Model-based decision support for future OEM power-train portfolios: academic solutions for practical requirements

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Meeting 21st century's challenges of climate change and scarcity of crude oil requires the transition to alternatively powered vehicles, such as electric vehicles. As a consequence, car manufacturers have to integrate these vehicles into their product portfolios. Decisions have to be made about, for instance, the power-train to be offered in specific vehicle models and their times of introduction. This is a complex decision making task, especially due to high uncertainties about the future development of the market demand for alternatively powered vehicles.

We here discuss how the application of system dynamics and agent-based simulation can contribute to manage the transition to alternatively powered vehicles from a manufacturer's perspective. To this end, we present practical requirements on a model-based decision support and a scientifically novel simulation approach to fulfill these requirements. The simulation approach was developed in cooperation between university and industry. It integrates a system dynamics model with an agent-based discrete choice model to simulate aggregated system behavior and individual consumer choices based on industrially proved data. We show that our novel approach meets users' requirements and can offer multiple benefits for decision making in industry. We discuss how these benefits can be exploited in future.

Keywords: automotive industry, alternative power-trains, product portfolio decisions, agent-based simulation, system dynamics

1 Introduction

Automobile manufacturers are currently focusing on alternatively powered vehicles to reduce the environmental impact of their vehicle fleet. This is first due to stricter political regulations such as the CO2-emission regulation of the European Union (European Union 2010) or other countries, second, due to the approaching scarcity of crude oil and gas, and, third, due to society's expectations. Alternatively powered vehicles such as sustainable natural gas vehicles, battery electric or fuel cell electric vehicles can be operated independently of crude oil and gas. They thus seem promising to meet these challenges. For this reason, automobile manufacturers are striving to integrate alternatively powered vehicles into their vehicle portfolio.

This is typically a task of strategic product portfolio planning. Here the product portfolio offered on the market has to be designed so that it is synchronized with the market demand over time. For this, the question has to be answered, which vehicle models should be introduced to the market at what point in time. On this strategic planning level, a vehicle model is typically characterized by its size class and body style (Adelt 2003) and in future also by its power-train (Frick et al. 2011). Automobile manufacturers thus have to decide about offering vehicle models with a specific size class, a specific body style, and a specific power-train at a specific point in time (Kieckhäfer et al. 2012).

In the automotive industry, strategic product portfolio decisions are mainly based on a so called cycle plan or long range product plan (Adelt 2003, Hill et al. 2007). Here, milestones for all vehicles of the current and future product portfolios are depicted. For product portfolio planning, different cycle plans are developed and evaluated based on their financial performance as well as on other aspects such as innovativeness and legal compliance.

The development of the financial performance strongly depends on the future market development of the different vehicle models included in the cycle plan. Forecasting these developments is very challenging: First, the expected total market volume has to be approximated. Afterwards, it has to be estimated which shares of this market volume are attained by the vehicle models. By taking into account competition, sales volumes for every vehicle model of a manufacturer in a market can be deduced. These sales volumes are then used to calculate the financial performance of the vehicle models as well as their technical and ecological consequences and thus to evaluate different cycle plans (Hill et al. 2007).

In practice, the development of the market shares of different vehicle models is often estimated using scenario technique (as done e. g. in ifmo 2002, Shell 2009). For this, important influencing factors that determine the business environment are identified. Based on qualitative statements from expert elicitations, the future development of these factors and their interrelations are estimated (Mietzner and Reger 2005). These estimates are then used to construct possible scenarios projecting the future development of the automotive market. For each of the constructed scenarios, e. g. the optimistic, the pessimistic, and the trend scenario, assumptions about the influence of these developments on the market shares are made. Based on these assumptions, the market shares of the different vehicle models are estimated.

Within this procedure some shortcomings can be identified. On the one hand, cause-effect relationships and feedback loops are only regarded to a very small extent. This holds true for the interdependencies between the different influencing factors as well as the interdependencies between the influencing factors and the market shares of the vehicle models. On the other hand, assumptions and mental models of the experts that lead to the statements about the developments of the influencing factors and the market shares are only implicitly included, but are not made explicit.

