design freeze, but adaptable design features—should be used. This enables engineers and suppliers to work on cost optimization at an early stage, allowing for further cost savings in combination with design improvements. Furthermore, only critical design changes should be passed on to production. Flexibility for these changes is provided by the vehicle's supply structure and the planned flexibility of operating resources. Far-reaching design changes, e.g. according to customer requests, should, therefore, be integrated only into new vehicle models. For the aCar, therefore, individualization is initially only intended to be achieved by adapting the add-on parts and the load compartment structure (figure 4.13). The remaining components should be globally standardized.

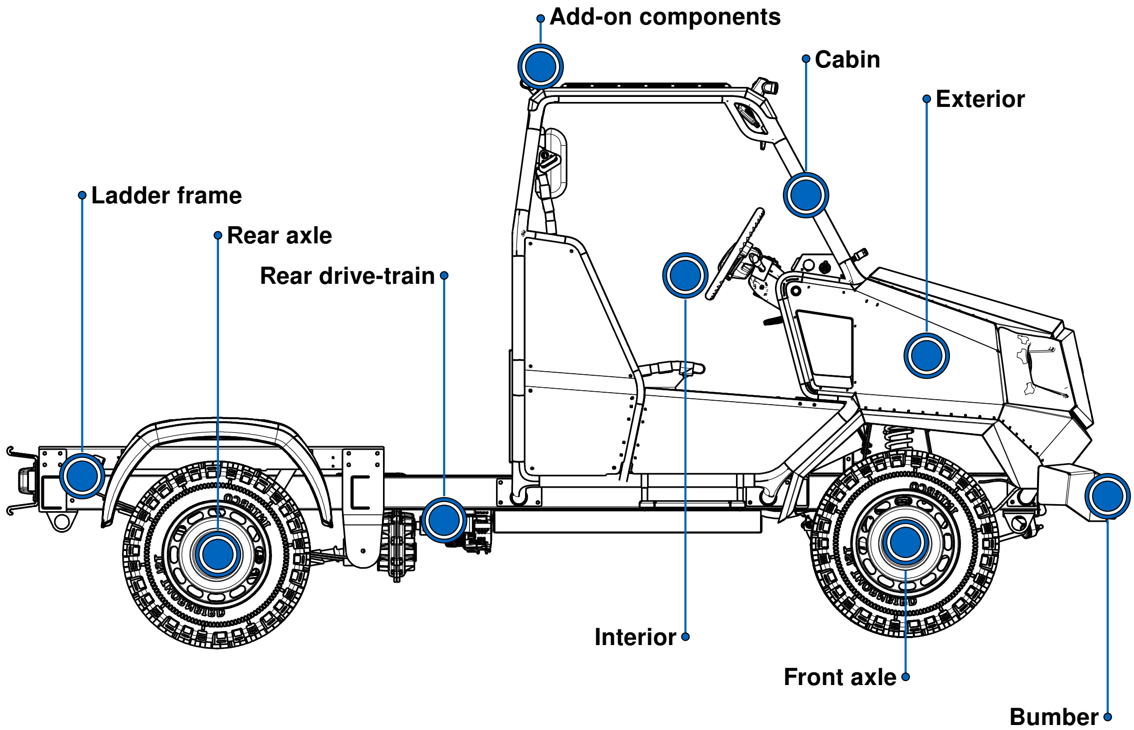


Figure 4.13: Assemblies designed for local mounting.

Worker training is an integral part of the on-boarding process for new employees, even for increasing quantities, as the simulation results indicate. The simulated value, at the border of the category "into the job" to the category "along or near the jobs" can be implemented such, that selected specialists complete part of the training in the model factory in Germany. With the help of training experts, the selected specialists then qualify the entire production personnel on-site. The scope and content of the training should vary depending on the employee's level of qualification and work task. The training for production planners, for example, should integrate up to three months spent at the factory in Germany to acquire company-specific know-how about planning processes, bench-marking and visualization methods, quality management tools, and knowledge about products and production processes. For machine operators and assembly personnel, four-week training courses at the plant in Germany are recommended to acquire specific knowledge about products and production, as implemented at Honda Hero in India [14, p. 260]. Furthermore, an internal training concept, e.g. similar to the Wallys (section 3.2.2), should be implemented to convey the required qualifications, quality standards, and the company philosophy. Working with electrical components installed in electric vehicles requires additional qualification measures, as employees must be trained for the handling of these components. Moreover, for work tasks to be carried out by qualified electricians, training in electrical and voltage engineering as well as vehicle engineering know-how and knowledge must be provided.

Nevertheless, investments in internal employee training are only useful when employee turnover is low. For example, the high turnover rate of trained employees, which is typical for developing economies—in this case Ghana—is a challenge. It is a management task to create *incentives for employees* to prevent dismissals. Additional expenditure due to higher wages, modern facilities, and social events can save costs in the long-term if a lower staff turnover rate is achieved. In the case of the aCar production in Ghana, a variable financial compensation, equivalent to Honda Hero in India [14, p. 259], is recommended, as the personnel costs are oriented to the order volume. Besides, non-financial incentives, such as employee-centric design of the work environment, positively influence product quality and productivity at Honda Hero [14, p. 259] and are thus recommended for the aCar production site.

It is highly recommended to *integrate the social and societal dynamics* into the decision-making process. The simulated value slightly increases with higher production volumes. Integration of local authorities is essential for success, and the example of the national support programs of African governments, like those in Uganda, Nigeria, and Kenya [5, p. 11], indicate their interest in supporting vehicle projects. Cooperation with governments and local decision-makers also enables joint poverty reduction. Before starting production, it is important to identify relevant local stakeholders and to define how management interacts with them since transparency and corruption is a challenge in Ghana [258, 259]. It is, therefore, required to define standards of how bribes are handled and how the company addresses corruption. Additionally, decisions on production design should consider local (environmental) aspects and standards. For example, many Ghanaians rely on family member's economic support to obtain education [260] and, thus, as social integration, support of the local education system may be provided.

The result shows that vehicle production in Ghana should be accompanied by a sufficient large *number of expatriates* during the start-up phase. This recommendation is given despite the costs of an expatriate oriented strategy, as the transfer of business and production processes as well as the corporate culture is essential for a long-term successful foreign production. Thus, between 15 and 30 expatriates should be on-site during the start-up phase to avoid production and organizational bottlenecks. Besides, due to a large number of expatriates, the training concept can be implemented and the employees from Ghana trained in Germany can be supported in transferring know-how.

4.2.3 Summary

In this section, the developed method was applied, followed by a presentation of simulations to demonstrate the extent of how changing surrounding conditions, customer requirements, or vehicle specifications affect the production strategy. The simulation of unit costs reveals that these depend largely on the number of units and the surrounding conditions in the countries.

Subsequently, the developed translation of the simulation results is used to recommend a production strategy for a facility in Ghana. This strategy is based on the assumption of a low production volume of 1 000 vehicles at the beginning but takes possible market developments into account. Besides, in figure 4.8, the representation of the simulation results, the actual state of the factory in Germany is visualized. This demonstrates that, for example, the production technology simulated for the start of production in Ghana is more cost-effective but requires more manual work than the technology implemented at the German factory. Furthermore, it becomes apparent that the planned training concept in the factory in Germany can be intensified to impart the processes to employees of future production sites. In parameters such as scale-ability, production network, and quality control, it is apparent that capacity at the German plant is limited and that processes at the subsidiary in Ghana need to be optimized if the planned quantities are produced.

Nevertheless, the strategy recommendation is based on assumptions as to how it was developed, which can change quickly, especially in developing economies. The implementation as a simulation model, however, allows a low-cost estimation of new situations, whereupon the strategy has to be iteratively adjusted.

5 Discussion

This section discusses the presented method, its limitations, and its advantages. Furthermore, as part of the developed method, the basic model and its added value and limitations are discussed. Finally, the scientific and managerial contribution of this work is outlined.

5.1 Evaluation of Research Objectives

This thesis aligns production strategy with corporate objectives, product characteristics, and surrounding conditions, and, thus, allows for an appropriate production strategy. Therefore, within the literature review section (section 2.3), the current research was evaluated using seven criteria. These criteria were used to assess to what extent production strategy research includes surrounding conditions in developing economies, and allows for suitable requirements and production parameters. Furthermore, production strategy development and decision-making approaches were evaluated for external and internal cause-effect relationships as well as their open-source capability. It is apparent that there is insufficient integration of specific production parameters relevant to production in developing regions. Thus, the representation of these parameters in strategy development methods and decision-making tools, too, is insufficient.

For this reason, the developed method specifically queries the external influences and offers a set of questions for guidance. Nevertheless, this assessment is subjective and not linked to measurement parameters. The parameter set of production system parameters is developed in this method based on the specified requirements. A subsequent expert survey ensures that the relevant parameters are complete. Afterward, it is recommended to exclude those parameters based on decisions already made. The granularity of the parameters, meaning their level of detail, varies significantly through this process. Thus, a fuzzy logic-based model is proposed for evaluation and selection, as this kind of expert system can deal with different levels of detail, incomplete data basis, and allows for modeling cause-effect relationships (section 2.2.2). However, the initialization effort depends on the number of parameters in fuzzy models [210, p. 89]. For this reason, a basic model is provided on GitHub, that can be used as a basis by companies, and thus lower their initialization effort. Within this basic model, surrounding conditions are integrated into the development of the parameter set. Additionally, the surrounding-specific input factors are linked to the output values via the rule base. To integrate the internal dependencies into the simulation, a recurrent fuzzy system is used. This recurrence integrates rules that evaluate inner dependencies and the simulation model thus balances internal and external dependencies. As corporate strategies are super-ordinate to production strategy, relating goals are included as input values. The method is neither company- nor industry-specific but represents a procedure for all kinds of manufacturing companies. The published model with its already integrated database serves as a basis on which specific decision parameters can be built, but these are only confirmed against an automotive setting.

Table 5.1 summarizes the evaluation criteria from section 2.2.2 and the implementation in this thesis. It can therefore be concluded, that the method, in combination with the simulation model, fulfills the criteria. But, the extent to which the transfer-ability is possible depends on the user and can only be proven in further applications.

Table 5.1: Evaluation criteria and implementation.

	Evaluation criteria	Implementation
C.1.	Query of surrounding conditions.	Summary of influencing factors, questionnaire
C.2.	Derivation of a production strategy parameter set.	Requirements development and structuring process
C.3.	Evaluation of production strategy in developing economies.	Selection process, expert model
C.4.	Linking of external factors with the parameters of the production system.	Integration of external influencing factors into the expert model
C.5.	Mapping of the internal cause-effect relationships of the decisions.	Integration of the recurrence into the system
C.6.	Integration of corporate strategic objectives into production strategy development.	Implemented as input values in the simulation model
C.7.	Transferability and open-source capability of the decision process.	Publication on GitHub, process to extend the rule-base

In addition to the specific criteria listed, general requirements are described in section 3. According to those, the method should be *transparent and understandable* for the user, which is demonstrated by the application in section 4. The users who accompanied the sub-steps were able to contribute to the modules, provided specific input, and transferred the simulation results to a strategy. Hence, the method's *applicability* was demonstrated with the applied case. In addition, the model is intended to offer a *holistic* approach to solving the challenges of local production. This is achieved by not excluding any production parameters during the methodical solution finding, but by considering the solution space holistic. With the model-based relation of the production parameters to each other, with upstream and downstream decision variables as well as external prerequisites, the scope of consideration is extended beyond the system boundaries of the production plant. With increasing complexity and associated number of parameters and rules, however, the initialization effort increases. In principle, the holistic integration of all influencing factors and parameters is possible. Moreover, the *expenditure* for multi-site planning is reduced by the developed model, as a multi-scenario simulation is possible. Furthermore, after a one-time initialization, the usage effort is low.

5.2 Limitations

Despite the structured approach to defining the strategic content and the basic model's availability, local expertise is still required. Local know-how is of advantage for processing the questionnaire, as well as for developing the requirements and the model's rule base. The defuzzification, the process of interpreting the simulation results, is also more meaningful when experts with know-how about production in developing economies are involved. This method, however, supports previously inexperienced users in the structured query of core elements and the identification of missing expertise. The production strategy parameters can be extended to suit the individual company and product. Even if pre-implemented parameters of the model are available, the significance of the result depends on the individual adaptation. This is because the expressiveness and accuracy of the model improve with its extension. At this stage, the model is limited due to its generic character. The implemented parameters and rules must be considered as reasonable due to the development process and validation, but only the automotive-specific decision-making process has been examined in detail. For the application in other industrial sectors it is advisable to reduce the effort of the adaptation, not to redefine the entire rule base and its links, but to specifically determine industry and company-specific deviations and adapt the model accordingly. An extended investigation and application in other industries are therefore recommended for further research.

To improve the model's limitations, a possible process can be an iterative approach, where new rules are added with completed projects from various industries. This iteration would follow the suggestion of Hill and Hill [58, p. 114] as well as Hayes and Wheelright [29, p. 42], who describe strategy development as a process which benefits from adaption. This should also be made available as open-source database. Furthermore, by fuzzifying the qualitative, unsharp input values and linking them to qualitative rules, the output values should not be understood as exact values, but rather as tendencies for strategic planning. The associated scope of interpretation, which was demonstrated in section 4.2, points out the simulation limits. Nevertheless, the methodology enables the user to make this interpretation considering the relevant expertise.

