




Testing Scenarios of Strategic Production Configuration Using Fuzzy Logic

Matthias Brönnner¹(✉) , Dominik Fries², Julia Pelka¹, and Markus Lienkamp¹

¹ Institute of Automotive Technology, Technical University Munich,
Boltzmannstr. 15, 85748 Garching, Germany
Broenner@ftm.mw.tum.de

² EVUM Motors GmbH, Joseph-Dollinger-Bogen 26, 80807 München, Germany

Abstract. Strategic production configuration in developing economies requires verified knowledge of the production system and its environment. In order to model these reproducibly, we use a fuzzy logic based model in this paper. This allows for simulation of dependencies within strategic production configuration. The results are transparent and reproducible and support strategic decisions-making. Thus, this method clarifies the correlations between business strategy, product, assembly and production system in developing economies. To evaluate the impact of local conditions on location configuration, we test scenarios such as changing competitive priorities, locations in different countries and product adaptation. The scenarios are tested within the aCar mobility project, a project in which an electric vehicle was designed for local value creation in Africa. The results allow for identifying similarities and differences in strategic recommendations, and therefore to develop a suitable production configuration. Thus, the key findings of this paper are the highlighting of effects of scenarios on the production strategy in developing economies. It becomes evident that for a sustainable strategy the possible scenarios of the development must also be taken into account in the early decision making process.

Keywords: Production strategy · Fuzzy logic · Production configuration

1 Introduction

The United Nations define 17 Sustainable Development Goals, aiming at a sustainable change of less developed regions [28]. Many of the goals are directly and indirectly linked to local employment in these regions. The automotive industry, with its wide-ranging value creation networks, is one of the industries that may change regions through local value creation [6]. Meanwhile, many countries are promoting the development of a local vehicle industry [23], through trade barriers for the import of new and used vehicles or local content requirements [2]. If

automobile manufacturers plan a local assembly site, either for financial reasons or for reasons of sustainability, they must handle a small and strongly fluctuating demand [21]. With different boundary conditions in African countries, locations must also be planned individually in order to avoid over-dimensioning and thus investment risks. Additionally, with the market development, customer requirements may change [23]. This must be taken into account when planning an assembly plant [2].

Due to the effort involved in planning an assembly plant in Africa, we have developed a simulation model based on fuzzy logic to enable application-specific production site configuration. We use this simulation to evaluate the impact of changing boundary conditions, e.g. customer priorities, on the production site configuration. The results are not to be understood as fixed values, but rather as input for further strategic planning.

1.1 Theoretical Background

In this section, we explain the content of a production strategy as well as the impact of the surrounding conditions. This highlights the difference between the development of a sales-oriented strategy and one to be applied in developing economies. Further, we describe the current approach of the automotive sector. We conclude in the demand of a simulation model, that includes the surrounding conditions into decision making.

A production strategy is the part of the corporate strategy that includes the strategic and operational planning of value creation [11]. In strategic planning, the purpose is to plan a cost-, quality-, time-optimal and flexible production [9]. The optimum of these decisions are not the extreme values, but trade-off decisions [24]. Trade-off decisions weight in between the extreme values, such as a fully automated production and a purely manual assembly. The appropriate decisions are essential for the competitive advantage [11], while having an efficiency limit [25]. For example, an increasing number of variants challenges cost efficiency in production. Content of a production strategy besides plant and equipment also includes production planning and control, laboratory and staffing, product design and engineering as well as organization and management [16,24].

This content is also valid for production strategies in less developed countries. Mefford and Bruun (1998) also show the relevance of trade-off decisions in these regions in their production strategy development process [16]. There, the competitive priorities of cost, time, quality and flexibility apply. These are influenced by the external influences of business costs, laboratory availability, competitive hostility, market dynamics and government regulation. Consequently, these must be taken into account in production strategy planning. Using the example of production strategies in Ghana, Ehie and Muogboh (2016) show the impact that the environmental conditions have on the decisions made there [9]. In particular, the political influence on competitive priorities should not be underestimated in developing economies [9]. In addition, the degree of adaptation of the products to the local conditions must be considered. Saranga et al. (2018) found in their

study of the Indian market that specially developed products are often more efficient than adapting existing products [22].