Against this background, a cooperative project between industry and university has been initiated that aims at developing new methods to improve the scenario process and thus to support strategic product portfolio planning. We here report how system dynamics and agent-based modeling can help to support strategic product portfolio planning for the transition to alternatively powered vehicles. Using these approaches can be beneficial for decision making in industry in multiple ways. On the one hand, the approaches allow for modeling the automotive market in detail and for taking into account the important interrelationships therein. On the other hand, expert knowledge and data from various departments (market research, product management, research and development …) can be incorporated into the model and can thus be made explicit. This way, developments of market shares of different vehicle models can be simulated and well founded recommendations for strategic product portfolio planning can be derived. Confidence in the model outcomes and the resulting recommendations is enhanced by the broad institutional knowledge and data base. Beyond purely estimating how the market shares could develop, also insights into why they develop this way can be achieved. Thus, industrial decision makers can gain a deeper understanding of the behavior of the automotive market.

The remainder of the paper is structured as follows. In Section 2 we derive the requirements on a model based decision support for strategic product portfolio planning and present a market simulation model that integrates system dynamics and agent-based modeling to fulfill these requirements. In Section 3 we then discuss the potential of this simulation model, the current limitations for its practical application and implications for future work. Concluding remarks are given in Section 4.

2 Model-based decision support in theory and practice

2.1 Practical requirements

To follow the idea of supporting strategic product portfolio planning in the automotive industry by means of a simulation model, different requirements have to be regarded. These requirements can be deduced from the planning task "strategic product portfolio planning" and the procedure "scenario analysis", which is currently often used to support this planning task. The planning task itself requires simulating the development of the market shares of different vehicle models subject to the vehicle portfolio offered to the market. This means, the model has to allow for specifying vehicle models as combinations of size class, body style, and power-train as well as their time of introduction and concrete characteristics that influence the purchase decision (e. g. price, fuel consumption, and brand) for different markets.

To estimate the development of the vehicle models' market shares, various factors have to be considered in the simulation model, whose development and influence on the market development are analyzed in the scenario process. These factors stem from the five fields society, technology, economy, ecology, and politics. Within the field society, factors such as demography, urbanization, and changes in values are relevant. On a more detailed level, consumer characteristics like preferences, technology awareness, environmental awareness, income, mileage, holding period, life stage, age, or previous experiences have to be taken into account. Technological factors include the developments of the cost parameters (e. g. costs of the engine, costs of the battery, and costs of ownership) and performance parameters (e. g. fuel or energy consumption, cruising range, engine power and characteristics) of the conventional and alternative power-train technologies. With regard to the economy, factors such as the GDP, the availability of resources, infrastructure (especially service stations for refueling or recharging) or fuel prices are of interest. Ecological factors are used to describe the environmental situation of the market in question thereby accounting for environmental problems such as pollution, scarcity of resources, CO_2 emissions etc. These factors often go together with political factors which include the regulations to diminish environmental problems such as the CO_2 emission regulations set by the European Union (European Union 2010).

Additional practical requirements exist on how the different factors are incorporated into the simulation model. Factors from the economic, ecological, and political field define the business environment. These factors can only be influenced by an OEM to a very small extent, if at all. However, they have a significant influence on supply of and demand for vehicles. Additionally, the development of these factors is highly uncertain. This is why they should only be depicted as exogenous parameters on a high aggregation level. In contrast to this, the development of the power-train technologies is strongly dependent on the actions of an OEM and the market share developments. It thus has to be modeled endogenously thereby considering possible innovations and leaps in technology. Also societal factors should be depicted in detail based on available data to model consumer behavior as accurately as possible. The market share development to be estimated is directly dependent on the consumer response to the vehicles offered to the market. Thus, modeling realistic consumer behavior is necessary to ensure that industrial decision makers confide in the model results. Especially, the purchase decisions have to be explained by means of a highly sophisticated purchase decision model which is accepted by an OEM. Usually, such a model should explain the consumer choices taking into account the vehicle and the consumer characteristics. Furthermore, the consumers should be divided into different consumer segments (e. g. based on their life stage) to account for heterogeneous consumer behavior. At best, the consumer characteristics and their resulting behavior should be considered on an individual level.

2.2 Literature review

With regard to the automotive market different system dynamics models exist that allow for simulating the development of the market shares of alternatively powered vehicles. These models have been developed to analyze the market diffusion of alternatively powered vehicles (e. g. Janssen et al. 2006; Meyer and Winebrake 2009; Sheperd et al. 2012; Struben and Sterman 2008; Walther et al. 2010; Wansart et al. 2008). To this end, the main feedback loops between the development of power-train technologies, service stations, consumer awareness, and consumer choice are modeled (cf. Figure 1). Often, also regulatory measures are incorporated into the model to analyze their impact on emission reductions in the transportation sector (e. g. BenDor and Ford 2006; Bosshardt et al. 2008; Meyer 2009; Walther et al. 2010; Wansart et al. 2008).