What is essential when applying this method?

- The method requires local expert knowledge, but the method supports the structured query of this expertise.
- Requirements and production strategy parameter set are company and product specific. Therefore, these must be developed and tested for a detailed statement with the appropriate experts.

What causes a loss in quality and significance in the results?

- The model is dependent on the rules and weightings defined. Therefore, the result improves with experience-based rules, but, the ability to transparently understand the results decreases at the same time.
- Standardized membership functions lead to a loss of accuracy. Users should, therefore, customize these functions as required.
- Iterative procedures for the traceability of results optimize the quality of statements in the long-term, and may adapt them to changing conditions.
- By fuzzifying the unsharp input data, the results are no exact values, but rather a tendency for further detail planning.

5.3 Benefits

The designed method's advantages also become apparent in its application. The simulation model allows, as shown in the application, for a comparison between different scenarios, and thus to consider the effects of changing surrounding factors in the planning process at an early planning stage. Moreover, the method allows for a structured query of local expert knowledge, which is often only available in an unstructured form.

The model itself is characterized by a low initialization effort when using the implemented rule base. The procedure described in appendix A.3.4 makes it possible also for inexperienced users to work with the model. Another benefit is the already discussed possibility of linking a database with further rules from different users. The plausibility check for the implemented rule base reveals that adequate results can be achieved with this published model and the sensitivity analysis highlights the relevance of worker training and its dependencies, which have to be considered in detail in the course of further planning.

When and for whom is this method suitable?

- For the transparent and structured query of local production expert knowledge.
- Companies planning several locations in developing economies benefit from an individual extension of the rule base through the finer granularity of the results.
- Due to the low initialization effort with the pre-implemented rule base, the simulation supported method is particularly suitable for companies that have little or no experience with producing in developing economies.
- The model is particularly suitable for comparing and analyzing different scenarios, as focal points and sensitivities become transparent in the deviations caused by the scenarios.
- For companies who want to make a first estimation, a general model with literature values is available on GitHub.

How must the model be evaluated?

- As a tool for decision-making in the early phase of production planning in developing economies, the result of the model is a starting point.
- The model is open-source available and can be used with the pre-implemented rule base. A major added value would be a database where companies, especially SME, can add their rules and thus increase the level of detail of the model and the rule base.

5.4 Implication

On the scientific level, this thesis contributes to the alignment of the influence from the surrounding, products, and production-strategic decisions, as identified as open questions in the literature [33, 53]. With the summary of factors influencing the local production site, a catalog is provided, which can form the basis for further investigations. Specific models, in particular, allow for a more in-depth investigation of the interrelations between environment and strategy [33]. Thus, the method and the simulation model contribute to highlighting the interrelations and thus to discuss their relevance.

Besides the scientific contribution, the managerial implication of this work is given by the questionnaire and the simulation tool. The detailed and visual comparison of strategic scenarios based on company-specific requirements is useful for decision-making. Furthermore, it is determined that the recommendations for an automotive production location in developing countries are mainly determined by a change in production volumes, but still, the regional characteristics should not be neglected. Companies must, therefore, decide which strategy parameters will be decided location-specific and which can be adopted from existing locations.

6 Summary and Outlook

The final section summarizes the method described and applied. Furthermore, an outlook on electric vehicle production research and the aCar project is provided.

6.1 Summary

The integration of organizational capabilities, their context, and operational activities is an essential management task in developing countries [85]. This work, therefore, deals with the development of local production strategies. Resulting open questions are summarized in table 6.1, concurrently with the respective sections in which they are discussed. Hence, section 3.2 answers the question of influencing factors in developing economies and prepares a questionnaire for the assessment of companies. Following in section 3.3 these influencing factors are converted reproducible into requirements, wherefore the requirements engineering process is adapted to the structure of producing companies. With knowledge of the requirements, the question of solutions for them arises. With section 3.4 the solution space of the requirements is worked out and, subsequently, in section 3.5, a model based on casual relationships allows for the simulation of scenarios. Afterward, the applicability of the developed methodology and model is shown in section 4. Within this section, it becomes clear that the simulated results are useful indicators for further planning and that a strategic recommendation based on simulated scenarios becomes more meaningful. Thus, the benefit of the developed methodology and a recommendation based on simulations becomes obvious. In the discussion section, the limitations are analyzed and the added value that would result from a database is highlighted.

Table 6.1: Summary of the process to develop the presented method.

Section	**Question**	**Measures**	**Implementation**
Section 3.2: Influential factors	Which surrounding conditions in developing economies influence local production systems?	Literature research, case study research	*Module 1*
Section 3.3: Requirements	How to define requirements for the local production system based on these surrounding conditions?	Requirements Engineering based approach	*Module 2*
Section 3.4: Production strategy parameters	Which production strategy parameters are needed based on the requirements?	Summary of essential parameters, validation by experts	*Module 3*
Section 3.5: Simulation	How do new products, changed overall conditions, and new customer requirements affect the production strategy focus?	Knowledge based decision-making tool, modeling of the dependencies, expert based weighting	*Module 4*

Further detailed planning can then build on the results, since the production network planning can be initiated with the defined production strategy, as suggested by Sager [261, p. 8] and Pawellek [8, p. 4]. Designing the production network thereby includes the detail of the supply chain planning, the task planning of the locations, and the internal and external network planning [261, p. 7]. Furthermore, after defining the production strategy, the detailed planning of the plant is possible. This includes, for instance, the plant structure, logistics, and implementation planning [8, pp. 4-6].

6.2 Outlook

The motivation for this work is to create an awareness about the challenges and chances of profitable and sustainable local production in developing economies, especially in sub-Saharan Africa. With mainly small, uncertain, and heterogeneous markets [5, p. 7], the current situation in Africa contrasts the plan for a profitable location. Additional, with the focus on automobile manufacturing, there is the additional challenge, that, nowadays, most of the automotive value creation takes place at a few locations in core markets [18]. The investment in large-scale final assembly lines often amounts to more than 200 000 000€ [262, p. 19]. Also, current innovation cycles of automobile production span several years, and production periods are long, while individualization is low. For this reason, research concentrates on small series capability for future (European) vehicle assembly. This capability is characterized by reducing investment costs combined with a guarantee for competitive quality level [18]. But small-scale capability would also enable local production in heterogeneous micro markets—solving the major problems of high investment costs and lack of major scaleability [5, p. 6]. Additionally, these small local series are more robust against global crises and fluctuations [100]. Integrated into a global value-adding network, large quantities are possible, to which development costs can be allocated, as many products for developing economies already demonstrate [263]. Electric vehicles, which can be adapted to small series through adaptable vehicle architectures and concepts, suit these goals well [18]. This also allows incorporating demand and consumer priority changes in these micro-markets [99, p. 197, p. 201]. An exemplary change of priorities is the shift from a price focus to a price-value focus in the passenger car segment in India [7]. The procedure developed over the course of this work is, therefore, intended to assist companies in learning about the challenges of production in developing economies and to support them in evaluating and overcoming these challenges in a systematic process.

As the aCar is specially developed for local value-adding in developing economies, it relies on standardized high-tech components, that have to be supplied. In contrast, many components and assemblies have been developed in such a way, that they can be produced with low effort and invest in small quantities. This lays the foundations for a successful product in the long run. As shown in this thesis, the strategic production decisions and the possibility to adapt the production system to the local challenges with low effort are crucial. With the presented method and implementation, recommendations for local value creation of this vehicle are given. Investigation of the implementation possibilities in Ivory Coast and Ethiopia, with the respective surrounding and market conditions there, the requirements for the vehicle, and its drive-train will be examined in the further course of the project.

The presented method should not only support the future research of the aCar mobility project but also reduce the planning effort for other companies and thus motivate them to plan production sites in developing economies. The goal of increasing industrialization and, above all, the local share of value-added in Africa contributes to achieving the sustainability goals of the UN [1].

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Bibliography

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List of Pre-publications

During the writing of this dissertation, publications and student research projects were published, in which partial aspects of this work are presented.

Journals; Scopus/Web of Science listed (peer-reviewed)

[106] S. Wolff, M. Brönner, M. Held and M. Lienkamp, „Transforming Automotive Companies into Sustainability Leaders: A Concept for Managing Current Challenges," *Journal of Cleaner Production*, p. 124179, 2020, DOI: https://doi.org/10.1016/j.jclepro.2020.124179. Available: http://www.sciencedirect.com/science/article/pii/S0959652620342244.

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M. Brönner, S. Kalt, S. Koberstaedt and M. Soltes, „A methodological approach for selecting the assembly concept for mounting all-electric vehicles within existing assembly lines,“ in *2018 IEEE 9th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMIMT)* IEEE, 2018, pp. 110–116, DOI: 10.1109/icmimt.2018.8340431. Available: https://mediatum.ub.tum.de/node?id=1445816.

L. Nicoletti, M. Brönner, B. Danquah, A. Koch, A. König, S. Krapf, A. Pathak, F. Schockenhoff, G. Sethuraman, S. Wolff and M. Lienkamp, „Review of Trends and Potentials in the Vehicle Concept Development Process,“ *2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, pp. 1–15, 2020, DOI: 10.1109/EVER48776.2020.9243115.

S. Kalt, M. Brönner and M. Lienkamp, „Application-Based Design of Electric Machines for New Vehicle Concepts in Developing Countries,“ *2019 Fourteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, pp. 1–6, 2019, DOI: 10.1109/EVER.2019.8813520.

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Dissertation relevant open source software

[206] M. Brönner. „Production Strategy Development Tool,“ 2020. [Online]. Available: https://github.com/TUMFTM/Production_Strategy_Development [accessed 06/05/2020].

Supervised Student's Thesis

The following student research projects were developed within the framework of the dissertation under the author's supervision in terms of content, subject matter, and scientific research, as well as under his author's authoritative guidance. In the following, the bachelor, semester, and master theses related to this dissertation are listed. Many thanks to the authors for their extensive support within the scope of this research project.

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V. Baumgartner, „Personalqualifizierung zur Elektrofahrzeugmontage in Entwicklungsländern," Master's Thesis, TU München, München, 2018.

C. Brem, „Methodik zur Optimierung eines Elektrofahrzeuges für Entwicklungsländer basierend auf den fahrzeugspezifischen Anforderungen," Bachelor's Thesis, TU München, München, 2018.

A. Candar, „Potentiale der Nachhaltigkeit in der Automobilindustrie: Fokus Elektrofahrzeuge und Entwicklungsländer," Bachelor's Thesis, TU München, München, 2019.

M. Hagenauer, „Methodik zur Bewertung der Nachhaltigkeit von Elektrofahrzeugmontagen in Entwicklungsländern," Master's Thesis, TU München, München, 2018.

F. Hallmayer, „Nachhaltige Standortanalyse und -empfehlung für eine Elektrofahrzeugproduktion in Subsahara-Afrika," Master's Thesis, TU München, München, 2018.

L. Heinke, „Analyse eines Fahrzeugprototyps im aCar mobility Projekt in Bezug auf Gewicht und montagegerechte Gestaltung," Bachelor's Thesis, TU München, München, 2018.

R. Janus, „Anforderungen an eine Elektrofahrzeugproduktion in Subsahara-Afrika," Master's Thesis, TU München, München, 2019.

J. Jovanovic, „Adaptation of the requirements engineering process for production transfer," Semester's Thesis, TU München, München, 2019.

K. Keuthen, „Evaluation der Produktionseinflussfaktoren in Entwicklungsländern," Semester's Thesis, TU München, München, 2019.

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J. Mosch, „Strategische Entscheidungen bei der Produktionskonfiguration in Subsahara Afrika," Master's Thesis, TU München, München, 2020.

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B. Steidl, „Anpassung eines Elektrofahrzeugprototyps für Sub-Sahara Afrika an die TÜV-Zulassungskriterien," Bachelor's Thesis, TU München, München, 2018.

B. Sun, „Empirical Analysis of the Challenges of Electric Vehicle Production in Developing Countries," Semester's Thesis, TU München, München, 2019.

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Appendix

A Appendix

A.1 Methods and Definitions

Subsequently, methods and definitions used to develop this thesis are presented. Outlined are research design, procedure of literature research, preparation and evaluation of interviews.

A.1.1 Literature research: Okoli and Schabram

To examine the empirical data a systematic literature review has to be conducted. Whereby in this thesis the procedure presented by Okoli and Schabram [128, p. 2] is used. According to them "a detailed methodological approach is necessary for any kind of literature review" [128, p. 2].

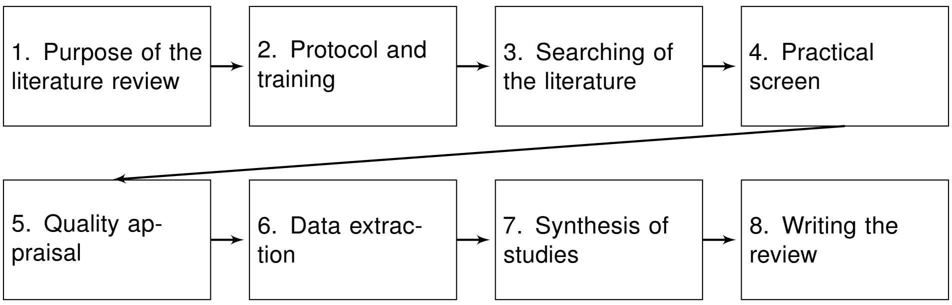

Figure A.1: Eight steps of literature analysis according to Okoli and Schabram [128, p. 7].

