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INTEGRATING AGENT-BASED SIMULATION AND SYSTEM DYNAMICS TO SUPPORT PRODUCT STRATEGY DECISIONS IN THE AUTOMOTIVE INDUSTRY

Karsten Kieckhäfer
Grit Walther

TU Braunschweig
Institute of Automotive Management and Industrial Production
Katharinenstraße 3
Braunschweig, 38106, GERMANY

Joachim Axmann

Volkswagen AG
Products Division,
Dept. of Process Development
Mailbox 1256
Wolfsburg, 38436, GERMANY

Thomas Spengler

TU Braunschweig
Institute of Automotive Management and Industrial Production
Katharinenstraße 3
Braunschweig, 38106, GERMANY

ABSTRACT

Especially in the European Union both, regulatory requirements regarding the CO2 emissions of new vehicles and the shortage of crude oil force car manufacturers to introduce alternative fuel and powertrain concepts. Due to high investments and long development times as well as the parallel offer of conventional and alternative technologies, an appropriate product strategy is required. Car manufacturers have to decide, which powertrain to introduce at which time in which vehicle class. Hence, the aim of this paper is to develop a framework for the analysis of product strategies in the automotive industry with special regard to alternative fuel and powertrain technologies. The framework integrates System Dynamics and Agent-based Simulation in a simulation environment. On basis of this analysis recommendations can be deduced concerning the implementation of different product portfolios.

1 INTRODUCTION

Public discussions concerning the contribution of the traffic sector on climate change lead to ever stricter CO2 regulatory requirements in the automotive sector, especially in the European Union. Here, car manufacturers are required to ensure that the average emissions of the new vehicle fleet are below a manufacturer specific target. If the average CO2 emissions exceed the target, manufacturers have to pay high penalties. Furthermore, increasing fuel prices are expected due to future scarcity of crude oil. Hence, car manufacturers have to reduce CO2 emissions and fuel consumption of passenger cars. However, only slight reductions of fuel consumption are possible for conventional passenger cars. Consequently, car manufactures have to develop and introduce alternative fuel and powertrain concepts, in order to comply with legal and customers requirements in the European Union and other regions worldwide.

High investments and long development times, as well as the parallel offer of conventional and alternative technologies require an appropriate product strategy. Due to legal and customers requirements, in particular a strategy has to be developed, which considers the offer of a great variety of vehicles, powertrains and fuels. Thus, active decisions about the arrangement of different product portfolios including the consideration of substitution effects (on supply and demand) between powertrain and fuel technologies, as well as between vehicle classes have to be taken. Thereby, the aim of the manufacturer is to achieve required market and financial objectives considering regulatory and public requirements, in order to secure existence of business.

Regarding to such product strategy decisions, popular examples for missing market success in Germany are two passenger cars of the Volkswagen Group. Introduced in the smallest vehicle class in 1997 respectively 1999, both the Volkswagen Lupo and the Audi A2 were offered as fuel economic cars. Based on different measures, such as light construction, start-stop-function and motor management, a special model of both vehicles has a fuel consumption of only 3 l/100 km. After a positive initial response to the offered models, demand broke down, production was stopped and e. g. only 6.500 vehicles of the Audi A2 3L were produced (Figure 1). Nowadays, demand for the Audi A2 3L on the second-hand car market is twice as high as supply and the price of a second-hand car is approximately 3.000 € higher than the list price. Furthermore, the then new and neglected technologies are getting more and more integrated in current vehicles. Hence, it seems that the right technology was introduced at the wrong point in time (PwC 2007, Flohr 2008). In order to counteract such economically inefficient strategies, a decision support is required, which can deal with the dynamic complex character of the challenge of the introduction of alternative powertrain and fuel concepts.