Automotive manufacturers often use a multistage-approach, to enter new markets in less developed regions. First stage, in small and volatile markets, vehicles are imported as Fully Build Up (FBU) vehicles. There is no local added value, which is why import duties of up to 100% of the vehicle value have to be paid [14]. In the second stage, Semi Knocked Down (SKD) vehicles are shipped from the main factory [1]. These vehicles are partially pre-assembled and shipped as a kit. The Completely Knocked Down (CKD) strategy offers more locally added value, with larger assembly volumes in the target market. Therefore the CKD concept is dependent on a functioning logistics concept [8]. The SKD assembly is often the preliminary stage of the CKD assembly and is demanded e.g. by the Nigerian government after 5 years of SKD assembly [4]. A local production and associated development offers the largest share of local added value, which is only realized with appropriate market size [15]. For the local added value of vehicles, assembly site planning is therefore essential at the beginning of a planning process. Relevant parameters of such planning of small-scale vehicle production sites, with the focus on electric vehicles, are summarized in [5].

In summary, for local production strategies, the environmental conditions must be integrated more than in existing approaches. In these, the selection of the strategy is primarily focused on customer requirements and sales potential (see [11, 12, 24]). However, in order to be able to make a well-founded decision regarding the production strategy, it is necessary to compare different scenarios with each other without much effort. For this reason simulations are used in early planning phases [13, 17, 27]. Due to the qualitative nature of the planning and uncertain data set at the beginning, a fuzzy logic based planning is appropriate [29]. Fuzzy logic allows for linking decision relationships using *If... Then... Rules*. With this, expert knowledge can be translated into mathematically logical models for decision-making. Classical fuzzy systems can be extended by a recurring traceability [3, 10, 27]. The schematic procedure of a recurrent fuzzy system is visualized in Fig. 1.

So far, a procedure was missing that integrates the existing dependencies between external influences and internal possibilities of a strategy into a simulation model. In [7] we present such a procedure, which we use in this paper to simulate the effects of different scenarios and discuss their results using the example of a small series car manufacturer.

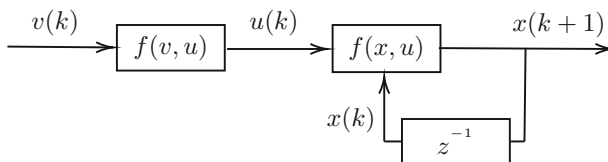


Fig. 1. Recurring fuzzy system

2 Model Description and Method

Based on the described theoretical background, we have developed a model to support production and assembly strategic decisions for small series production in Africa. The justification for choosing fuzzy logic as a method and the model structure are explained in detail in our publication [7]. In the following, a short summary of the model and this paper’s focus, the procedure for testing different scenarios, are presented.

2.1 Model

Our model links country, product- and company-specific input factors with production configuration parameters. The link is made by *If...Then...* Rules implemented in a Matlab Simulink (2019b) model using the integrated Fuzzy Logic Designer. The model is described in detail in [7] and published under an open source license in Github¹. The framework of the model is shown in Fig. 2. As illustrated, this framework can be used to set m input parameters with n output parameters in dependency.

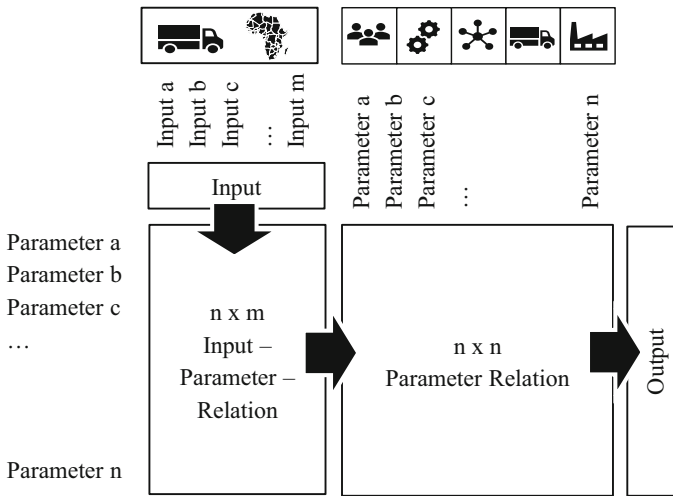


Fig. 2. Framework for production strategy simulation

The model parameter for our use case have been evaluated by industry experts for our application. The evaluation involved two workshops. Our first workshop was held with experts from EVUM Motors GmbH, a company planning vehicle production facilities in developing economies. A second workshop was organized in Ghana, Kumasi with entrepreneurs, vocational training staff