This method of literature research consists of eight steps and begins with the definition of the research objective. In the presented case, the aim was to apply the question of influences on production sites in developing economies. Subsequently, in step two the reviewers are briefed, which is equivalent to clarifying the procedure of the literature search. This is followed by the search itself, which is already described in section 3.2. The results obtained by the search are evaluated in step four, the practical screen, and reduced according to defined exclusion criteria. In step five, the quality of the results is checked and then in step six, the data of the results are extracted. The following synthesis summarizes the extracted statements, to summarize in this case the statement regarding the factors described as influences or challenges. Step eight involves writing the review published in this paper and with study [131].

A.1.2 Interview proceeding

Qualitative expert interviews typically take place with experts or stakeholders and are evaluated regarding central statements [264, p. 40]. Interviews are divided into unstructured, semi-structured and fully structured interviews [196, p. 358], whereby the advantage of the semi-structured interview variant is the inclusion of the interviewee's own words and formulations.

Concurrently, key questions that are formulated as open questions guide the interview. This guideline enables the comparison of different the interviews [196, p. 372]. The questions can be derived from the literature or corresponding definitions of the subject area. Thus, the expert interview can be used as a confirmation of the already known knowledge content [264, p. 55, 61]. For the interviews conducted within the scope of this research document, e.g. with Omar Guiga of Wallys, the semi-structured qualitative interviews are used. As suggested by Niederberger and Wassermann [264, p. 61], this interview was saved as an audio recording and transcribed for evaluation. The hypothesis confirmation for the production strategy parameters is carried out as a closed questionnaire, which corresponds to a standardized expert query instrument, whereby the advantage of closed questionnaires is the possible conduction as a postal or online survey [196, p. 359, p. 401]. An expert is generally characterized by knowledge of a subject and its context, which often arises from a professional or social task [264, pp. 51-53].

A.1.3 Identification of Experts and Stakeholder

The identification and exchange of expert knowledge are challenging for global manufacturing companies. Especially, when the exchange of knowledge includes not only physical distances but also cultural and language barriers [14, p. 313]. In the methodology presented in this thesis (e.g., module 1), external knowledge of (local) experts is required due to the lack of (internal) knowledge. Their expertise allows—if used purposefully—to integrate valuable experience into the decision-making process. For this reason, the identification and selection of experts are essential to determine influencing factors, local requirements, define dependencies, and validate results. Hereby, experts are defined as people who can demonstrate special expertise and competence in a specific area of reality, often based on professional experience [264, p. 12].

Figure A.2 visualizes the procedure of Müller et al. [186, pp. 93-96] as a basis for selecting experts. This procedure is recommended, because of its suitability for situations where no list of experts is available at the outset [186, p. 94].

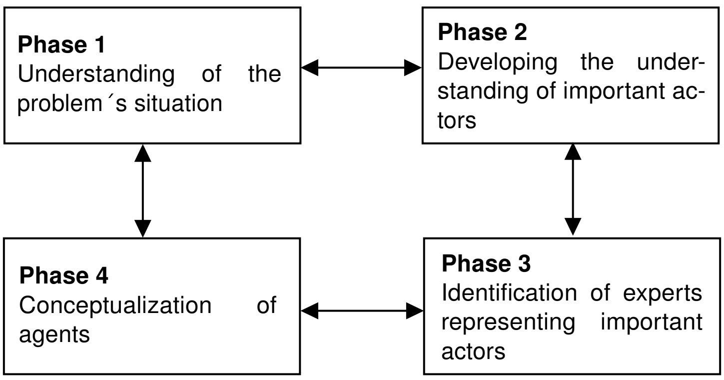

Figure A.2: Iterative method for the identification of experts according to Müller et al. [186], which supports the delimitation of socio-technical problems and thus guides the selection process of experts.

Phase 1: To investigate problems with little explicit and documented knowledge it is necessary to gain a general understanding of the problem situation. This can be achieved through everyday knowledge, assumptions, and information on the internet. The lack of accuracy of the sources in this phase is solved by specification in the following phases [186, p. 94].

Phase 2: In this phase, an extended understanding of the problem is to be achieved by literature research, numerical data, internet search, and interviews. Iterations in this phase allow for increasing accuracy and verification of the problem. Furthermore, actors are identified and divided into important and unimportant participants [186, p. 95].

Phase 3: Within this phase, contact persons and experts who can contribute to the problem area must be identified. A selection of experts with different backgrounds allows for a multifaceted perspective on the problem and reduces subjective bias [186, p. 95, 264, p. 37].

Phase 4: This phase condenses the acquired knowledge of actors into so-called agents, which represent ideal-typical representations of actors [186, p. 95].

Phase 3, the identification of experts and the verification of their statements, represents the most challenging and important phase in this process, especially against the background of production in Africa. The literature suggests to brainstorm potential experts, to set up stakeholder-issue interrelationship diagrams [265, p. 37], or obtain suggestions for further participants from already contacted experts [186, p. 95]. In the course of this work, requests for contact via professional networks such as Xing and LinkedIn, the Chamber of Foreign Trade, the Germany Trade & Invest Association, and local industry associations such as the African Association of Automotive Manufacturers have proved useful. Furthermore, local consultants and entrepreneurs offered valuable insights. For the final selection of the experts, besides their professional expertise, it is important that different disciplines and points of view are represented by the sampling and that the basic actors of the object under investigation are involved [264, p. 223].

A.2 Additional Information: Conception of the method

A.2.1 Summary of the Influential Factors

Table A.1: Literature research. Note: Published in Brönner et al. [131].

	Category	Challenge	∑	Source
🏛	Corporate	Influence on corporate culture	2	[30, 266]
		Psychological fear	1	[150]
		Need for and availability of local corporate management	1	[144]
		Lack of local competency	11	[7, 139, 141, 142, 143, 152, 157, 267, 268, 269, 270]
		Lack of and need for local partnerships	2	[145, 146]
		Uncertain set up duration	1	[271]
		High distance to main plant	3	[139, 141, 170]
		Rising complexity though decentralization	1	[100]
		Difficult communication between subsidies and parents	1	[175]
		Lack of or unknown local labor standards	1	[147]
		Lack of established after-sales processes	1	[272]
	Investment	Lack of investment climate	8	[100, 134, 136, 137, 141, 174, 269, 272]
		Lack of FDI and uncertain long-term effects	2	[30, 135]
		Lack of local financing options	3	[133, 134, 273]
		Planning of appropriate profits	3	[7, 138, 139]
	Strategy	Unknown or strong local competitors	8	[97, 147, 148, 152, 159, 161, 178, 272]
		Uncertain timing for market entry	2	[14, 150]
		Uncertain time-to-Market	2	[148, 149]
		Uncertainty of demand	5	[134, 139, 159, 180, 269]
		Expected small margins	2	[145, 151]
		Cannibalism effect in the home market	1	[178]
		Lack of intellectual property rights	3	[14, 159, 267]
		Fear of spin-offs	8	[139, 156, 239, 248, 274, 275, 276]
		High economic expenditure to adapt products and technology	2	[140, 141]
⚙	Process	Need for adequate and low in expedience processes	8	[30, 137, 141, 154, 155, 159, 163, 277]
		Need for processes which are flexible in speed, product mix and quantities	5	[148, 149, 161, 162, 278]
		Need for low complex processes	2	[14, 145]
		Need for low effort processes	1	[148]
		Need for robust processes	1	[98]
		Need for processes which avoid tests	1	[158]
		Need for processes which are fast to ramp up	1	[279]
		Need for standardized processes and measurement	8	[143, 154, 156, 157, 170, 172, 251, 280]
		On the worker‘s skill level depending output	3	[136, 159, 160]
		On local technological capabilities depending output	4	[136, 155, 162, 176]

Continued on next page

Table A.1 – continued from previous page

Cluster	Category	Challenge	∑	Source
		Need for processes which are appropriate to local requirements and assembly intensive	9	[14, 134, 141, 144, 151, 153, 154, 155, 159]
		Need for or lack of local information system	4	[143, 145, 154, 269]
		Need for energy saving processes	1	[281]
		Lack of local manufacturing norms and waste reduction	12	[98, 134, 135, 137, 148, 154, 152, 278, 279, 282, 283, 284]
		Lack of work safety standards	1	[154]
	Productivity	Low productivity and performance	11	[7, 14, 134, 137, 144, 172, 268, 284, 285, 286, 287]
		High scrap rates	1	[162]
		Lack of capacity utilization	1	[7]
		Need for constant development and improvement	2	[30, 279]
	Investment	Need for low initial investment	8	[18, 141, 146, 153, 167, 251, 285, 288]
		Need for economic efficiency for small-scales	3	[159, 172, 251]
	Environment	Need to be robust against environmental influences	4	[141, 144, 163, 164]
	Components	Need to be appropriate in costs, function and quality	27	[100, 133, 134, 139, 140, 141, 143, 144, 146, 151, 152, 159, 161, 166, 177, 178, 239, 269, 272, 277, 284, 288, 289, 290, 291, 292]
		Need for reduction of components	1	[293]
		Need for standardization of components	6	[141, 154, 165, 239, 251, 280]
		Need for reduction of resources (financial, material, time)	9	[134, 135, 138, 141, 143, 144, 145, 150, 167]
		Need for involvement of local population	2	[145, 164]
		Need for and lack of local testing	2	[164, 177]
		Need for consideration of life cycle	1	[164]
		Need for a plan for reuse	1	[294]
		Need for a maintenance and spare parts concept	9	[133, 141, 144, 153, 154, 167, 176, 274, 282]
		Need for constant quality improvement	1	[148]
		Need for quality assurance	8	[4, 14, 133, 141, 148, 162, 172, 274]
	Costs	Need to provide competitive value	1	[166]
		Need for low material costs	2	[145, 295]
		Need for low break-even points	7	[95, 141, 144, 145, 151, 216, 251]
		Need to achieve economies of scale and scope	5	[140, 144, 145, 152, 159]
	Qualification	Lack of skilled employees	27	[14, 133, 134, 139, 143, 144, 146, 150, 154, 155, 157, 159, 162, 167, 170, 176, 180, 267, 268, 270, 274, 276, 296, 297, 298]
		Lack of implicit product knowledge	1	[140]
		Different education level in different developing economies	1	[136]
		Difficult attraction of top talents and managers	2	[7, 143]
		High turnover of trained employees	2	[168, 169]
		Lack of learning experience	1	[175]

Continued on next page

Table A.1 – continued from previous page

Cluster	Category	Challenge	∑	Source
		Need for worker training	4	[269, 276, 277, 297]
		Need to focus on long-term relationship with employees	5	[133, 139, 145, 169, 297]
		Need for integration of local culture and language	11	[133, 141, 146, 150, 154, 157, 170, 180, 248, 269, 286]
		Need to ensure income equality, combat human rights violations, inequality and poverty	8	[133, 145, 144, 150, 164, 169, 248, 288]
	Technology	Need for know-how-transfer standards and processes	18	[135, 152, 157, 159, 165, 175, 176, 177, 267, 268, 270, 274, 276, 277, 286, 299, 300]
		Need for a suitable know-how transmitter	7	[14, 170, 172, 173, 271, 274]
		Need for an appropriate age of technology	2	[170, 173]
		Need to appropriately codify the know-how	2	[173, 297]
	Politics	Lack of or uncertain local requirements (e.g. safety, security, recycling)	19	[4, 100, 133, 142, 145, 146, 148, 152, 159, 177, 180, 239, 269, 272, 273, 274, 276, 284, 285]
		High import taxes, trade barriers, local content, financial restrictions	18	[4, 14, 30, 97, 137, 140, 141, 144, 148, 153, 162, 172, 176, 251, 274, 284, 288, 301]
		Need for social commitment	8	[100, 137, 139, 145, 148, 164, 282, 288]
		Lack of political support	1	[174]
		Presence of corruption, abuse, theft	7	[134, 135, 159, 174, 180, 248, 269]
		Instability and high inflation rates	1	[162]
$	Supplier	Requirement of local suppliers	5	[30, 133, 142, 144, 154]
		Presence of quality issues	1	[174]
		Unreliable delivery times, high communication costs, inflexibility and lack of innovation culture	21	[134, 140, 141, 145, 146, 149, 151, 152, 153, 157, 161, 172, 176, 177, 267, 274, 276, 278, 287, 291, 302]
		Need for supplier training	2	[267, 303]
		Need for a collaborative partnership	4	[30, 157, 286, 303]
		Need for or requirement for integration of suppliers into global network	1	[166]
	Product	Need for the usage of modules	1	[140]
		Lack of standardized suppliers	4	[174, 177, 267, 303]
	Technology	Lack or uncertain technological capabilities of supplier	2	[140, 176]
	Infrastructure	High logistic/Distribution costs	10	[139, 141, 143, 146, 151, 152, 161, 174, 178, 285]
		Underdeveloped business ecosystem	1	[178]
		Need for building clusters	5	[169, 172, 179, 267, 304]
		Lack of reliable infrastructure	5	[14, 133, 148, 282, 295]

A.2.2 Case Study

The case study's results are published in Salah [182, pp. xi-xxvi] and Brönner et al. [131].