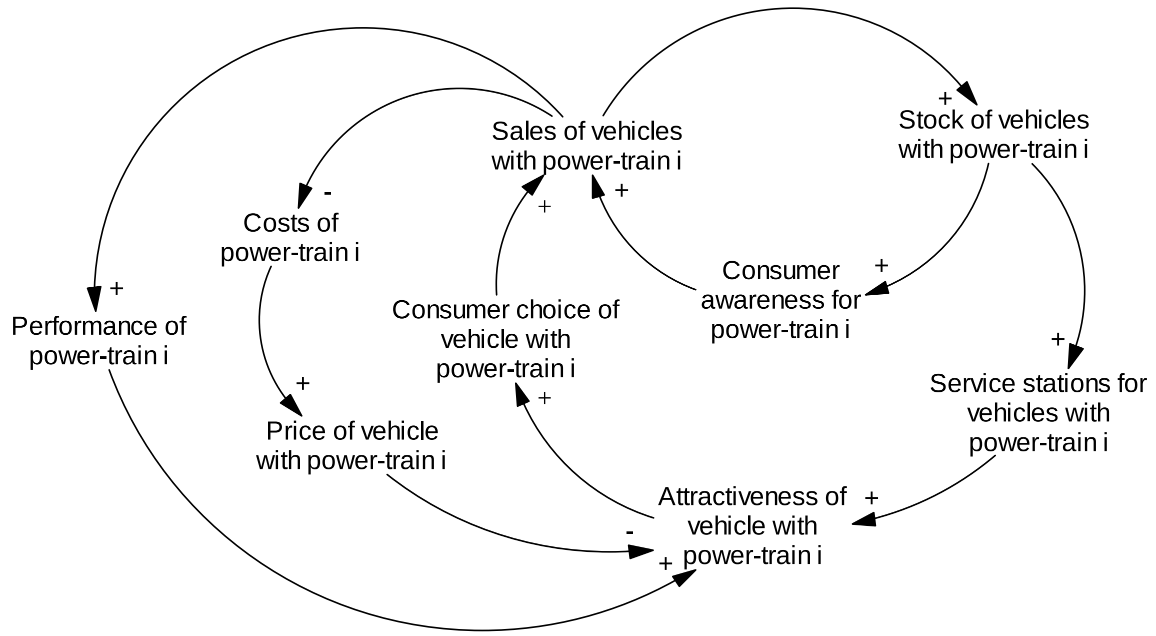

Figure 1: Main feedback loops considered in system dynamics models to simulate the development of the market shares of alternatively powered vehicles

Overall, the system dynamics models meet a multitude of the practical requirements. However, the models have two main shortcomings. (1) Homogeneous consumer behavior is assumed, which is clearly in contrast to actual consumer behavior in the automotive market (e. g. Achtnicht et al. 2008). A common approach is using a discrete choice model (Train 2009) to model the purchase decision of an average consumer taking into account the vehicle and the consumer characteristics. The choice model is combined with adaptations of the Bass innovation-diffusion model (Bass 1969) to take into account consumers' awareness of alternatively powered vehicles and their willingness to consider them within a purchase decision. (2) The models usually do not depict strategic product portfolio decisions. The vehicle models are only distinguished by their power-trains and all vehicle models are offered to the market right from the beginning. Obviously, these assumptions are not in line with reality. Only the simulation model presented by Walther et al. (2010) and Wansart et al. (2008) allows for considering vehicle models as combinations of power-trains and size classes as well as their time of introduction.

In addition, agent-based models have been developed that allow for simulating the market shares of alternatively powered vehicles and analyzing their market diffusion. In contrast to the system dynamics models, the focus of these models lies on the individual consumer behavior. Individual purchase decisions are considered here. This is usually done by integrating discrete choice or conjoint-based choice models into the agent-based simulation models (e. g. Günther et al. 2011; Mueller and De Haan 2009; Zhang et al. 2011). Furthermore, consumer awareness is modeled on an individual level, either based on a stationary Markov process (Mueller and De Haan 2009) or on consumer interaction on the micro level (Günther et al. 2011; Zhang et al. 2011). Another advantage of the agent-based simulation models lies in the consideration of highly differentiated vehicle portfolios. However, important developments in the business environment and the development of the power-train technologies as well as their interrelation with consumer behavior are largely neglected.