¹ <https://github.com/TUMFTM/Production.Strategy.Development>.

and scientists. Among the attendees (n = 7), 29% stated experience in corporate, business or production strategy, 57% have experience in production, manufacturing and assembly, 29% in qualification and training and 14% in engineering. The rule base of the model is based on dependencies mentioned in the literature, which were evaluated and weighted by (n = 5) experts. The selection of the experts was based on their knowledge of the vehicle and project, as well as their experience in production in a developing economy. The number of experts interviewed is based on the selection according to these criteria.

The output values of the model are between 1 and 10, whereby the output range is output dependent (Table 1). For example, in the case of the output value automation degree, an output value of 1 expresses a manual (very low automated) production and 10 a fully production assembly.

Table 1. Output parameters

Output parameter	Parameter range	
Degree of automation	Low	High
Production system	Push	Pull
Depth of value added	Buy	Make
Production/assembly line structure	Workshop	Flow
Standardization of processes	Low	High
Linkage of processes	Low	High
Operating material flexibility	Special	Multi-functional
Equipment operating time	Temporary	Series operation
Warehouse concept	No stock	Large stock
Quality control	Low	High
Design stability	Freeze	Continuous improvement
Additional worker training	Low	High
Integration of society and politics	Low	High
Manufacturing technology	Conventional	Innovative
Production network	World factory	Local for local
Scalability of technology	Low	High
Number of expatriates (ramp up)	Low	High
Additional incentives	Low	High

2.2 Method

This model is used to analyze the impact of different scenarios for the configuration of production or assembly. For this purpose, we define the reference and

test scenarios first. Then, the respective input parameters of the scenarios are simulated. Finally, the results are compared and an overall recommendation is derived.

3 Application Case and Testing

Before defining the test scenarios, the use case is described. We simulate a strategy of a small series electric vehicle manufacturer, who plans to enter the markets in various countries in sub-Saharan Africa. The standard product is an all-wheel electric vehicle with a simple structure (ladder frame, folded exterior and interior). The vehicle is to be manufactured economically with locally added value. In addition to local final assembly of the purchased components, local production of the interior and exterior is also planned. This use case is derived from the aCar Mobility project².

3.1 Reference Scenario

To examine the effects of the test scenarios, we first define a reference scenario. As reference, we simulate a local production site in Kenya, as Kenya is the second largest economy in East Africa with a strong focus on agricultural value creation. For this application as well as the following cases, we use the input values summarized in Table 2.

The production location in Kenya has a low degree of automation and therefore prefer manual work tasks (Fig. 3). The production system is primarily a pull system, with a medium depth of added value. The resources should be flexible and planned for smaller series in terms of operating time. For the warehouse concept, low stock levels should be planned, as delivery times are not prioritized high. Quality controls have to be planned due to employee qualification, despite low quality priority. To secure a stable ramp up, the number of expatriates during this phase should be high. Training for new staff needs to be planned and motivation needs to be ensured in order to avoid fluctuation. It is crucial to involve local authorities in the planning process.

3.2 Scenario 1: Changing Competitive Priorities

With the development of the markets, customer priorities change. In India, for example, customer behavior is currently changing from purely cost-driven vehicle purchasing decisions to price-performance decisions [22]. As a result of this change, new automobile manufacturers such as Geely and BYD have emerged in India and China [23]. A successful product which was developed to satisfy this change of priorities is the Renault KWID in India [18, 23].

For this reason, *Scenario 1* examines different customer priorities and their impact on the configuration of assembly or production. *Priorities 1* examines

² [www.http://www.acar.tum.de/en/home/](http://www.acar.tum.de/en/home/).