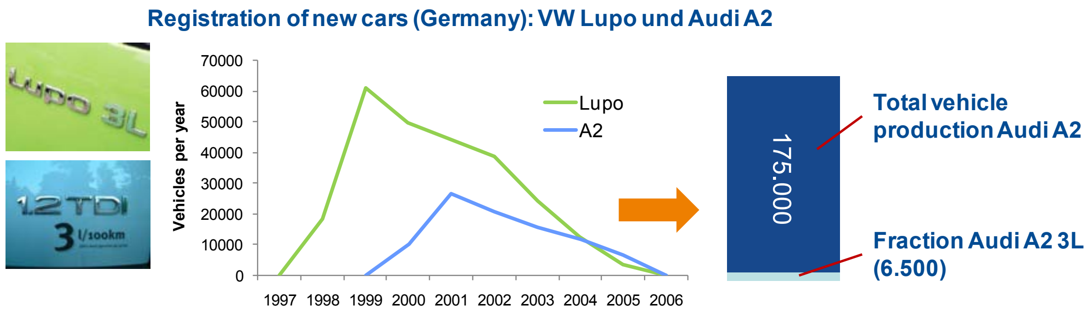

Figure 1: Market development VW Lupo, Audi A2

Against this background, the aim of this paper is the development of a framework for the analysis of product strategies in the automotive industry with special regard to alternative fuel and powertrain technologies. The framework has to allow the simulation and analysis of different strategy options of a manufacturer, in order to assess portfolio decisions. To this end, a detailed analysis of the socio-economic system is necessary. On basis of this analysis, requirements regarding the development of the framework will be derived. Afterwards, the framework will be developed considering the interactions between vehicle supply and demand, competitor behavior, supply of infrastructure, as well as macro-economic and regulatory conditions. In order to comply with requirements derived by this framework, System Dynamics and Agent-based Simulation will be integrated.

2 ANALYSIS OF THE AUTOMOTIVE MARKET

The automotive market is mainly characterized by the interaction of three actors: car manufacturers, customers, and legislature. While legislature pursues public goals (e.g. reduction of emissions), both the manufacturers (e.g. maximization of profit) and at the customers (e.g. economic mobility) pursue individual goals. Thereby, each of these actors has different options of action, which are affected by the further groups of interests (Figure 2).

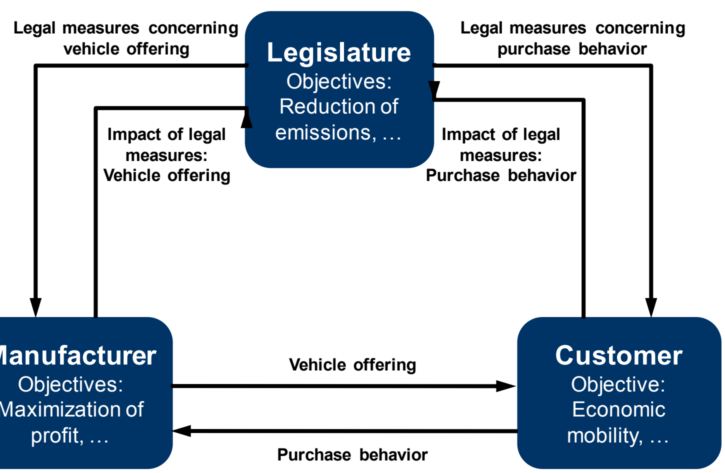

Figure 2: System automotive market

Legislature determines the basic conditions in the automotive market. By the employment of legal measures (e. g. incentives, subsidies, malus payments, taxes) legislature tries to influence both, vehicles offered by the manufacturers and purchase behavior of the customers. Thereby, decisions of measure depend on the expected reaction of the manufacturers respectively customers. Regarding the regulation on CO2 emissions from cars in the European Union the interaction between the two stakeholders can be described as follows: The European, Japanese and Korean car manufacturers' associations committed to reduce the average CO2 emissions from new passenger cars to 140 g CO2/km until 2008 or 2009. Since in 2004 the average CO2 emissions of new passenger cars were still about 161 g CO2/km and considerable improvements were not expected, the European Commission decided to revise their strategy proposed in 1995. For this reason, the European Commission is currently developing a legislative framework focusing on mandatory measures. From 2012, manufacturers will be required to ensure that the average emissions of the new vehicle fleet are below a manufacturer specific target, which will be lowered gradually to 120 and/or 130 g CO2/km until 2018. At the same time, the European Commission forces the adaption of a proposal for a directive on passenger car taxation, which aims at calculating the annual tax on motor vehicles on the basis of CO2 emissions. Furthermore, an amending proposal for the directive relating to the availability of consumer information on fuel economy and CO2 emissions in respect of the marketing of new passenger cars is developed. Similar to the sector of household appliances, in the future passenger cars are assigned to energy efficiency classes. This way, sales of more efficient and environmentally friendly vehicles shall be increased (EU 2007, EU 2008).

According to this, legislature's action forces **car manufacturers** to adapt the range of vehicles, in order to fulfill regulatory requirements. For this purpose, different options are available to car manufacturers. On the one hand, maintaining the present range of products while decreasing the fuel consumption of conventional gasoline and diesel engines is an option. On the other hand, offering a higher number of vehicles in small classes (e.g. Volkwagen Fox, Smart, Toyota Aygo) or the introduction of alternative powertrain and fuel concepts (e.g. hybrid, electric power train, biofuels) is conceivable (PwC 2007). The choice on these options leads to implications, e. g. with regard to forecast of sales volumes, as well as allocation of research & development and production capacities.