Overall, neither the system dynamics models nor the agent-based models that have been developed so far meet all practical requirements. Thus, they cannot directly be applied to support strategic product portfolio planning in the automotive industry. This is why we developed a novel hybrid simulation model we will briefly present in the following.

2.3 Modeling approach

To best meet the practical requirements, we developed a simulation model that integrates a system dynamics model with an agent-based discrete choice model. The model was developed at the university in close cooperation with the support of a large German OEM. It allows for simulating the development of the market shares of alternatively powered vehicles subject to the vehicle portfolio offered to the market. The model is implemented in the software AnyLogic from XJ Technologies, which allows for the integration of the system dynamics and the agent-based model (Borshchev and Filippov 2004). To support strategic product portfolio planning, the vehicle portfolio offered to the market, the consumer behavior in the market, and scenarios of uncertain developments in the business environment can be defined exogenously. Vehicle models to be considered in the portfolio can be specified by means of their power-train, size class and time of introduction. Body styles are not subject of the investigation in the first step.

The basis of the hybrid simulation approach is a system dynamics model. It draws on experiences of modeling the automotive market with system dynamics gained within longstanding research projects (Meyer 2009; Walther et al. 2008; 2010; Wansart 2008). The model allows for considering the main feedback loops between consumer choice, consumer awareness, development of power-train technologies, and service station availability (cf. Figure 1). To take into account heterogeneous consumer behavior, the agent-based discrete choice model from Mueller and de Haan (2009) is adapted and integrated into the system dynamics model (cf. Figure 2). This way, the model parts of consumer choice and consumer awareness are refined.

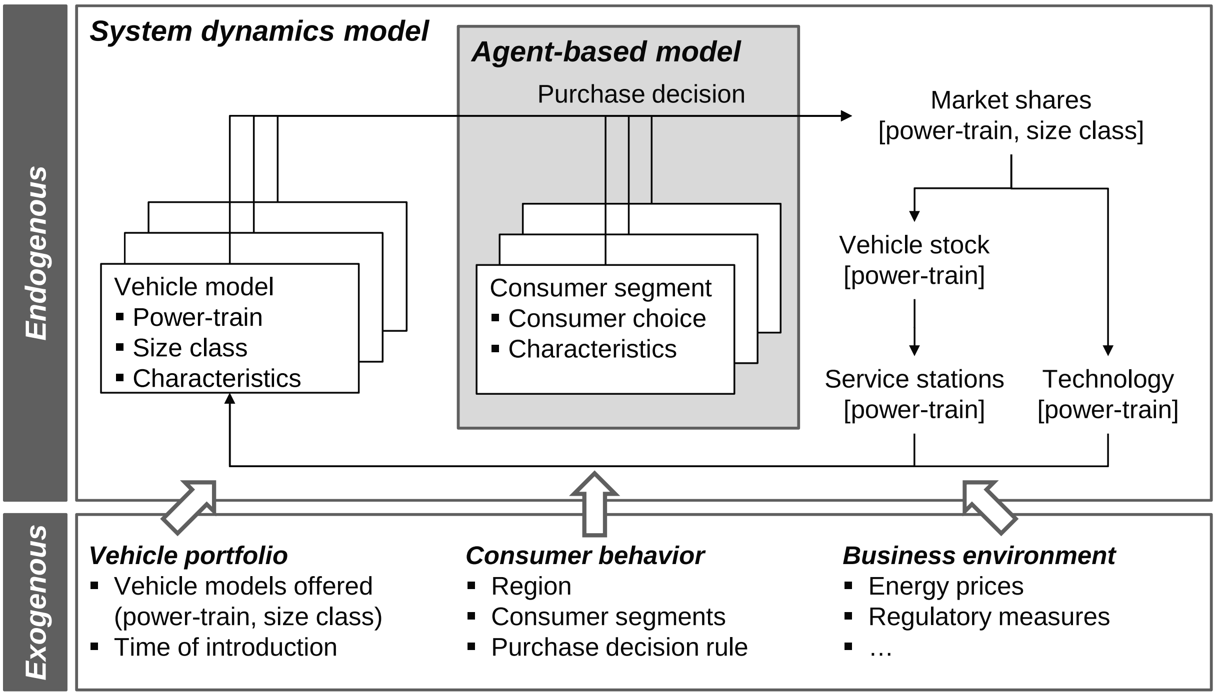

Figure 2: Concept of the integrated system dynamics and agent-based model to support strategic product portfolio planning in the automotive industry (Kieckhäfer et al. 2012)