Wallys

Founded in 2006, *Wallys* is a family-owned Tunisian automotive manufacturer with approximately 120 employees. Of these, 40 work directly in administration, development, and production at the main plant in Tunis. In 2008, *Wallys* presented their prototype at the Paris Motor Show, started production in 2009, and released the second model in 2013. With 350 vehicles per year and more than 2,200 vehicles in total, *Wallys* is one of the largest domestic manufacturers of vehicles in Tunisia. *Wallys* aims to build reliable and safe vehicles.[1]

The *IRIS* is a convertible sport utility vehicle and built for daily use and leisure. The vehicle is maneuverable and easy to park. With a top speed of 139 km/h and acceleration (0-100 km/h) of 11.2 seconds, it satisfies the customer needs. Starting at 12 500 Euro, an extensive options list for additional features, like ABS, is available. The vehicle itself consists of a bent and welded main frame made from galvanized steel, making the vehicle suitable for challenging conditions. In this mainframe the drive and chassis components are mounted, whereby the engine is supplied by the PSA group. Next, the bodywork, manufactured by a supplier and made of fiberglass, is attached. The production processes of IRIS are designed for manual work, which enables the customization of almost every component.

Interview key questions

- K_1 What challenges do you face in the production and product development?
- K_2 How is the customer integrated into the product development?
- K_3 What processes are in-house and which are outsourced?
- K_4 What is the share of domestic and foreign origin purchasing components?
- K_5 What kind of processes do you automate, which processes are manual and how is investment kept low?
- K_6 How do you define quality standards and how do you ensure quality in production?
- K_7 What is challenging in working with suppliers?
- K_8 What is the skill level of potential employees and how are they prepared for their work task?
- K_9 How do you recruit employees?
- K_{10} How is the governmental support or partnership?
- K_{11} How do you ensure the after-sales service?

Extract of the Interview

Translated from Tunisian dialect to English
Interviewer/Translator: Skander Salah [182, pp. xi-xxvi]
Interviewee: Omar Guiga, CEO of Wallyscar S.A.
Date, place: 19.06.2018, Tunis

K_1 **What challenges do you face in the production and product development?**

Interviewee: There is a very important thing when you want to make the concept of the vehicle: you have to first know your suppliers. For example, if you want to have a windscreen with a rounded pane here in Tunisia is already a mistake because here in Tunisia there is no one who manufacture them. There are only straight windscreens. That is an example to show that you must know which suppliers you have and based on that you make the conception of the vehicle. There are many things that are not feasible in Tunisia. If you are going to have an import rate of around 80 %, of course everything is possible, you can for example make the rounded panes for the windscreens. But if you want a high rate of Tunisian or local integration then you must know your suppliers. This is the first difficulty; and to know your suppliers is not simple because there are many companies who are under the authority of customs and excise and if that is the case they don't give you the name and what they do. You must do a big research. That is one difficulty. [...] Then on the administrative level there are difficulties as well. Tunisia is not an automotive manufacturer and we don't have an automotive culture so when you want to make a homologation in Tunisia, they don't understand you and tell you we must do a European homologation. Even if you make your

[1] https://www.wallyscar.org/

best and bring all the thousand documents they ask for, we always stay prisoners of the Europeans because the Tunisian administration doesn't know how to homolog a vehicle and they will end up saying we have to homolog it in Europe. You can make a very good vehicle, even better than any European vehicle but you won't have the means to homolog it, a homologation cost around 150 000-200 000 Euro. Imagine: you make a vehicle of high quality but you don't have 200 000 Euro in Europe to homolog it there, you cannot homolog it in Tunisia. 200 000 Euro is 600 000 Dinars and if you don't have them, the Tunisian administration won't give you the homologation even if you made an excellent vehicle. So here is what the difficulties are, the real ones, but we can talk about all difficulties till tomorrow.

K_2 **How is the customer integrated into the product development?**

Interviewee: As you see our cars are customizable. There are customers who want their car with an LED headlight and those who don't for example. Many people come and say: "oh these are not the same cars, it is a different bodywork what should that mean?" No, these are exactly the same cars, and the bodywork is exactly the same you can check it if you want: the chassis are also the same, the wheels are the same. But there is so much personalization that they say it is not the same car. And that in some markets, Africa for example in my opinion, they don't care about it. But in Europe it is very important. When you tell it is a handmade vehicle – for example we participated at the "salon de l'automobile" (cars' fair) in Paris in 2008 and in 2012- when you tell it is a handmade vehicle out of fiberglass, they think it would cost around 30 000-40 000 Euro and when they hear "handmade" they think it is around 60 000 Euro so when you tell them no it is 11 000 Euro they don't believe it.

K_3 **What processes are in-house and which are outsourced?**

Interviewee: There [pointing to a workshop] we do the prototyping of the new models and so on. Here we construct. Here we make the chassis. We do the welding ourselves and we have a supplier who does the metal folding because a folding machine would cost around 600 000 Euro to one million euros and that is a lot of money. That's why we resort to supplier who does the folding and we take care of the welding.

K_4 **What is the share of domestic and foreign origin purchasing components?**

Interviewee: PSA for the running gear and engine. Solutions composites for the bodywork, based in Tunis. For the chassis, I honestly forgot the name since we have a lot of turnover but have around 2 or 3 but they are not reliable at all that's why we have another one named Normeca which is very good but very expensive. Ansi électronique for the software, based in France. Cabletech in Tunis who do the wiring. That's it. For the wheels and tires, we don't have a fix strategic supplier; today we use tires from Michelin but tomorrow it can be someone else. The lights are not a problem as well. The seats are not a problem. We have different models and it is not a paralyzing thing to change. The ones who can pose problem are the ones I mentioned before. For example, if Cabletech tomorrow doesn't send us any wiring, the whole production will be paralyzed. With no chassis, you can do nothing. With no bodywork, you can do nothing. For example, for the windows, even if they don't send a delivery you can see any other supplier and you get them in a week or so. On the other hand, doing the conception of the wiring once again takes up to 6 months. It is very paralyzing. And we have in Tunis SIAM who makes the suspension for us. They work with Peugeot and we buy directly from them in Tunis. The fuel tanks are from Centrax.

K_5 **What kind of processes do you automate, which processes are manual and how is investment kept low?**

Interviewee: As you can see: it is a factory "on a human scale", everything is handmade, there are no machines.
Interviewer: Are there any future projects to upscale and invest in machines and automation?
Interviewee: You know just one a robotic arm cost around 350 000 Euro. Just one robotic arm! We can do many things, but a lot of money is needed.
Interviewer: And is there a technical reason behind it and behind the 3 cm gap between the door and the frame?
Interviewee: Yes Fiberglass is harder to adjust and form. The other examples are done with thermoforming. With the forms and the molds, you can get a precise form but not in the case of Fiberglass, there are always corrections and adjustments to do. It is mainly because of the adjustments of the bodywork that the production of one car takes around 10 days. The mechanical part is done in half a day or maximum one day. The engine and all the mechanical parts don't take long while the work on the bodywork takes around 4 to 5 days. Fiberglass in a small production is the best solution.
Interviewer: Because of the price?
Interviewee: Exactly. One mold of thermoforming for these costs around 30 000-40 000 Euro and is for 10 000 vehicles. And it adds up! If you don't have around one million euros to invest, it is best to use fiberglass. Well therefore we opted for Fiberglass. It has other advantages for example you don't have any problems with corrosion or

rust. Plus, it is very solid like a ship. But the adjustments are a problem. You saw the dynamic I showed you and we talked about how the door gets in the inside while opening; once closed you have another problem and that is the gap. It is not a problem with water or air because of the sealing gaskets but it is esthetically not good! Even with the ameliorations that gap persists. When you see cars from Renault and so on, when they work with fiberglass, it is always like this. Gaps like this are not avoidable.
Interviewer: [W]hat would be the next investment in machinery you would make?
Interviewee: We would invest in Software. Or if we would buy a machine, it would be an automated welding machine. For 500 000 Euros you can get two robotic welding machines which would allow to produce 20 chassis a month. For that rate we would need 30 workers. These are simple machines. On the other hand, other machines which transport the chassis and so on are very expensive and need a lot of space and we don't really need them.

K_6 How do you define quality standards and how do you ensure quality in production?

Interviewee: We have two employees who do this the whole day long. There are two who are here in the factory who do the quality checks and we work with a software called Qualitas. And we have a third employee who goes to every supplier and checks the quality before the goods are sent to us. Because otherwise the supplier would send the goods and then when we notice that there are quality flaws, we have to send it back; we lose a lot of time that way. And when you get to know the supplier, he will know that he must keep the quality and not mess and disappoint. [...] When the bodyworks are delivered to us, we do the adjustments and retouches ourselves because they are never perfect.
Interviewer: And what are the criteria? Is there a difference to the ones in Europe?
Interviewee: Not really. We respect the requirements and specifications of a small French manufacturer which apply if you produce less than 1 000 vehicles a year. The homologations are then flexible. For example, we don't have airbags. If you produce less than 1 000 cars a year, you are allowed not to have airbags; you are allowed not to have ABS. Nevertheless, by not having an airbag, the chassis must be stronger than a car with airbags. In the crash test, it is necessary that the vehicle can withstand a specific impact. These are very technical things but if you check the bar between the bodywork and the engine, they are over dimensioned. It is thicker than the one in ISUZU. The ISUZU has no airbag and no ABS, and it is the most sold vehicle in Tunisia. So that's it: respect the French laws about the homologation and the procedures. We were certified ISO 9001 and will have other certifications as well. And that's it.

K_7 What is challenging in working with suppliers?

Interviewee: [...] even if the supplier wasn't on point, we made a lot of pressure and pushed them. There is work but we aren't seeing what he is doing so we are really pushing them. And they only accept to be pushed when they see that there is real potential; if the company is small, they don't know you and so on, they won't accept it and will prefer to be leaved alone with "take it or leave it" attitude. If there is a collaboration since some years, trust between the two and a vision they don't mind pushing their limits and delivering better output.

K_8 What is the skill level of potential workers and how are they prepared for their work task?

Interviewee: About the workers; The know-how is the entrepreneurial culture. There is no worker here who worked in automobile industry before. All of them in garages and so on. We as a company work in a good atmosphere and we show them with patience because there are many who were used to work in oily workshops. You can see our factory is very clean. They are not used to work in such a clean environment. It takes around two to three months to show them how. There are ones who want to work this way but there are others as well who would prefer to work how they used to and don't stay. We have a turn-over rate of about 30 %. And especially when the vehicle is artisanal, there is an experience period of around 2-3 months in which they understand the vehicle. When it is an assembly-line work, it is easier: each one knows his own task and that's it. Here it is not the case and that takes more time. Otherwise you can use machines and that is way easier. This is from the point of view labor: the learning takes time and accepting the culture of the enterprise where everything is clean and tidy. Order is not an easy thing in Tunisia, but it is our job to implement this. There are Tunisians who work for BMW and who work in order but when they come to a Tunisian company they don't, because their bosses don't work with order either.

K_9 How do you recruit employees?

Interviewee: We use all means: employment bureaus, universities, through friends of the workers if they know someone well disciplined who works well, from overall . . .
Interviewer: So there is no defined Criteria: like a diploma or a certain training or experience?
Interviewee: No on the contrary: the less experience they have, the better it is. When someone has 30 years of

experience in a garage, he will want to stick to how he used to work. On the other hand, the younger ones, of course with some technical background and understanding of some mechanics, not someone who did a diploma in law and wants to be a mechanic, when they don't have much experience, you can train him and show him the dos and don'ts. When someone has a lot of experience, he is normally not as flexible in his way of work. Did you see the average age here? All of them are young.

K_{10} **How is the governmental support or partnership?**

Interviewee: Unfortunately, there is nothing at all. Well they gave us a certificate and congratulated us, but they didn't even symbolically order even one car. It is not a big deal but well! The Tunisian government isn't a leader, they are followers; that means if you succeed they will come but if they see you trying to do something they will watch. That is the problem. And to be a real leader state is the opposite: to see potential and push it. [...] But our government is the opposite... well not that exaggerated... there is potential, but they never proposed any support. But it is not a problem.

K_{11} **How do you ensure the after-sales service?**

Interviewee: In the conception of the Wallyscar, we had the question how to be a small cars manufacturer and not have mechanics' garages and so on all over the world where we export to, it is impossible, it costs too much, but at the same time our customers must be able to repair their cars everywhere in the world even if there is no Wallyscar garage. Making a bodywork very simple to repair; to unmount it you don't have anything complicated, just some bolts, screws and nuts. Anyone can repair it as well with some resin; rub and paint and it is good to go. To have a big car manufacturer with you is important. There are so many Chinese manufacturers who would sell you the running gear and engines and they are everywhere to find. But if you export a car to Switzerland for example with a Chinese engine, the customer won't be happy because Chinese spare parts are impossible to find. So the real difficulty in any automotive project is to have the support of a big cars manufacturer on your side. And this is very difficult.