Referring to the **customer**, legal measures might have an impact on the purchase behavior, if influencing factors, which are considered by the customer during a purchase decision, are affected and/or information about these factors is made available. Factors influencing the purchase decision are hygiene factors (e. g. security and reliability), technical factors (e. g. performance, acceleration, range, and fuel consumption), economic factors (e. g. purchase price and running costs), as well as emotional factors (e. g. design and brand). In terms of the amending proposal for the directive relating to the availability of consumer information on fuel economy and CO2 emissions, customers must receive information about the vehicle efficiency. Hence, customers will be able to monetarize the technical factor fuel consumption during their purchase decision. Also, the annual tax on motor vehicles based on CO2 emissions is expected to increase the impact of fuel consumption on the purchase decision. Thus, higher consumption comes along with a higher tax rate and higher running costs. Assuming constant values of the further influencing factors (e. g. performance, purchase price, and range), sales of less fuel consuming passenger cars should be increased (Gärtner 2005, Lane 2005).

In order to reach their individual goals, customers and manufacturers interact directly in the automotive market. Due to the fact that the automotive market in the European Union is getting more and more a mature market, the market can be characterized as a buyers' market. Customers requirements are becoming very diverse and sophisticated while manufacturers face high competition. For this reason, car manufacturers expand their model variety. On the one hand, they offer vehicles in different vehicle classes. On the other hand, the number of vehicle variants offered in one vehicle class is increased (e. g. VW Golf, VW Golf Plus, VW Golf Variant) (Becker 2007, Schneider 2008).

The behavior of the different stakeholders in the automotive market is influenced by dynamic and uncertain **basic conditions**. Especially basic macro-economic conditions like crude oil prices, income distribution or demographic change have an impact (Becker 2007). Furthermore, the competition between transportation modes (e.g. public passenger traffic), as well as the supply of infrastructure respectively energy has to be considered (Struben and Sterman 2007).

To sum up, car manufacturers are facing the following challenges in the automotive market. Forced by customer and regulatory requirements as well as changing basic macro-economic conditions, they have to develop an appropriate product strategy, in order to achieve business goals. As mentioned above, different options are available for the manufacturers (Figure 3): maintaining the present range of vehicles while decreasing fuel consumption, changing the range of vehicles by increasing the number of vehicles supplied in smaller classes, or changing the range of vehicles by introducing alternative powertrain and fuel concepts. Currently, a combination of these options occurs in practice. At short notice, manufacturers are improving the fuel consumption of new passenger cars, while in the long run alternative powertrain and fuel concepts will be applied.

To succeed with a strategy option, car manufacturers have to come to three major decisions. First, they have to decide which powertrain and fuel concepts shall be offered respectively introduced at which time to match with regulatory requirements. Here, especially dynamic relations with regard to the diffusion of new technologies have to be considered (Bass 1969, Milling 2002). Second, the offered vehicles have to match with customer requirements in terms of exhibiting the right vehicle characteristics (e. g. performance, range and price) at any time (Train and Winston 2007). Third, product interdependencies on supply (e. g. complementary relations between different vehicles and/or powertrains in production) and demand (e. g. substitution effects between different vehicles and/or powertrains) have to be taken into account. Hence, vehicle portfolio decisions have to be carried out (Devinney and Stewart 1988). Expanding model variety results in ever higher product and process complexity and thus in increasing costs (Becker 2007, Schneider 2008). Due to the fact that the forced introduction of alternative powertrain and fuel concepts causes an acceleration of this process, limiting model variety during portfolio decisions seems to be important in order to realize profit.