Table 2. Input parameters of test scenarios

Input parameter	Kenya (Reference)	Priorities 1	Priorities 2	Country 1	Country 2	Multiple products 1	Multiple products 2
Volume	1	1	1	5	10	1	1
Market entry strategy	5	5	5	5	5	5	5
Qualification level of employees	1	1	1	4	8	1	1
Importance of economies of scale	1	1	1	1	1	1	1
Importance of delivery time	1	3	5	1	1	1	1
Importance of product cost	10	7	5	10	10	6	4
Importance of quality	1	3	5	1	1	1	1
Importance of flexibility	3	3	3	3	3	5	7
Importance of innovation	1	3	5	1	1	3	6
Importance of environmentally friendly products	10	10	10	10	10	10	10
Importance of committed social responsibility	10	10	10	10	10	10	10
Type of product	7	7	7	7	7	5	3
Product complexity	2	2	2	2	2	5	8
Labor cost	3	3	3	4	8	3	3
Market demand	6	6	6	6	6	6	6
Supplier market competition	2	2	2	5	8	2	2
Intra corporate resources	3	3	3	3	3	3	3
Availability of local workforce	10	10	10	8	6	10	10
Fluctuation of local workforce	10	10	10	8	6	10	10
Energy supply	2	2	2	5	8	2	2

the change from pure cost-motivation of the customer to more quality and faster delivery times. With *Priorities 2* we simulate customers who rate delivery time, quality and costs as equal. The results of this and the following simulations are summarized in Fig. 3.

The simulation of *Scenario 1* and its variations demonstrates that, compared to the reference configuration, the scalability requirements have to be adjusted. Furthermore, the requirements on the warehouse concept increase and the production system changes to pull processes. Quality controls, on the other hand, increase in both cases compared to the reference scenario and decrease in the case of equal evaluation of competitive priorities. Unaffected by customer priorities are for example the depth of added value, operating material (operating time and flexibility), training, integration and the number of expatriates to be calculated.