A.3 Additional Information: Basis Model

A.3.1 Input and Output Parameters

Table A.2: Input parameters. Note: Published in Brönner et al. [115]

Input	Description
Production volume	The production volume is a market-specific input factor, since it depends on the size of the sales market. In Africa, the market is usually small, so that the products and processes must be adapted to the smaller production volume [144]. The volume has an influence on the degree of automation [207], the selection of operating resources [70] and on the structure of the production and assembly line [58].
Market entry strategy	The market entry strategy differs from the company's objective: either to be a pioneer and to be the first on the market (first mover) or to enter the market later (fast follower or follower) [305]. In the case of serving the local market, the entry strategy must be adapted to the competitive situation. If there are competitors in the local market, the company is a follower. If there are no competitors who serve the local market, the company is a first mover.
Labor skill availability	In Africa there are unequal educational standards [136] and in many countries there is a lack of university graduates. The lack and inadequacy of the training of skilled workers is a central issue [14]. The qualification level effects the degree of automation [207], the process span [58] as well as the required employee training [14].
Importance of economies of scale	This factor depends on the industry [55]. In the automotive industry, economies of scale are an essential factor for cost-efficient and thus globally competitive production [306]. Achieving economies of scale is a challenge for low volumes. By orienting the scalability on the level of individual functions, i.e., using the functions of a vehicle in different configurations and derivatives, economies of scale can still be achieved [216]. The importance of scale effects influences the degree of automation [14], the process span [58], the standardization of processes [307], the design stability as well as the linking of processes [70].
Importance of delivery time and reliability	Delivery time and reliability indicates how essential the fast and reliable delivery of a product to the customer is for success [29]. The delivery time also includes the time-to-market for a new product. This input variable influences the choice of the production system [243], the structure of the production and assembly line [58], the warehouse concept and the production network [14].
Importance of product costs	Cost is the best-known competition priority [29]. Although manufacturers focus on costs savings, most do not compete mainly on this basis [308]. Typical cost measurement parameters are labor productivity, resource use, value creation, efficiency and cost per operating hour [70]. The importance of costs has an influence on the strategy parameters degree of automation [70], production system [243], process span, structure of the production and assembly line [58], standardization of processes [307], linking of processes, warehouse concept [219], quality control [55], design stability and scalability of the technology [70].
Importance of quality	High-quality products increase customer loyalty to brands and support companies in differing in highly competitive markets. Superior quality can be achieved through higher product reliability, higher product performance or available product features [29]. Quality can be measured by the number of errors per unit, number of customer complaints, reject rate, number of warranty claims or customer satisfaction [70]. Between high quality and low costs there is a trade-off [55], so that costs for the provision of higher quality must be brought into line with the willingness of the market to pay [29]. The importance of quality influences the degree of automation, the product design [207], the structure of the assembly line [58], the standardization of processes [70], the linking of processes [70] and quality control [55].

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Table A.2 – continued from previous page

Input	Description
Importance of product and process flexibility	Flexible facilities allow for agility and adaptability [14] and are essential to manage demand and capacity in response to changes in customer needs. Product and process flexibility gives an organization the ability to quickly introduce new products, quickly adapt capacity or products, and quickly manage changes in product mix [70]. Product and process flexibility influence the output parameter degree of automation [207, 208], the structure of the production and assembly line [58], the standardization of processes, the linkage of processes [70], the design stability, the scalability of the technology [70] and the production network [14].
Importance of product innovation	This input parameter indicates how important innovative products are for the company's success. It influences the required employee training and manufacturing and assembly technologies [14].
Importance of ecologic sustainability	Environmentally friendly products and production are an important political issue. The effects of the sustainability measures of a company are brand image and therefore pricing power. Additionally, cost savings are possible due to higher operational efficiency, more efficient use of resources and supply chain optimization, as well as improved opportunities to win over, retain and motivate staff. Furthermore, customer loyalty will be strengthened and access to capital, financing and insurance improved [309]. The importance of environmentally friendly products and production depends on the integration of the local society and politics [164].
Importance of social sustainability	Even though savings through lower labor costs are the most common reason for setting up production in Africa [14], there may be other reasons. Examples are the promotion of international peace [310], the support of economic and social development and the sustainable strengthening of rural regions in developing countries. The importance of social responsibility also has an influence on the strategy options required employee training and integration of local society and politics [164].
Type of product	A distinction is made between a special product and a standard product. A special product is a product that is not required several times in the same form, or where demand is irregular and there are long periods between orders. A standard product describes a product that is manufactured several times and whose demand is repeated. The term "custom" refers to a product manufactured to a customer's specifications. Demand for a customer-specific product can either not be repeated or be repeated [58]. The type of product influences production volume [58], degree of automation [208], structure of the assembly line [58] and selection of equipment [70].
Product complexity	A product can be complex due to product variety, number of parts, multi-functionality, manufacturability or size and geometry [311]. Product complexity influences production design and has effects on the output parameter automation degree [208] and required employee training [14].
Labor costs	The development of wage costs is linked to prosperity. In affluent countries, wages are very high due to strong and sustained economic growth and continue to rise steadily, while in countries that have not been able to keep pace with rapid economic development, wage development has slowed down [14] (p. 9–10). Lower labor costs are the most likely reason for relocating production abroad [312]. Labor costs have an influence on the output parameter degree of automation [207] and structure of the production and assembly line [14].
Market demand	The parameter market demand provides information on demand stability. Volatile market demand requires high product and process flexibility and affects the choice of production system [243], depth of added value [14], production network [14], warehouse concept [14] and process standardization [307].
Competition in the supplier market	The competitive situation in the supplier market influences companies in their decisions as to whether parts are produced by companies themselves or purchased, and is therefore in interaction with the depth of value-added. If there is no competition between the suppliers, suppliers have a good position in price negotiations, as the buyer has no or few alternative suppliers [313]. Whether a company has a domestic or foreign supplier is a primarily strategic decision [58].

Continued on next page

Table A.2 – continued from previous page

Input	Description
In-house resources	For internal company resources, a distinction is made between tangible and intangible resources. The former is defined as tangible assets. These are the machines, computers and equipment owned. Intangible resources include, e.g., brand strength, supplier relationships, process knowledge [70], technical expertise, know-how [55], information and time [70]. Internal company resources have an impact on make-or-buy decisions and thus on the process span [58].
Availability of local workforce	The availability of workers interacts with their level of education and thus with the internal training in companies. The wage cost situation is also dependent on the availability of workers [14, pp. 38-40]. The processes must be planned according to the available workforce.
Turnover of local workforce	The departure of skilled workers from the company is a know-how drain [105, p. 155]. To replace these employees quickly, it is necessary to install simple processes. On the contrary, for know-how intensive processes it means ensuring that staff turnover is low. Staff turnover is linked to the wage situation and incentives in the company [14, pp. 258-259]. If the turnover rate is very high a large investment in the training of employees is questionable [169].
Energy supply	Poor supply of electrical energy is present in African countries [5, p. 14, 65] and is therefore a major cost driver in Africa [281]. The energy intensity of the processes depends, for example, on the availability of energy and its price [14, p. 35].

Table A.3: Output parameters. Note: Published in Brönner et al. [115]

Output	Description
Degree of automation	The degree of automation, the distribution of physical and cognitive tasks between humans and technology, is described as a continuum ranging from completely manual to fully automatic [208]. A low degree of automation allows for a high degree of flexibility and low fixed machine costs [70, p. 260]. In the contrast, a high degree of automation has the advantage of economies of scale and a lower share of personnel costs [14]. The degree of automation is thus linked to the scalability, the process coupling, the number of variants and the volume [70, p. 260].
Production control	This output specifies the extent to which the production control is designed as decentral (pull) or central (push) production control. With the push principle, the production orders are scheduled with a planned start date on a specific work system, and "pushed" through production. The outgoing quantity is planned, and inventory is monitored. In a pull system, orders are monitored by the consumption and material is "pulled" through production. An upper stock limit is ensured by the system and the outgoing quantity is monitored [14]. The pull principle is a consumption-oriented control method [71]. This production control contains a variety of methods for efficient, competitive and modern production, whereby avoiding waste and continuous improvement is emphasized [14]. Furthermore, especially in international organizations, situation-specific planning, control of (local) production processes and order processing is necessary depending on the product [314].
Depth of value-added	The depth of value-added indicates the share of in-house and purchased components. In deciding the strategic importance of the component, availability of suppliers [14], retention of core technology, achievement of cost advantages, access to capabilities missing in the company, increased control over the competitive environment and opportunities to differentiate products through in-house production are taken into account. Alternatives to in-house manufacturing may include joint ventures and non-equity-based collaborations. It must also be decided whether the outsourcing should take place via domestic or foreign suppliers [58]. Regarding the purchase type, a distinction is made between single sourcing (one supplier for one purchased part) and multiple sourcing (several suppliers for one purchased part) [58].
Production choice	The output parameter production choice summarizes production, manufacturing and assembly line processes in order to provide information about the production principle. It involves the spatial arrangement of the machines and workstations. A distinction is made between order-related production, flow production and group production. In shop floor production, similar machines are grouped at one location [315].

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Table A.3 – continued from previous page

Output	Description
Process standardization	The standardization of products and processes allows for savings and optimization [14]. The development and introduction of complex instruments for process standardization such as guidelines, plan specifications, decision criteria and controls is efficient when large quantities of similar products are produced [70, pp. 124-125]. In the case of complex or highly variable tasks, process standardization are not appropriate [315]. Adaptation to local environmental factors makes standardization more difficult [14].
Process coupling	Advanced process technologies obtain their competitive costs and benefits by linking previously separate activities. The link can consist of physical links between the installations or they may mean that the planning and control of these machines can be combined. The integration of separate processes is associated with high capital costs, which can be reduced through the integration of associated processes. In addition, linked processes lead to a higher degree of synchronization, which reduces inventory and costs [70].
Operating resources flexibility	Especially in dynamic environments, it is necessary to provide appropriate flexibility in the production structure. This flexibility, implemented for example through more flexible operating resources, must therefore be planned in the system context [316]. The choice of resources in terms of flexibility indicates the multi-functionality, i.e., universally applicable, and to which extent the equipment can be used for special applications. Universal tools can be used for a wide range of processing activities required for a wide variety of products. Specialized tools are designed to meet specific requirements and are therefore suitable for lower product variance [70] .
Operating resources life-cycle	The choice of equipment in terms of duration indicates whether the equipment is intended for one or more periods of usage [217, p. 121], whereby lifetime of operating material and the planned product life are mutually dependent [8, p. 396, 40, p. 517]. Thus, this choice also affects the investment risk, which increases alongside a shorter product life [40, p. 517]. To take account of uncertainties regarding future product adaptations and increasing volumes, a medium-term period of between 7 and 14 years should be provided for, which according to Fisel [217, p. 212], corresponds to one to two product life-cycles of an electric vehicle.
Level of inventory	The level of inventory describes all measures relating to inventory-holding within the company including the associated planning, scheduling and administrative activities [315]. The level of inventory in raw material, work-in-progress and finished goods [58, p. 163] as well as the throughput time determines the warehouse system and concept [219].
Quality control	During the quality control, the design quality as well as the execution quality are checked. As part of the quality control, a target/actual comparison is used to check if products meet the quality requirements [58]. Since quality and costs are trade-offs, quality control must be chosen, depending on the competition priorities. Either low cost/low quality, or high cost/high quality [55]. Quality control itself can focus either on the product or the process [257, pp. 16-17]. In this respect, a quality control does not replace a company-wide quality management.
Design flexibility	The output parameter describes the design flexibility of the product during the production period. Before the design freeze, designers work on the aesthetics of the product. After the design freeze, the product is handed over to production, and engineers deal with feasibility issues. Since design elements are not changed from that point on, designers are no longer directly involved. They track the product to ensure that the previously “frozen” design is preserved. Freezing the design reduces expensive production system changes [58]. Besides, normal changes due to product life cycles influence changes in technology, production structure and operating resources [317].
Worker training	This output parameter provides information on the extent to which additional employee training is required. Training brings with it a variety of benefits, including improved employee performance, improved satisfaction, remediation of weaknesses, increased productivity, compliance with quality standards, reduced employee turnover, better reputation, and innovation in new strategies and products [70].