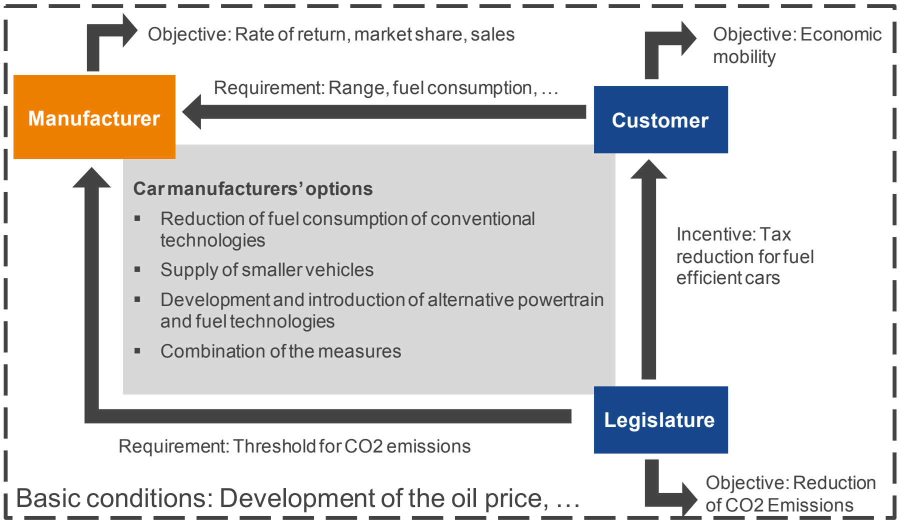

Figure 3: Car manufacturers' options

Based on manufacturers' decisions regarding the described challenges, further questions arise. For example research and development budgets have to be allocated and advertising measures have to be implemented, in order to ensure both, the introduction of competitive products as well as awareness of customers (PwC 2007, Schneider 2008). To conclude, developing product strategies in the automotive sector requires the consideration of many actors with different objectives and decision rules, various interdependences and feedback loops between the influencing factors, several delays between cause and effect, as well as uncertainties regarding the development of the basic conditions. Hence, the problem is characterized by dynamic complexity (Sterman 2000). Due to this circumstance, results desired by the introduction of new passenger cars can fall short off expectation. For example business goals and/or regulatory requirements can be missed, because the offered technologies are not accepted by the market, or the required infrastructure is missing.

3 REQUIREMENTS AND LITERATURE REVIEW

In order to develop appropriate product strategies, the automotive market must be seen as a dynamic interaction between vehicle supply and vehicle demand embedded in changing macro-economic and regulatory conditions. Special regard has to be paid to competitor behavior and supply of infrastructure. Several requirements for an appropriate decision support concerning the introduction of alternative powertrain and fuel concepts can be derived from this understanding. Both, an appropriate modeling of the socio-economic system of the automotive market, as well as the analysis respectively evaluation of strategy options of the car manufacturer must find consideration. This implies the consideration respectively modeling of

- the system elements as well as the individual actors in the market (e.g. different customer groups),
- quantified decision rules and existing feedbacks of the decisions on different aggregation levels (e. g. disaggregated purchase decisions and aggregated decisions about the supply of infrastructure),
- uncertainties regarding the development of the basic conditions,
- interdependences between the vehicles and/or powertrain and fuel concepts,
- the development of different company objectives under uncertainty.

Several models already exists for the analysis of the market potential respectively the market development of alternative powertrain and fuel concepts, mostly focusing on public and macro-economic questions. With regard to System Dynamics, (Struben and Sterman 2007) model the interaction between supply of infrastructure and demand in the automotive market. (Bosshardt et al. 2008; Walther et al. 2008) model basic regulatory conditions, in order to examine the effectiveness and efficiency of regulatory measures. A first approach focusing on the description of manufacturer and consumer behavior, regarding the introduction of alternative powertrain and fuel concepts is presented by (Wansart, Walther, and Spengler 2008). Here, the impact of different strategy options of a manufacturer on the compliance with regulatory emission requirements and on company objectives are analyzed. Due to the fact that adjustment of the range of vehicles takes place to fit with regulatory requirements, reactive manufacturer behavior is presupposed. Active decisions about the arrangement of different product portfolios including the consideration of substitution effects (on supply and demand) between powertrain and fuel technologies, as well as between vehicle classes are largely neglected. Most of the models consider the impact of changing basic macro-economic conditions like increasing crude oil prices. In any case, the models are based on generic model structures regarding the description of diffusion processes, manufacturers' behavior/reaction to changing market conditions, as well as the installed base and aging chains, which can be found amongst others in (Forrester 1961, Milling 2002, Sterman 2000). Besides that (Größler 2007) introduced a System Dynamic Model to analyze price and product strategies. To conclude, these models fulfill several of the derived requirements, but there are two major points of criticism. First, consumer behavior is modeled homogeneously, due to the fact that System Dynamics takes an aggregated view. Second until now, no portfolio decisions are considered, which can also be attributed to the aggregation level. Modeling a complete product portfolio is at least very difficult with System Dynamics.

In order to take a disaggregated view and model individual decision rules, as well as a great number and diversity of vehicles, Multiagent Systems respectively Agent-based Simulation can be used. Here, the description and analysis of socio-economic systems is not based on feedback loops, but on the disaggregated interaction between the agents, as well as between the agents and their environment (Rahmandad and Sterman 2008, Schieritz and Milling 2008). Different Agent-based Simulation models have been introduced, which consider either the introduction of alternative powertrain and fuel technologies or the analysis of consumer behavior. (Garcia 2007; Stephen and Sullivan 2004; Sullivan et al. 2005) use Agent-based Simulation to describe the interaction between infrastructure and demand, as well as to model vehicle choice behavior. (Haan et al. 2007) introduce an Agent-based model to analyze the impact of different regulatory measures on purchase behavior. In order to analyze individual purchase decisions, the model allows both, a distinction between several consumer groups as well as the consideration of a detailed vehicle fleet. Although it would be possible, portfolio decisions of the manufacturer are not taken into account in these studies. Furthermore, main elements as wells as cause and effect chains of the automotive market are largely neglected. For this reason and because of the general potential to complement each other (Schieritz and Milling 2008), an integration of Agent-Based Simulation and System Dynamics seems to be appropriate for the decision support. The next section deals with this integration, in order to design the framework for the development of product strategies in the automotive sector.