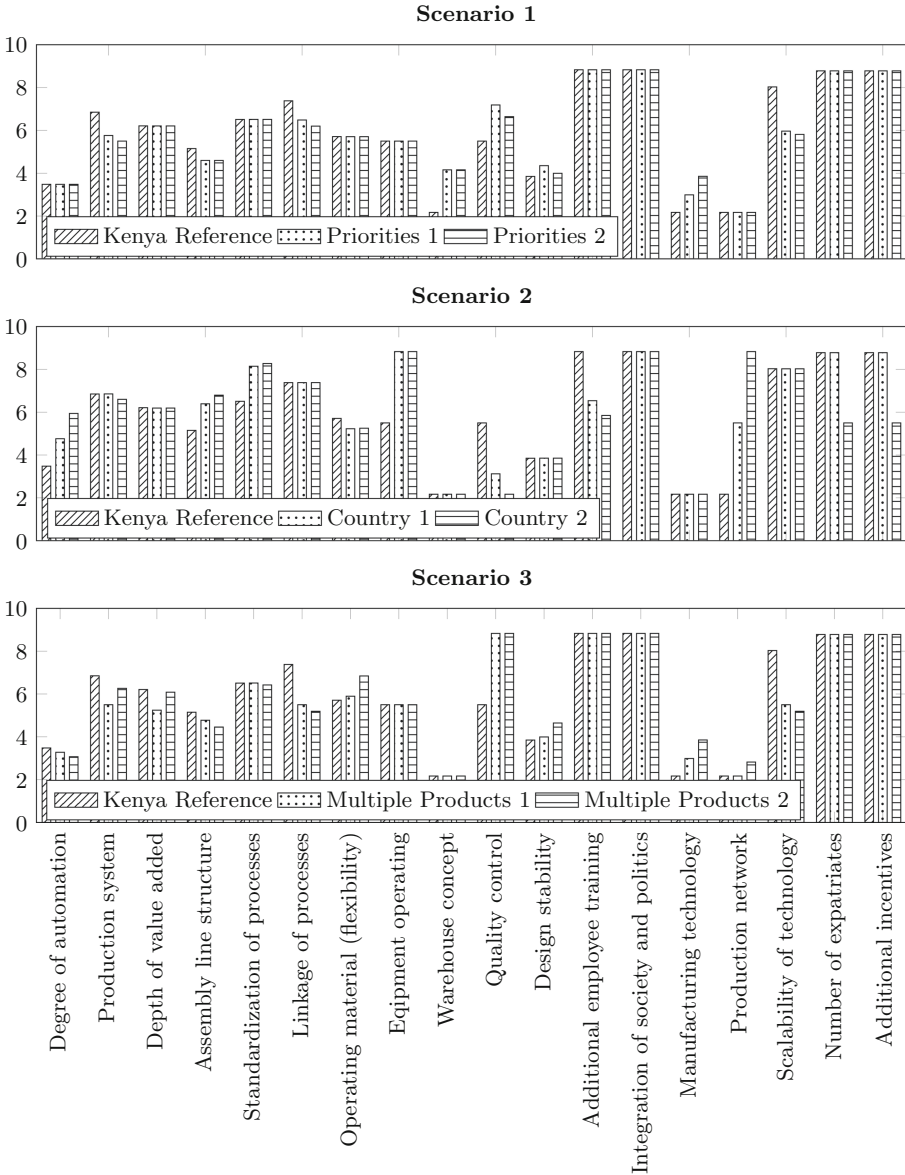


Fig. 3. Results of the test scenarios

3.3 Scenario 2: Different Countries

The effort to adapt a production to new locations is economically challenging, even with constant product requirements [2]. But, differences between the African countries are significant, as they differ in market size and thus in the

possible sales volume [4]. The extent to which suppliers are available in the African countries and which quantities and quality can be supplied differs. Concurrently, the number of deliverable components is decisive for their costs [4]. Further, essential for the strategic decision of Nigerian manufacturers, is the availability of a skilled workforce [9].

Therefore, in *Scenario 2* the extent to which these planned production volumes impacts the production configuration is tested. Additional differences are the availability and qualification of skilled employees and their fluctuation. Furthermore, the influence of the availability of local suppliers is investigated.

The scenario of different countries has a decisive influence on the degree of automation, the operating time of the equipment and the production network. In addition, the necessary expenses for employee training are reduced. Furthermore, in the case of *Country 2* the number of expatriates and the necessary incentives are lower than in the reference scenario Kenya.

3.4 Scenario 3: Multiple Products

Especially in new markets, customer behavior is constantly changing [9]. The desire for individualization arises with the change in customer requirements. This makes adapted, customer-specific vehicles more important [22]. For this reason, it can be of interest to vehicle manufacturers to assemble several vehicle variants on site. Concurrently, the product complexity and the location flexibility increase [2].

The multiple products scenario examines the impact of multiple products at one site. Therefore, requirements in flexibility and innovation is increasing, while the cost focus is decreasing. Concurrently, we assume a rise in product complexity.

The simulation indicates the change of the linkage of the processes and increasing quality controls. The focus of scalability and assembly line design decreases with the trend towards fewer flow processes. Regardless of the product variants, for example, the training requirements, integration of local authorities and the number of expatriates required do not change.

4 Discussion

The findings of the simulation can be summarized for the application case as follows. The degree of automation is mainly altered by the change in volume for various countries. In contrast, the production system hardly changes and must be planned as a pull system. In this system, the processes should be largely linked. If the number of variants increases and customer priorities are uncertain, processes should be decoupled in order to ensure an assembly flow. This assembly line design is sensitive to the input changes in *Scenarios 2* and *3*. In *Scenario 2* the assembly line design should be planned more as a flow system, while in *Scenario 3* there is a slight shift towards workshop assembly.

The depth of value added is dependent on the number of variants and, largely independent of the volume, but mainly with a focus on purchased components. In all scenarios, the operating material flexibility is largely constant in the middle range, while the equipment operating time requirement increases significantly in *Scenario 2*. As a result, it can be concluded that the operating time of the equipment is to be configured as a long-term series equipment from a medium planned volume. The orientation of the production network also depends on the volume. If local demand increases, the strategy changes from a network production to a local for local production site.

The required employee training only decreases with increasing qualification in *Scenario 2*, but must still be planned as intensive. In contrast, the integration of local authorities is indispensable in each of the tested scenarios. With increasing customer demands (*Scenarios 1 and 3*) regarding quality, the assembly and manufacturing technology should be selected in order to meet these requirements. The number of expatriates required for a problem-free ramp-up decreases as the qualifications of the available employees increase (*Scenario 2*).

Figure 4 summarizes the variance of results.