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Table A.3 – continued from previous page

Output	Description
Integration of society	Local society as well as local authorities influence production through local requirements concerning security, import taxes and necessary permits [14]. Governments handle foreign investment as part of their foreign policy and therefore significantly impact the build-up of production sites through subsidies or obstacles [4]. The technology must be transferred to the local standards and the specific context of Africa to be effective and sustainable [164]. In addition to the technological aspects, local environmental aspects and socio-cultural dynamics are taken into account [4].
Production technology	The output parameter production technology summarizes manufacturing and assembly technologies in order to specify the extent of new technologies. New technologies require financial resources and the development of new skills. If the introduction is successful, the technology supports maintaining or building a leadership position [58].
Production network	The central world factory enables economies of scale and is appropriate in industries with diversification advantages, high product value density and long delivery times. Production at just one location improves the availability of qualified personnel and know-how, allows for a stronger specialization, a more intensive exchange of knowledge and shorter delivery times between the processing stages. The model "local for local', a decentral network strategy allows for high market proximity. The reduced influence of economies of scale and the greater importance of flexibility and short delivery times have prompted many companies to invest in foreign markets via local subsidies [14].
Process scale-ability	The output parameter process scaleability indicates the capacity and thus size of the individual process units. Crucial is the ability to quickly, cost-effectively and flexibly adapt products. The larger the process unit, the higher the capital costs, but the lower the capital costs per capacity unit. Similarly, the cost of installing and maintaining the technology per local production unit is lower. There is a trade-off between large-scale units that exploit economies of scale, but create an imbalance between capacity and demand, and local technology units with better consistency between capacity and demand, but less economies of scale. In addition, few, global process units lead to major damage in the event of a failure [70, pp. 260-261].
Staffing strategy	The deployment of expatriates at a new location is considerably more cost-intensive than the deployment of local specialists and managers. However, their know-how and company-wide connections are essential, especially in the startup phase. Studies show that in less successful new locations, companies invest the same amount in expatriates and in the training of local employees—in successful locations, companies invest twice as much in the training of local employees as in the deployment of expatriates [14]. The share of expatriates enables the transfer of proven approaches and corporate culture to the new location and facilitates local contact with the parent company. It is important to assign expatriates who have a comprehensive knowledge of company-specific products, equipment and management processes. Disadvantages are high expenses that are necessary for expatriates. The use of local specialists and managers is generally cheaper, especially in low-wage countries [14].
Incentives for employees	The boundary conditions may require motivation through incentives which can consist of additional salaries or benefits [216]. Thus, management must strive for maintaining motivation and morale to prevent labor turnover [14]. In addition to the labor turnover rate, there is also a correlation between employee skills, quality of the end product and the underlying remuneration and incentive system in production [257, pp. 236-239].

A.3.2 Input Parameter

Table A.4: Input parameters, range of values and calculation default.

Input $u(k)$	Unit	Description	Calculation	Data source
Production volume	[pcs.]	Planned volume [1, 100.000]	$I(x)=\begin{cases} I=1+4.3*10^{-4}x-3.4*10^{-9}x^2 & x\leq 10.000 \\ I=4.44+5.56^{-5}*x & 10.000<x\leq 100.000 \end{cases}$	Market research
Market entry strategy	A*	Corporate objective		Market research
Labor skill availability	[%]	Firms identifying an inadequately educated workforce as a major constraint [0 %, 30 %]	$I=10-0.3x$	[171, 318]
Importance of economy of scale	A*	Production priority		Market research
Importance of delivery time	A*	Production priority		Market research
Importance of product cost	A*	Production priority		Market research
Importance of quality	A*	Production priority		Market research
Importance of flexibility	A*	Production priority		Market research
Importance of innovation	A*	Production priority		Market research
Importance of eco. sustainability	A*	Production priority		Market research
Importance of soc. sustainability	A*	Corporate objective		Market research
Type of product	[%]	Share of standard products	$I=0.09x+1$	Market research
Product complexity	[%]	Share of supplier components	$I=-0.09x+10$	Internal data, [5]
Labor cost	[$]	GNI per Capita [730 $, 52.788 $]	$I=0,173*10^{-3}x+0.87$	[319]
Market stability	A*	Stability of market demand		Market research
Competition in the supplier market	[%]	Share of components that can be sourced local	$I=0.09x+1$	Market research
Intra corporate resources	[%]	Share of available operating material, know-how, processes	$I=0.09x+1$	Internal data
Availability of local workforce	[%]	Employment-to-population ratio [50 %, 100 %]	$I=-0.18x+19$	[211]
Turnover of local workforce	[%]	Share of turnover per year [0 %, 50 %]		[14, p. 258]
Energy supply		Number of power outages per year [0, 365]	$I=0.025x+1$	[171, 252]

*Expert assessment on a 10-point scale

A.3.3 Rule Base

Table A.5: External to internal dependencies visualized in a DMM.

	Degree of automation	Production control	Depth of value-added	Production choice	Process standardization	Process coupling	Operating resources flexibility	Operating resources life-cycle	Level of inventory	Quality control	Design stability	Worker training	Integration of society	Production technology	Process scaleability	Production network	Staffing strategy	Incentives for employees
Production volume	×			×	×			×	×				×		×	×		
Market entry strategy								×						×				
Labor skill availability	×		×		×					×		×		×				
Importance of economies of scale	×				×	×			×						×	×		
Importance of delivery time and reliability		×							×		×			×		×		
Importance of product costs	×	×		×	×	×			×	×	×				×	×		
Importance of quality	×				×	×		×		×								
Importance of product and process flexibility	×			×	×	×	×			×	×	×			×	×		
Importance of product innovation	×		×		×			×			×	×		×				
Importance of ecologic sustainability													×			×		
Importance of social sustainability												×	×					
Type of product	×			×			×											
Product complexity	×					×						×						
Labor cost	×			×														
Market demand		×	×		×						×							
Competition in the supplier market			×															
In-house resources			×													×		
Availability of local workforce																×		
Turnover of local workforce																		
Energy supply																		

Table A.6: Internal dependencies visualized in a Design Structure Matrix.

	Degree of automation	Production control	Depth of value-added	Production choice	Process standardization	Process coupling	Operating resources flexibility	Operating resources life-cycle	Level of inventory	Quality control	Design stability	Worker training	Integration of society	Production technology	Process scaleability	Production network	Staffing strategy	Incentives for employees
Degree of automation				x	x	x	x											
Production control									x									
Depth of value-added																		
Production choice					x			x	x		x	x						
Process standardization								x	x		x			x				
Process coupling												x						
Operating resources flexibility																		
Operating resources life-cycle																		
Level of inventory																		
Quality control																		
Design stability												x						
Worker training														x				
Integration of society																		
Production technology																		
Process scaleability																		
Production network																		
Staffing strategy																		
Incentives for employees																		

Extract from the rule base of the base model. Complete rule base under https://github.com/TUMFTM/Production_Strategy_Development.

Table A.7: Rule base of the basic model.

				– Extract –			
If	Volume	is	high	THEN	Degree of automation	is	high
If	Volume	is	medium	THEN	Degree of automation	is	medium
If	Volume	is	low	THEN	Degree of automation	is	low
If	Skill Level of employees	is	high	AND	Product Complexity	is	high
				THEN	Degree of automation	is	low
If	Skill Level of employees	is	medium	AND	Product Complexity	is	medium
				THEN	Degree of automation	is	medium
If	Skill Level of employees	is	low	AND	Product Complexity	is	low
				THEN	Degree of automation	is	high
If	Importance of Economies of Scale	is	high	THEN	Degree of automation	is	high
If	Importance of Economies of Scale	is	medium	THEN	Degree of automation	is	medium
If	Importance of Economies of Scale	is	low	THEN	Degree of automation	is	manual
If	Importance of Quality	is	high	THEN	Degree of automation	is	high
If	Importance of flexibility	is	high	THEN	Degree of automation	is	low
If	Importance of flexibility	is	medium	THEN	Degree of automation	is	medium
If	Importance of flexibility	is	low	THEN	Degree of automation	is	high
If	Investment volume	is	medium	AND	Labor cost	is	medium
				THEN	Degree of automation	is	medium
If	Labor cost	is	high	THEN	Degree of automation	is	fully automatic
If	Labor cost	is	medium	THEN	Degree of automation	is	medium
If	Labor cost	is	low	THEN	Degree of automation	is	manual
If	Importance of delivery time	is	high	AND	Importance of price	is	low
				THEN	Production system	is	push
If	Importance of delivery time	is	medium	AND	Importance of price	is	medium
				THEN	Production system	is	push/pull
If	Importance of delivery time	is	low	AND	Importance of price	is	high
				THEN	Production system	is	pull
If	Importance of delivery time	is	high	AND	Importance of price	is	high
				THEN	Production system	is	push/pull
				– Extract –			

A.3.4 Simulation of Scenarios

The base model, the template and the scripts are available under the link https://github.com/TUMFTM/Production_Strategy_Development.

1. Definition of the simulation scenarios
2. Filling the Excel™ Scenario_Template
3. Open Matlab™, Basic_Model, Scenario_Simulation, Scenario_Plot
4. Set number of scenarios (variable z)
    - Scenario_Simulation
    - Scenario_Plot
5. Import Scenario_Template to workspace and define table as *Input*
6. Run Scenario_Simulation
7. Run Scenario_Plot

A.4 Additional Information: Application

A.4.1 Countries

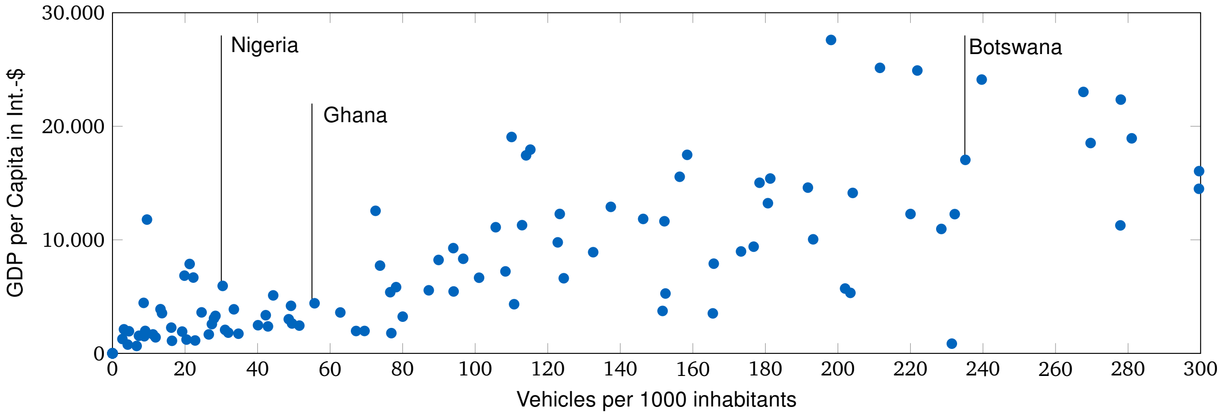

Figure A.3: Vehicles per 1.000 inhabitants by country.
Data Source [16, 17, p. 46].

A.4.2 Requirements

Table A.8: Requirements in production site planning in sub-Saharan Africa.

	Requirement
	Training must be offered and the participation of employees must be ensured.
	The work task must be adapted to the level of qualification of the employees.
	The local culture and language must be integrated into the company or the company must not prohibit or influence it.
	The production and qualification for this must not be negatively influenced by lack of experience in the field of learning.
	The production and qualification to learn these must not be negatively influenced by different educational levels in different countries.
	Production must prevent or not be influenced by employee fluctuation.
	The production must not be influenced by a lack of product knowledge of the employees and the training must convey this product knowledge.
	The company should attract local talents and managers and commit them to the company.
	The company should involve the local population as employees in the production process.
	The company should build long-term relationships with its employees.
	The company should prevent human rights violations, inequality and poverty.
	The company must transfer the necessary know-how for production through training and develop the product and process for this transfer.
	The company must offer the product at a competitive price and meet customer requirements at the best possible price.
	The product should be continuously optimized with regard to quality.
	At the end of its life cycle, the product is intended to have a way of further use of components or materials.
	The product should be optimized according to its entire life cycle.
	The product should consist of less components as possible.
	The product technology should be adapted to the market and customer requirements.
	The product costs in terms of materials should be low.
	The product should be tested and validated locally.
	The product structure should enable economies of scale.
	The product should consist of a maximum number of standardized supplier components and use standardized in-house developments.
	The know-how transfer to use the product features must be simple.

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Table A.8 – continued from previous page

	Requirement
	The product must also be economically producible in small series and be able to realize low break-even points.
	Product quality must be easy to ensure.
	The spare parts for the product must be available or the product must be capable of maintenance or repair without spare parts.
	The number of resources used should be as minimal as possible.
	The cost, function and quality of the product should be adapted to the customer requirements and the environmental conditions.
	The product should have a modular structure.
	Products in developing countries must not cannibalize those of the home market.
	The required number of local supply components must be integrated in the product.
	The technologies required for production should be sustainable.
	The technologies and processes should be economical even with low capacity utilization.
	The technologies and processes must prevent or identify scrap.
	The processes must be safe for the employee according to global standards and this safety must be ensured.
	The processes and technologies should be designed to be energy-saving.
	The processes and technologies should be fast and robust during ramp-up.
	The processes and technologies are designed to ensure quality without the need for testing.
	The processes and technologies must be robust against environmental influences.
	The processes and technologies should have a low expenditure in the planning.
	The processes and technologies should enable continuous improvement.
	The processes and technologies should have a low complexity for the user and during the process.
	The processes and technologies must enable economical small series production.
	The processes and technologies should enable production independent of the capabilities of the employees.
	The processes and technologies must not be influenced by a lack of or unstable local information systems.
	The processes and technologies must not be influenced by the lack of technological capabilities of the employees, or the processes must achieve the required output despite low complexity.
	The processes and technologies must enable adjustments in product mix, speed and quantity.
	The processes and technologies should be cost-effective in the initial investment.
	Processes and technologies must comply with global measurement standards.
	The processes and technologies should be adapted to the environmental conditions.
	The processes and technologies should contain manual work steps and be adapted to the location.
	The processes and technologies are designed to ensure productivity, regardless of environmental influences.
	The processes and technologies should meet both global and local requirements with regard to manufacturing standards and environmental standards.
	The processes and technologies must be transferable to the employees.
	The company must determine the quality and price of the product for the market segment.
	The company must define a strategy regarding aftersales process.
	The company must comply with local labor standards.
	The company should establish communication standards between the sites.
	The company should not be affected by the geographical distance between the main plant and the local plant.
	The company should shorten the duration of the construction of the new location.
	The company should hire local managers.
	The company should not be deterred by environmental influences in developing countries and should give up prematurely if problems arise.
	The company should keep the expenditure for local adjustments as low as possible.
	The company has to calculate small margins economically in the design of the process, the product and the location.
	The company should strive for the shortest possible time to market.
	The company should adapt the time of market entry to the political situation of the country and the customer needs.
	The company must handle the lack of foreign direct investments and aim for longterm effects in their investment.
	The company should integrate local partners in all areas as far as possible.
	The company must establish a corporate culture at the location and thus convey the values of the company.