4 FRAMEWORK

The framework for the development of product strategies in the automotive sector is designed as follows (Figure 4): in contrast to other analyses regarding the introduction of alternative powertrain and fuel technologies, the framework focuses on the car manufacturer. The product strategy, especially the defined vehicle portfolio of the manufacturer represents the starting point of the analysis (1). Based on the offered vehicle fleet, the interaction between supply and demand is regarded on a disaggregated level (2). This interaction takes place considering the competitor behavior of different modes of transport and the supply of infrastructure on an aggregated level. Furthermore, the success and failure of the product strategy is mainly influenced by basic macro-economic and regulatory conditions, which are also taken into account in the framework, in order to define different scenarios (3). The three main modules of the framework are discussed in depth below.

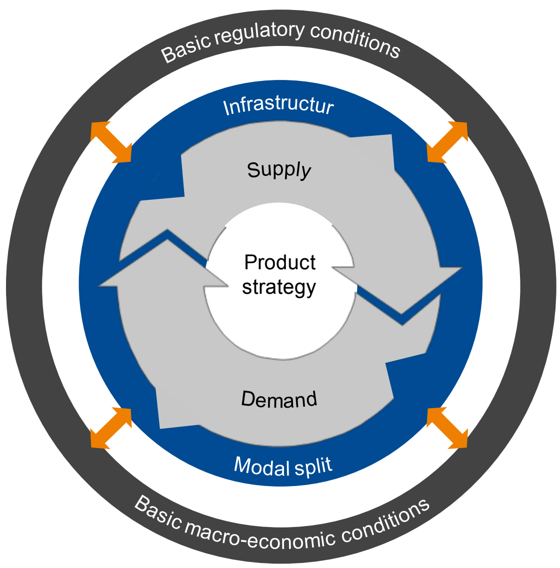

Figure 4: Framework product strategy in the automotive sector

(1) In order to define the vehicle portfolio regarding the introduction of alternative powertrain and fuel concepts, vehicles are classified on the basis of two characteristics: the class the vehicle belongs to and the powertrain, which is used. For this reason, decisions must be made, which powertrain and fuel concept to offer in which vehicle class (utilized and unutilized combinations in Figure 5). Afterwards, the different vehicle characteristics (e. g. range, price, fuel consumption) have to be configured for every combination of vehicle class and powertrain. This portfolio decision represents the strategy option of the car manufacturer, which will be defined exogenously as the system input, in order to evaluate different strategy options. Since the product portfolio has to match with customer requirements at any given time, decisions must also be taken with regard to the time of introduction respectively end of supply of the different powertrains in the individual vehicle classes. Furthermore vehicle characteristics have to be adapted over time (modified combinations in Figure 5). This adaption is based on the dynamic developments of the automotive market and thus is considered endogenously in the framework.

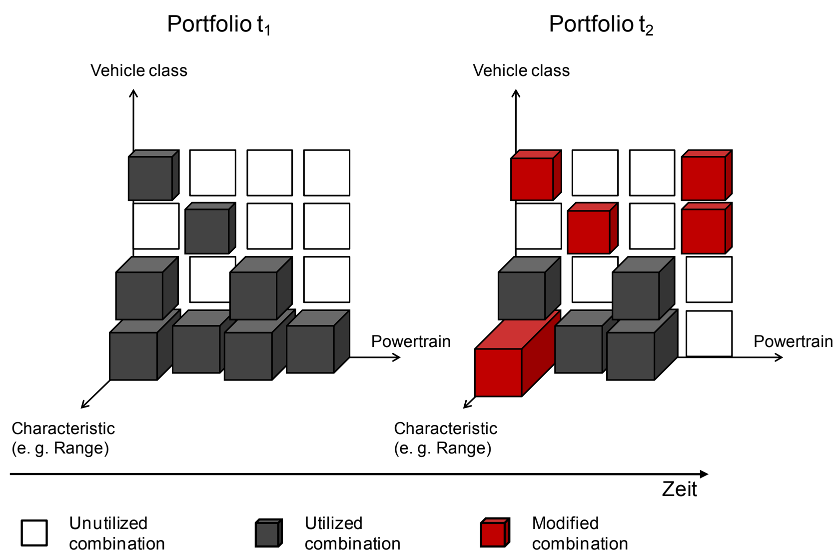

Figure 5: Definition of the portfolio

(2) The framework aims at defining the product portfolio in an Agent-based Simulation environment. This way, the definition of the vehicle fleet can be made accurately in terms of the consideration of a great number and diversity of vehicles. Furthermore, the segmentation of the population on the basis of socio-economic factors, which are relevant for the purchase decision (e. g. gender, income, age), and preferences (e. g. preference for passenger cars with low fuel consumption) becomes possible. Thus, purchase decision rules can be modeled individually and the interaction between car supply and demand can be considered on a disaggregated level. In the Agent-based model, the high degree of freedom to model agents, as well as their behavior and environment is used (Gilbert 2008, Jennings and Woolwridge 1998, Klügl 2001).