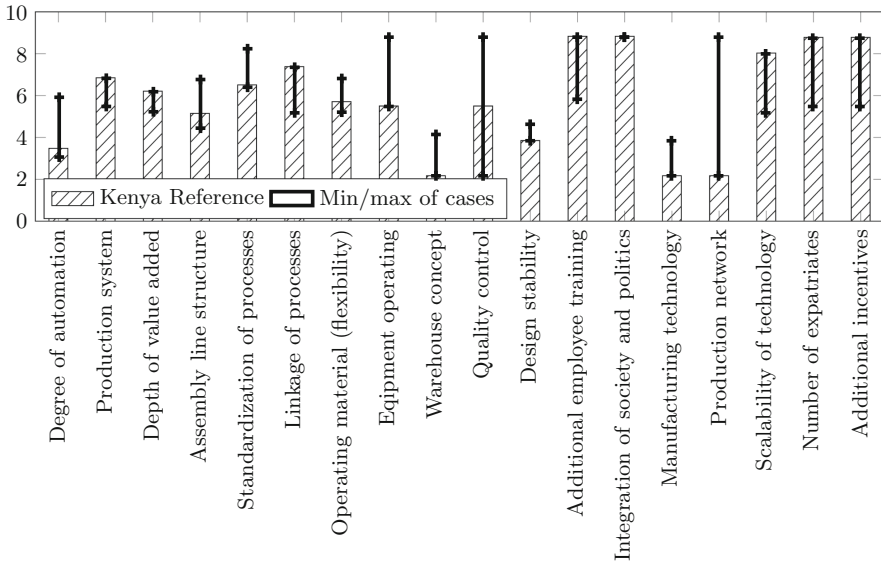


Fig. 4. Comparison of the extrema of the test scenarios

For this reason, a sensitivity analysis is carried out to describe the effect of individual parameter changes on the overall system. This allows a separation into important and less important factors [20,26] For this purpose we use Morris analysis, which uses a grid search to identify these dependencies [19]. The method developed by Morris varies each time step by one factor and outputs two

sensitivity measures [26]. Using this method, the highest average value is based on the qualification level of the employees on the motivation through external stimuli. The second largest average value is based on the size of the plant. This correlation also shows the highest standard deviation. Overall, the qualification level of the employees represents three of the four largest mean values. Other high combinations of mean value and standard deviation are, for example, market demand on the production system, the type of product on the flexibility of operating resources, the volume and market entry strategy on the duration of use of operating resources, the importance of innovation on production technology, and the importance of product costs on quality control and design stability.

5 Conclusion

The simulation results indicate that a factory must be planned individually for each location. Surrounding conditions such as political conditions, sales volumes, purchasing power, educational level and others influence the production strategy. This is illustrated by the variance of the simulation results. Including these boundary conditions in strategic planning reevaluates trade-offs in the decision-making process.

In conclusion, the influence of changing competitive priorities on the design of a production can be considered as low. Within this change, the corresponding manufacturing technologies and quality concepts should take into account the increased demands on quality and the storage concept should guarantee reliable delivery times. The differences between countries are mainly reflected in the degree of automation, which changes with the available employees, wages and sales volume. However, the degree of automation can still be classified as medium. This simulation reveals that employee qualifications affect the quality processes, despite constant customer demands for quality. Product diversification influences above all quality and technological decisions.

Nevertheless, commonalities can be determined for the application cases. The depth of value added (of the vehicle manufacturer) tends to be low, the focus is on supplier components. Although delivery difficulties are to be expected due to the challenging infrastructure, the warehouse must nevertheless be designed for low inventory levels. Only when customer requirements for delivery times increase does the inventory need to be increased. In general, expatriates to support the ramp-up are essential for a successful start, as is the integration of the population and government. In addition, if several locations are planned, the focus should be on a training concept that allows to reduce the training effort. Due to the lack of experience in the manufacturing industry, these should be provided for most employees. Changing demand and customer requirements also affect the demand for the flexibility of a location. Thus, this should be taken into account in the early planning stages.

In this paper, we demonstrate, that different scenarios can be simulated in the early stages of assembly and production strategy planning by using fuzzy logic model. This allows for future scenarios to be tested and the focus of further

configuration planning to be adjusted. Since this model was designed using the expert rules for the application case, the rule base needs to be adapted for further applications. In future research, this model could be extended by a monetary evaluation in order to estimate the additional financial expenditure required for different strategies.

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