Continued on next page

Table A.8 – continued from previous page

	Requirement
	The company must ensure that no know-how can be lost through employees, suppliers and competition.
	The company must calculate with low profits and thus also with the duration of the return on investment.
	The company should plan without or with few local financing possibilities.
	The company must handle the geographical distance to the main plant.
	The company must cope with fluctuating demand in the interpretation of all areas.
	The company must actively prevent the spin-off of spin-offs by employees.
	The company must consider local competition.
	The company must include the political and economic situation of the country in its planning.
	The company must plan with the lack of local competence, such as local research, or build this over time.
	The company must take high inflation into account.
	The company must actively prevent corruption and theft.
	The company should not be influenced by a lack of political support.
	The company should be socially involved in its environment.
	The organization should meet both global and local requirements with regard to manufacturing standards and environmental standards.
	The company must integrate import taxes and trade barriers into its planning.
	The company must take into account in its planning that the business ecosystems are not established in the countries, that regulations and laws are missing.
	The company should integrate global suppliers into the local value chain.
	The company must ensure the quality of the supplied components.
	The company should integrate the technological capabilities of its suppliers into its product development.
	The company should develop the suppliers and minimize the costs and effort involved.
	The company should use standardized suppliers.
	The company should integrate local partners in all areas as far as possible.
	The company must build a reliable infrastructure or have it built through political support.
	The company should force the merger with other companies to build clusters.
	The company must strive for low logistics costs.
	The company must incorporate the supplier's capabilities in terms of time, flexibility and innovation into product development and production process planning.
	When choosing a location, the tax conditions for the planned depth of value-added must be taken into account.
	When selecting a location, a comparison should be made between the necessary adjustments to the market size.
	When choosing a location, customer proximity can be taken into account in the decision.
	The external environmental conditions must be taken into account when choosing a location.

A.4.3 Production Strategy Parameter Set

Table A.9: Production strategy parameters for an aCar production sites. Note: Published in Brönner et al. [250].

Production strategy parameter	Range	
Training location	On-the-Job	Off-the-Job
Hierarchy (control and leadership)	Flat	Steep
Motivation through external factors	No	Many
Training time	Low	High
Number of workers (total, local, expatiates)	Low	High
Work task	Collaborative	Individual
Initial employee (high voltage) qualification	Local	Global
Wage	Fixed	Chord
Local supervisors	None	Many
Qualification for electric vehicle assembly	Few	All
Share of foreign white collar workers	None	Many
Share of foreign blue collar workers	None	Many
Degree of automation	Low	High
Supplier integration (production)	Low	High
Production system	Push	Pull
Order proceeding	Design to order	Make to stock
Depth of value-added	Low	High
Quality standards	Local	International
Operating life of the processes	Low	High
Span of processes (make vs. buy)	Low	High
Quantity	Low	High
Worker safety concept	Low	Complex
Assembly line design	Box	Flow
Throughput time and tact time	Low	High
Process modification	Low	Continuous
Standardization of processes	Low	High
Product flexibility	Low	High
Quality assurance (in-line, end-off-line)	Low	High
Unit costs (production)	Low	High
Handling of defect batteries	Local	Global
Linkage of processes	Low	High
Manufacturing and assembly technology	Conventional	Innovative
Integration of local society and politics	Low	High
Sales market	Local	Global
Procurement (market)	Local	Global
Employee integration	Low	High
Procurement (strategy)	Local	Central
Organization style	Local	Global
Risk affinity	Low	High
Market entry strategy (geographic)	Small	Big
Market entry strategy (investment volume)	Small	Big
Local social commitment	Low	High
Dependency between sites	Low	High
Supplier	Local	Global
IP protection	None	High
Unit costs (vehicle)	Low	High
Quality strategy (cost/reliability)	Low	High
Material for in-house production components	Local	Global
Vehicle equipment rate	Low	High
Design stability (during production period)	Frozen	Continuous
Technological risk	Established	Innovative

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Table A.9 – continued from previous page

Production strategy parameter	Range	
Supplier integration (development)	Low	High
Product complexity	Individual	Standardized
Number of components	Low	High
Modularity	Low	High
Safety concept (encapsulation of components)	Low	High
Safety concept (low to high voltage)	Low	High
Battery concept	Cell	Package
Standardization of vehicles (or local adaption)	Low	High
Nominal performance (in vehicles per year)	Low	High
Return on invest strategy	Low	High
Amortization period	Short	Long
Location (near the customer / material)	Customer	Material
Location strategy (steering of the locations)	Independent	Central
Dependency from local traffic infrastructure	Independent	Dependent
Dependency from local energy infrastructure	Independent	Dependent
Lifespan	Low	High
Energy supply	Central	Decentralized
Product flexibility	Low	High
Quantity flexibility	Low	High
Operating material maintenance	Local	Global
Warehouse concept	JIT	Stock
Warehouse safety	None	Permanent
Operating material (flexibility)	Specialized	Multifunctional
Operating material (maturity)	Temporary	Series

A.4.4 Validation

Statistical Data

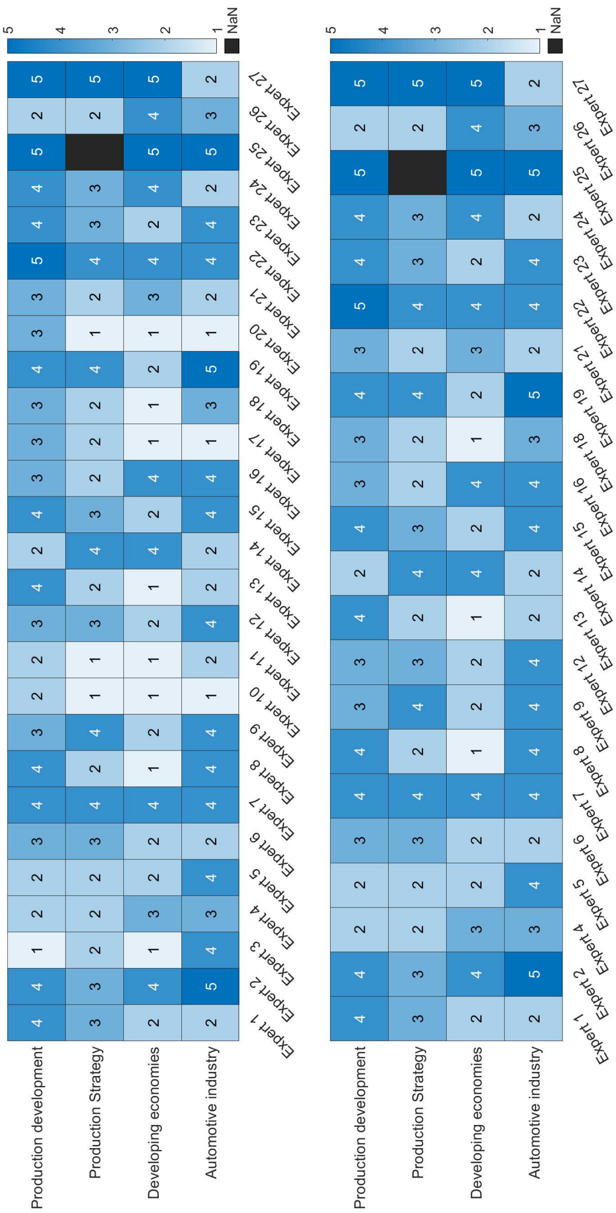

Figure A.4: Statistical data of survey participants. Self-assessment on a 5-point scale between 1 (no knowledge) and 5 (expert knowledge). Top: All survey participants (n = 27). Bottom: Selection of participants with above average experience (n = 22).

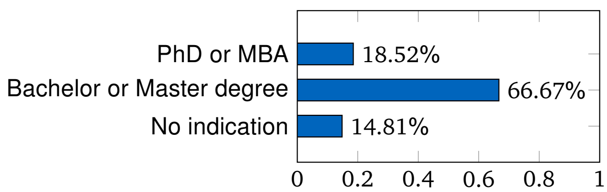

Figure A.5: Educational background of the survey participants. In percentage of total participants.

Expert Survey

Table A.10: Case-specific and mean expert approval rate.

		Degree of automation	Production control	Depth of value-added	Production choice	Process standardization	Process coupling	Operating resources flex.	Operating resources l.-c.	Level of inventory	Quality control	Design stability	Worker training	Integration of society	Production technology	Process scale-ability	Production network	Number of expatriates	Incentives for employees
Evaluation																			
Case 1 (n=14)	Approval rate [%]	100	79	79	67	83	71	69	83	100	62	73	92	86	100	64	82	67	83
Case 2 (n=8)	Approval rate [%]	75	83	71	75	88	88	71	67	86	71	57	75	71	100	100	100	71	75
	Mean rate [%]	88	81	75	71	85	79	70	75	93	66	65	84	79	100	82	91	69	79
Assessment																			
Case 1 (n=8)	Simulation	3.46	6.52	4.88	3.97	5.53	4.62	7.12	5.50	3.64	4.30	5.59	2.38	6.84	5.82	6.84	4.95	8.78	8.78
	Mean	2.75	6.00	3.25	3.88	6.50	5.00	6.50	3.63	3.63	7.25	4.13	7.00	8.50	2.50	8.00	5.25	5.38	6.63
	Standard deviation	0.13	0.02	0.04	0.04	0.02	0.08	0.01	0.08	0.07	0.05	0.08	0.09	0.07	0.00	0.18	0.09	0.02	0.04
	Deviation [%]	7.15	5.23	16.29	0.97	9.71	3.82	6.20	18.75	0.18	29.47	14.67	46.22	16.56	33.23	11.56	2.99	34.05	21.55
Case 2 (n=14)	Simulation	6.13	4.40	5.89	7.09	7.47	6.63	4.34	8.83	3.64	8.83	7.32	5.59	8.83	4.15	6.84	6.06	8.78	8.78
	Mean	6.50	5.43	3.77	7.29	8.14	6.31	6.00	8.69	5.38	6.79	3.43	6.07	7.50	3.79	6.36	6.15	5.00	6.50
	Standard deviation	2.93	3.16	1.42	3.10	2.03	2.72	3.31	1.18	2.14	2.81	2.47	2.16	1.16	2.33	2.98	2.67	2.16	2.32
	Deviation [%]	3.73	10.26	21.24	2.00	6.73	3.21	16.58	1.38	17.41	20.44	38.91	4.83	13.30	3.62	4.87	0.96	37.80	22.80
	Mean deviation [%]	5.44	7.74	18.77	1.49	8.22	3.52	11.39	10.06	8.80	24.96	26.79	25.52	14.93	18.42	8.21	1.98	35.92	22.17

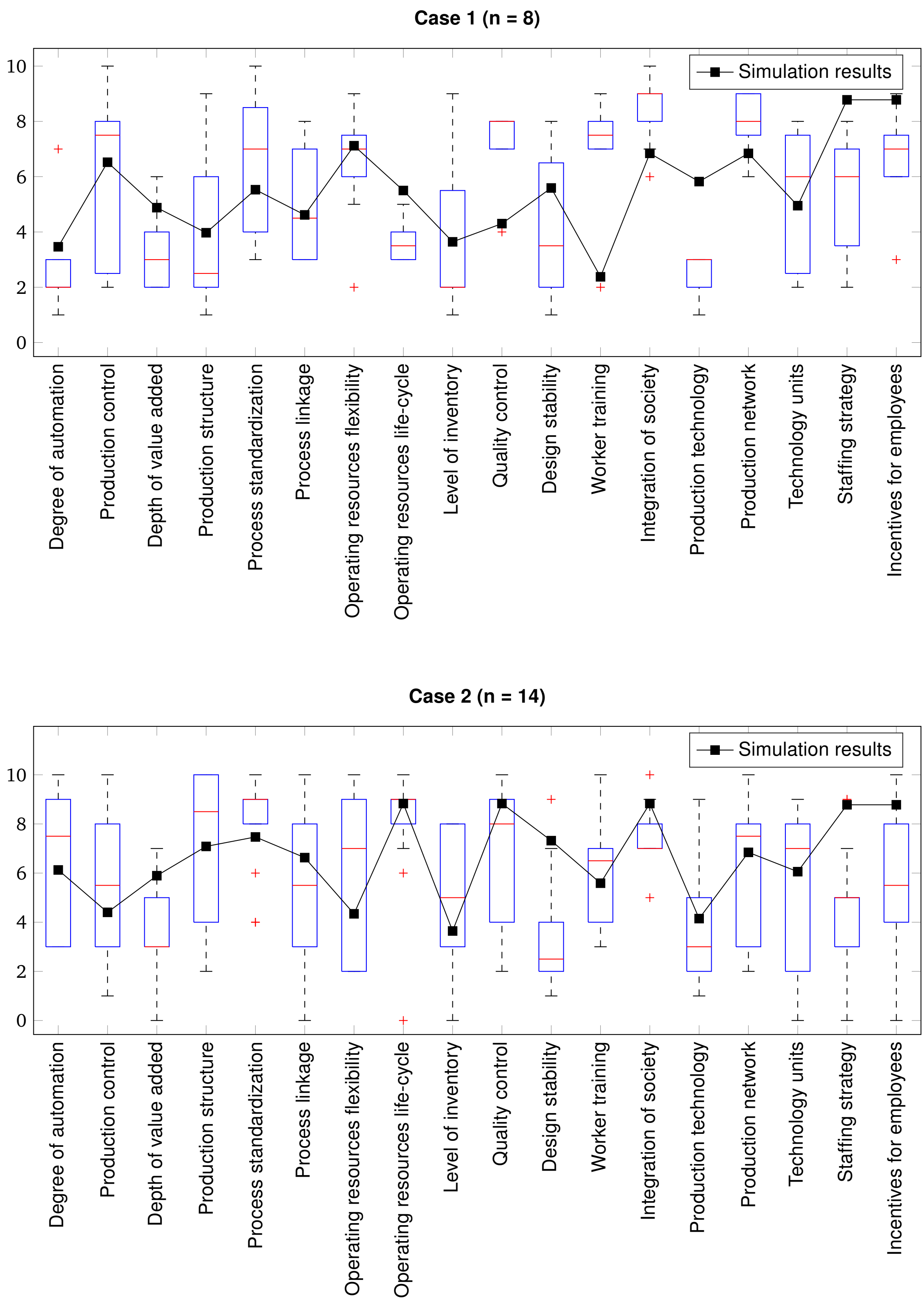

Figure A.6: Statistical evaluation of the expert assessment and comparison with the simulation result.