The customers are modeled as reactive agents. They take the purchase decision on basis of different information in terms of an if-then rule. While the information can change during a simulation run, the predefined decision rules of the different population segments remain constant. Thus, the same agent is able to take different decisions at different points in time. For example, although the influence of the factor fuel cost on the purchase decision is kept constant over time, different purchase decision can occur, due to the fact that fuel costs can change during a simulation run. In order to define the decision rules, Discrete Choice Theory is used based on Random Utility Theory. It combines basic approaches of the economic consumer theory with decision-theoretical aspects of the quantitative psychology, in order to model the probability of a purchase decision. The probability of choosing a certain passenger car is calculated on basis of utilities of the different vehicles, which are considered by the customer. In turn, the utility is a weighted function of the vehicle and customer characteristics. In order to take uncertainty into account, a stochastic random variable is used, which comprises unobserved product and customer characteristics as well as measurement errors (Bierlaire 1998, Train 2003). The combination of Agent-based Simulation and Discrete Choice Theory allows modeling the purchase decision close to reality, since the vehicle selection takes place individually and in consideration of uncertainty (Haan et al. 2007).

(3) In order to model the basic market structure accurately, the Agent-Based model is embedded in a System Dynamics simulation environment. Thus, the most important system elements and decision rules (besides the individual purchase decisions), as well as major cause and effect relations, feedback structures and delays, can be considered on an aggregated level. Here, existing model structures, which describe generic relations in the automotive market are used. For this reason, the

framework aims at implementing a modular system dynamics model, in order to integrate several modules. The generic structures include amongst others the adjustment of production capacities and infrastructure on basis of current demand. For example adjustment of capacities happens not immediately, due to long-range planning horizon in the automotive industry. This delays could lead to an under- respectively over-utilization of production, which possesses again influence on production cost and thus on vehicle price and demand. Additionally, the System Dynamics model allows the evaluation of different strategy options considering different scenarios. On the one hand, the definition of different basic macro-economic and regulatory conditions becomes possible by the use of exogenous time series (e. g. crude oil price forecasts) and constants (e. g. emissions thresholds). On the other hand, several objectives of the car manufacturer (e. g. vehicle sales and market share in different vehicle classes) can be taken into account.

Thus, the framework provides the integration of a continuous and deterministic System Dynamics model with a discrete and probabilistic Agent-based model. Furthermore, two different aggregation levels are taken into account, in order to model the socio-economic system automotive market appropriate for the evaluation. The linkage of the two models takes place by the exchange of information. On the one hand, global information of the continuous simulation model (System Dynamics) affects individual, discrete decisions in the Agent-based model. For example aggregated production cost information can be used to calculate different vehicle prices (Figure 6). Furthermore, disaggregated decision influencing factors like fuel costs can be calculated on basis of global (e. g. fuel price and kilometers travelled) and detailed (e. g. fuel consumption of a specific passenger car) information. On the other hand, accumulated effects of the individual agent decisions again have influence on system behavior of the System Dynamics model. For example, the decision rule for the supply of infrastructure for a specific powertrain can be modeled as a function of the installed base of this powertrain resulting from individual purchase decisions. This course of action allows the consideration of product independencies. For example, learning effects in production can be implemented in the System Dynamics model on basis of complementary relations, regarding the accumulated sales of a specific powertrain in different vehicle classes. Also, it is possible to identify substitution patterns between vehicles by changing the range of vehicles, vehicle characteristics, or the basic conditions.

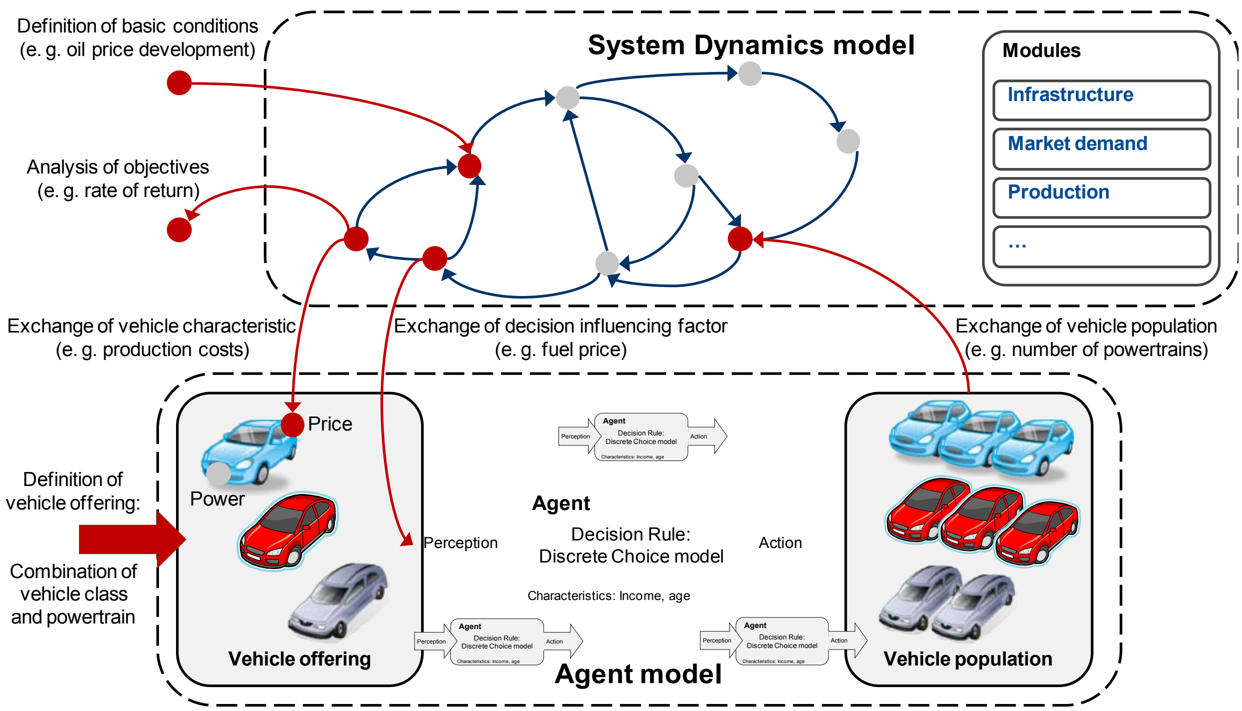

Figure 6: Method integration

5 EXAMPLE OF METHOD INTEGRATION

The following example is used to illustrate the integration of Agent-based Simulation and System Dynamics. We assume a car manufacturer, who offers vehicles with two different powertrains (i = ICE: Internal Combustion Engine, EPT: Electric Powertrain) in two different vehicle classes (j = Small, Large). The vehicles are described by two characteristics (k = Price, Range). Furthermore, two different population segments respectively agent groups (n= Rich, Poor) are defined, which are differentiated by the characteristic income. Customers respectively agents of the different segments purchase the offered vehicles in the Agent-based Simulation model. On basis of the purchase decisions, improvements in price and range of a certain powertrain are estimated in the System Dynamics model. To this end, the following notation is used:

$U_{ijn}(t)$	utility derived by a consumer of population segment n from choosing vehicle ij at time t
β_{nk}	taste of a consumer of population segment n for the vehicle characteristic k
$x_{ijk}(t)$	value of vehicle characteristic k of vehicle ij at time t
ε_{ijn}	random term capturing the uncertainty
$P_{ijn}(t)$	probability that a consumer of population segment n chooses vehicle ij at time t
$D_{n\tau}$	discrete demand in segment n and period τ
$S_{ijn\tau}$	number of sales of vehicle ij in population segment n in period τ
$S_{i\tau}$	number of sales of powertrain i over all vehicle classes and population segments in period τ
$AS_i(t)$	accumulated number of sales of powertrain i at time t
$C_i(t)$	cost of powertrain i at time t
λ_i	elasticity of unit costs of powertrain i

With regard to Discrete Choice Theory, the utility derived by a consumer of population segment n from choosing vehicle ij at time t is (Ben-Akiva and Bierlaire 2003)

$$U_{ijn}(t) = \sum_k \beta_{nk} \cdot x_{ijk}(t) + \varepsilon_{ijn} \quad \forall i, j, n \ ,$$

where the deterministic part of the utility is a linear in the parameters function, and ε_{ijn} is a random term capturing the uncertainty on basis of a probability distribution function. Thus, the utility derived by a rich consumer from choosing a small vehicle with electric powertrain at time t is given by

$$U_{EPT,Small,Rich}(t) = \beta_{Rich,\mathrm{Price}} \cdot x_{EPT,Small,\mathrm{Price}}(t) + \beta_{Rich,Range} \cdot x_{EPT,Small,Range}(t) + \varepsilon_{EPT,Small,Rich} \ .$$