A.4.5 Questionnaire for the Validation of Parameters

Table A.11: Extract from the validation of the parameter set.

Dear Participant,

thank you very much for supporting our study, which is conducted as part of a dissertation project. The aim of the project is to develop production strategy parameters which have to be decided during production strategy development. These parameters should be valid for electric vehicle production in sub-Saharan Africa. The parameters were derived by a systematic procedure and should be confirmed or rejected with this study. Furthermore, the extreme values that this parameter can assume are interesting. Therefore, these are also queried within this study. In this survey, LDC describes the abbreviation for Least Developed Countries, which is based on the classification of the United Nations.
For this purpose, the following 76 hypotheses are presented to you. We ask you for your opinion (agree / disagree). If you have any questions, please contact your survey partner. If you subsequently have additional parameters please add them on the last page.

The survey does not take longer than 20 minutes. Participation in this study is voluntary and can be aborted at any time without giving reasons. In addition, you have the possibility not to answer individual questions. Your answers will be kept strictly confidential and stored anonymously. They are used exclusively for scientific purposes. Conclusions about your person are not possible at any time. If you have any questions and/or comments, please send an e-mail to Broenner@ftm.mw.tum.de.

Many thanks for your support!

0	**Personal information**
a	Please indicate your professional background and experience:
a	☐ Corporate/Business/Production strategy
a	☐ Production/Manufacturing/Assembly
a	☐ Logistics/Distribution
a	☐ Qualification/Training
a	☐ Other:_________________
b	Please indicate your experience in least developed countries:
b	☐ Experience
b	☐ No experience
b	☐ I cannot or do not wish to give an answer

Employee-related parameters

1	**Trainings location**	
a	Hypothesis:	The choice of the location where employees are trained is a production strategy parameter in developing economies.
a	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer
b	Hypothesis:	The decision scope is between on-the-job and off-the-job training.
b	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer

3	**Motivation**	
a	Hypothesis:	The choice of external motivation factors (e.g. money and additional services) is a production strategy parameter in developing economies.
a	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer
b	Hypothesis:	The extrema of the external motivation strategy are no and many factors in LDC.
b	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer

4	**Training time**	
a	Hypothesis:	The choice of the training time is a production strategy parameter in developing economies.
a	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer
b	Hypothesis:	The extrema of the trainings time choice are low and high in developing economies.
b	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer

5	**Number of workers**	
a	Hypothesis:	The choice of the number of workers (total, local, expatiates) is a production strategy parameter in LDC.
a	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer
b	Hypothesis:	The extrema of the number of workers choice are low and high in developing economies.
b	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer

7	**Initial qualification**	
a	Hypothesis:	The choice of the initial qualification concept (e.g. high voltage qualification) is a production strategy parameter in developing economies.
a	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer
b	Hypothesis:	The extrema of the initial qualification concept choice are local (on site) and global (off site) qualification in developing economies.
b	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer

8	**Wage system**	
a	Hypothesis:	The choice of wage system is a production strategy parameter in developing economies.
a	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer
b	Hypothesis:	The extrema of the wage system are fixed wage and chord wage in developing economies.
b	Answer:	☐ I agree ☐ I disagree ☐ I cannot or do not wish to give an answer

Notes and comments:

A.4.6 Results of the Questionnaire

Table A.12: Validation of strategy parameters.

	Parameter	Confirmation	Rejection	Abstention
	Trainings location	100%	0%	0%
	Hierarchy	86%	0%	14%
	Motivation	100%	0%	0%
	Training time	100%	0%	0%
	Number of workers	86%	0%	14%
	Work task	86%	0%	14%
	Initial qualification	71%	14%	14%
	Wage system	100%	0%	0%
	Supervision	100%	0%	0%
	Control and management	86%	14%	0%
	Qualification for electric vehicle assembly	100%	0%	0%
	Degree of automation	100%	0%	0%
	Job design	71%	14%	14%
	Supplier integration (production)	100%	0%	0%
	Production system	100%	0%	0%
	Order processing	100%	0%	0%
	Depth of value-added	100%	0%	0%
	Quality standards	71%	14%	14%
	Lifecycle of the processes	86%	0%	14%
	Span of processes	57%	0%	43%
	Quantity	71%	14%	14%
	Worker safety concept	100%	0%	0%
	Assembly line design	86%	14%	0%
	Throughput and tact time	100%	0%	0%
	Process improvement concept	86%	0%	14%
	Standardization of processes	86%	14%	0%
	Product flexibility	86%	14%	0%
	Quality assurance concept	100%	0%	0%
	Unit costs (direct production costs)	100%	0%	0%
	Handling of defect batteries	86%	0%	14%
	Linkage of processes	86%	0%	14%
	Manufacturing and assembly technology	100%	0%	0%
	Integration of local society and politics	86%	0%	14%
	Sales market	100%	0%	0%
	Procurement market	86%	0%	14%
	Employee integration	86%	0%	14%
	Procurement strategy	100%	0%	0%
	Organization style	71%	0%	29%
	Risk affinity	86%	0%	14%
	Market entry strategy	86%	0%	14%
	Time-to-market	100%	0%	0%
	Local social commitment	86%	0%	14%
	Communication between sites	71%	14%	14%
	Dependency between sites	71%	0%	29%
	Supplier strategy	100%	0%	0%
	Location steering	71%	0%	29%
	Overall quality concept	100%	0%	0%
	Vehicle costs	86%	0%	14%
	Vehicle quality	100%	0%	0%
	Material selection	100%	0%	0%
	Vehicle equipment rate	71%	0%	29%
	Local adaption	71%	0%	29%
	Design stability	86%	14%	0%

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Table A.12 – continued from previous page

	Parameter	Confirmation	Rejection	Abstention
	Technological risk	71%	14%	14%
	Supplier integration (development)	86%	0%	14%
	Product complexity	100%	0%	0%
	Number of components	100%	0%	0%
	Vehicle modularity	86%	0%	14%
	Safety concept of the vehicles	100%	0%	0%
	Operating voltage of the vehicles	100%	0%	0%
	Battery concept	86%	0%	14%
	Number of vehicle versions	86%	0%	14%
	Time span of return on invest	86%	0%	14%
	Nominal performance of the production site	71%	0%	29%
	Location choice	100%	0%	0%
	Dependency from local traffic infrastructure	86%	0%	14%
	Dependency of local energy infrastructure	86%	0%	14%
	Period of the location operation	86%	0%	14%
	Energy supply	100%	0%	0%
	Product flexibility	86%	0%	14%
	Quantity flexibility	86%	0%	14%
	Operating material maintenance	86%	0%	14%
	Warehouse concept	100%	0%	0%
	Warehouse safety	86%	0%	14%
	Operation material flexibility	86%	0%	14%
	Operating material maturity	71%	0%	29%

A.4.7 Outputs

Table A.13: Output parameters and aCar-specific dedicated recommendations. The recommendation based on the sharp output value for the strategy parameter is considered the predominant implementation within the assigned category.

$x(k+1)$	1	2	3	4	5	6	7	8	9	10	Additional information
Degree of automation*	Manual processes			Hybrid processes				Automated processes			[40, p. 106, p. 193]
Production control*	Central control			Hybrid control				Decentral control			[214, 58, p. 326]
Depth of value-added*	External production			Differentiated decision				In-house production			[215, p. 34]
Production choice*	Project	Job shop			Batch		Line flow		Continuous flow		[58, p. 161, 216, p. 240, 70, p. 190]
Process standardization**	Individual					→				Highly standardized	[70, p. 187, 14, pp. 204-205]
Process coupling**	Intermittent					→				Continuous	[70, p. 190]
Operating resources flex.*	Special resources			Depending on process				Multi-functional resources			[58, p. 162]
Operating resources l.-c.*	<7 years operating time			7-14 years operating time				>14 years operating time			[217, p. 121]
Production technology*	Low-tech			Medium-tech			High-tech		Super-high-tech		[70, pp. 652-653]
Production network*	World factory				Hub and spoke			Local for local			[14, pp. 164-168, 33, 18]
Process scale-ability*	Local/small			Regional/medium				Global/huge			[218, 70, pp. 260-261]
Level of inventory**	No inventory					→				High inventory	[14, p. 291, 58, p. 163]
Quality control*	No control			Statistical control				Continuous control			[40, p. 16]
Design stability*	Frozen design			Adaptable design				Continuous improvement			[14, p. 204]
Worker training*	On-the-job training			Instruction and training				Off-the-job training			[105, pp. 68-73]
Integration of society**	No integration					→				Highly integrated	
Staffing strategy*	Locally oriented staffing				Cross-country oriented staffing		Expatriate oriented staffing				[14, pp. 249-251]
Incentives for employees*	No incentives			Non-monetary incentives			Financial Incentive				[95, p. 165, 14, p. 259]

*Classification into output categories
**Continuous output value

Table A.14: Input data of the scenarios: Raw and processed data.

	Ghana	Priorities 1	Priorities 2	Increasing demand 1	Increasing demand 2	Botswana	Nigeria	Different products 1	Different products 2
Raw data									
Production volume [pcs.]	1000	1000	1000	10000	100000	1000	1000	1000	1000
Labor skill availability [%], [171]	15.30	15.30	15.30	15.30	15.30	32.20	5.70	15.30	15.30
Labor cost, [171] [$]	2130.00	2130.00	2130.00	2130.00	2130.00	7750.00	1960.00	2202.00	2202.00
Availability of local workforce, [211] [%]	77.10	77.10	77.10	77.10	77.10	69.40	60.80	77.10	77.10
Energy supply, [252]	101	101	101	101	101	49	394	101	101
Input data									
Production volume	1.43	1.43	1.43	4.96	10.00	1.43	1.43	1.43	1.43
Market entry strategy	5.50	5.50	5.50	5.50	5.50	8.00	3.00	5.00	5.00
Labor skill availability	5.41	5.41	5.41	5.41	5.41	1.00	8.29	5.41	5.41
Importance of economies of scale	1.00	1.00	1.00	5.00	10.00	1.00	1.00	1.00	1.00
Importance of delivery time	1.00	3.00	5.00	5.00	10.00	1.00	1.00	1.00	1.00
Importance of product cost	10.00	7.00	5.00	10.00	10.00	10.00	10.00	6.00	4.00
Importance of quality	1.00	3.00	5.00	1.00	1.00	1.00	1.00	1.00	1.00
Importance of flexibility	3.00	3.00	3.00	3.00	3.00	3.00	3.00	5.00	7.00
Importance of innovation	1.00	3.00	5.00	1.00	1.00	1.00	1.00	3.00	6.00
Importance of ecologic sustainability	5.50	7.00	10.00	5.50	5.50	5.50	5.50	10.00	10.00
Importance of social sustainability	5.50	7.00	10.00	5.50	5.50	5.50	5.50	10.00	10.00
Type of product	7.00	7.00	7.00	7.00	7.00	7.00	7.00	5.00	3.00
Product complexity	2.00	2.00	2.00	2.00	2.00	2.00	2.00	5.00	8.00
Labor cost	1.24	1.24	1.24	1.24	1.24	2.21	1.21	1.25	1.25
Market demand	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Supplier market competition	2.00	2.00	2.00	2.00	2.00	5.00	8.00	2.00	2.00
Intra corporate resources	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Availability of local workforce	5.12	5.12	5.12	5.12	5.12	6.51	8.06	5.12	5.12
Fluctuation of local workforce	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Energy supply	3.52	3.52	3.52	3.52	3.52	2.23	10.00	3.52	3.52