Using a Multinomial Logit Model (Ben-Akiva and Bierlaire 2003, Bierlaire 1998), the probability that a consumer of population segment n chooses vehicle ij at time t is

$$P_{ijn}(t) = \frac{e^{\sum_k \beta_{nk} \cdot x_{ijk}(t)}}{\sum_i \sum_j e^{\sum_k \beta_{nk} \cdot x_{ijk}(t)}} \quad \forall i, j, n \ .$$

On basis of the purchase probability, which is calculated continuously, the customers respectively agents in the Agent-based Simulation model take their purchase decision at discrete points in time. To this end, a transition from the continuous time t to discrete time periods τ takes place. Assuming a given discrete demand $D_{n\tau}$ in segment n and period τ, the number of sales of vehicle ij in population segment n in period τ is

$$S_{ijn\tau} = f(D_{n\tau}, P_{ijn}(t = \tau)) \quad \forall i, j, n, \tau \ .$$

Thus, the number of sales of powertrain i over all vehicle classes and population segments in period τ is

$$S_{i\tau} = \sum_j \sum_n f(D_{n\tau}, P_{ijn}(t = \tau)) \quad \forall i, \tau \ .$$

For example the number of sales of electric powertrains in period τ is

$$\begin{aligned} S_{EPT,\tau} = f(D_{Poor,\tau}, P_{EPT,Small,Poor}(t=\tau) + f(D_{Poor,\tau}, P_{EPT,L\arg e,Poor}(t=\tau)) + \\ f(D_{Rich,\tau}, P_{EPT,Small,Rich}(t=\tau)) + f(D_{Rich,\tau}, P_{EPT,L\arg e,Rich}(t=\tau)) \end{aligned} \quad \forall \tau \ .$$

On basis of variable $S_{i\tau}$, cost reduction and range improvement due to learning effects in production can be implemented in the System Dynamics model. To this end, the number of sales of powertrain i has to be accumulated continuously over time in the System Dynamics model

$$AS_i(t) = \int_{t=\tau} S_{i\tau} \quad \forall i \ .$$

Using the experience curve concept (Montgomery and Day 1985, Sterman 2000), cost of powertrain i at time t is given by

$$C_i(t) = C_i(t=t_0) \cdot \left(\frac{AS_i(t)}{AS_i(t=t_0)} \right)^{-\lambda_i} \quad \forall i \ .$$

Cost reduction on basis of the experience curve can be passed into purchase price. In a similar manner, increase in range of a certain powertrain can be calculated. Again, improvements in price and range lead to a changed purchase behavior in the Agent-based Simulation model.

6 CONCLUSION

The introduced framework allows the development of product strategies in the automotive industry with special regard to alternative fuel and powertrain technologies. To this end, the framework provides a detailed and appropriate description of the socio-economic and dynamic complex system automotive market. This is achieved by the integration of System Dynamics and Agent-based Simulation in a modular simulation environment and the use of different aggregation levels. The usage of a simulation environment makes the analysis of different strategy options respectively vehicle portfolios possible. Several company objectives as well as uncertainties about the development of basic conditions can be considered. This way, recommendation can be derived regarding the introduction of alternative powertrain and fuel concepts.

In the next steps the introduced concept is to be modeled and implemented in a simulation environment. Suitable validation methods are to be selected and utilized. In order to evaluate the different strategy options, a procedure of strategy formulation and an evaluation procedure for the several objectives are to be considered. With regard to the evaluation of the objectives, recourse to portfolio theory seems promising. For example correlations between sales development of different vehicles or powertrains could be used as a risk measure for defined portfolios.

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AUTHOR BIOGRAPHIES

KARSTEN KIECKHÄFER is research and teaching assistant at the Institute of Automotive Management and Industrial Production (AIP). His main fields of research are modeling and simulation of dynamic systems, and model-/simulation-based product strategy development in the automotive industry. His email is <k.kieckhaefer@tu-bs.de>.

GRIT WALTHER is postdoctoral research fellow at the Institute of Automotive Management and Industrial Production (AIP) at Technische Universität Braunschweig. Her main fields of research interests are sustainable supply chain management, eco-efficient production and logistics, and modeling and simulation of sustainable systems. Her email is <g.walther@tu-bs.de>.

JOACHIM AXMANN is head of the department Process Development at the Volkswagen AG and applied professor at the Technische Universität Braunschweig. His main fields of research interests are evolution, system and neuro bionics as well as modeling, simulation and optimization of technical and economical systems. His email address is <j.axmann@tu-bs.de>.

THOMAS S. SPENGLER is full professor at the Institute of Automotive Management and Industrial Production (AIP) at Technische Universität Braunschweig. His main fields of research are production planning and control, modeling and simulation of production systems, material flow management, and (closed-loop) supply-chain management. He is vice president of the Technische Universität Braunschweig for research and young scientists and board member of the Automotive Research Centre Niedersachsen. His email address is <t.spengler@tu-bs.de>.