The integration of the system dynamics and the agent-based model is based on the vehicle portfolio offered to the market as well as on sales and stock figures resulting from the purchase decisions of the agents. The characteristics of the vehicle models that can be purchased by the agents in the agent-based simulation model are influenced by the simulated developments in the system dynamics model. In turn, the developments in the system dynamics model are influenced by the sales and stock figures that are calculated in the agent-based simulation model as a result of the simulated purchase decisions of the agents. Roughly, from a process-oriented perspective the simulation model is constructed as follows.

(1) Initialization

At the start of the simulation, the vehicle portfolio offered to the market as well as the agents are initialized. To initialize the product portfolio, vehicle models are added to the simulation model as objects. As already mentioned, these models differ in terms of power-trains and size classes. In addition, vehicle characteristics that influence the purchase decision (e. g. purchase price, cruising range) are specified. To initialize the consumer agents, they are divided demographically into different consumer segments. Each agent represents a certain number of consumers in a specific segment of the regarded market. The agents are characterized by means of socio-economic and socio-demographic attributes (e. g. age, environmental awareness, kilometers travelled). Furthermore, decision rules for carrying out the purchase decision are predefined. At the end of the initialization step, one specific vehicle model is randomly assigned to every agent. This is done by taking into account the actual power-train and size class split of the current vehicle fleet that is operated in the regarded market. It allows for considering a realistic composition of the vehicle stock at the start of the simulation.

(2) Simulation of the purchase decisions in the agent-based simulation model

After the initialization step, the agents turn into new car buyers. To this end, the time of purchase is determined first. This is done by defining the holding period of a vehicle for each agent. The holding period is modeled as an exponentially distributed random variable. Thus, every agent replaces the current vehicle at a certain point in time and passes a multistage purchase decision process following Mueller and De Haan (2009).

In the first step of this process, an agent specific choice set is determined. To this end, the choice set size and composition are specified. The choice set size is drawn randomly. To compose the choice set of an agent, vehicle models from the product portfolio offered on the market are selected. The selection process is modeled as a stationary Markov process, which is based on transition matrices for the attributes size class and power-train. These matrices describe the likelihoods that an agent includes a vehicle model with a specific size class and power-train into the choice set given the power-train and size class of the current vehicle model.

In the second step of the purchase decision process, the actual purchase decision is modeled. To this end, discrete choice theory (Train 2009) is utilized to describe the selection of one specific vehicle model from the choice set by the agent. First, the utility for every vehicle model in the choice set is computed. This utility is a function that is deterministic and linear in the parameters. It is dependent on the vehicle characteristics and the characteristics of the consumer/agent. Afterwards, the purchase probabilities for the vehicle models in the choice set are determined. Here, a nested logit model is used (Achtnicht et al. 2008). The nests are built with regard to the different power-trains. Based on the estimated purchase probabilities, the purchase decision of the agent is simulated using random wheel selection.

The purchase decisions of the agents lead to a recalculation of the vehicle sales and stock figures in the agent-based simulation model. These figures are transferred to the system dynamics model.

(3) Simulation of the developments in the system dynamics model

The system dynamics model serves to simulate the values of the vehicle characteristics that have an influence on consumer choice. To this end, the development of the number of service stations and the development of the cost and performance parameters of the power-trains as well as the corresponding development of the vehicle characteristics are modeled endogenously (Walther et al. 2010). These developments are influenced by the purchase decisions of the agents. For instance, the more agents purchase a vehicle with a specific power-train, the higher is the demand for a certain energy carrier and the more service stations are required (Struben and Sterman 2008). To account for these dependencies, the information about the sales and stock figures from the agent-based simulation is used.

In the following, we will exemplarily illustrate this procedure by focusing on the characteristics purchase price and cruising range of a battery electric vehicle. Their development is modeled depending on the development of the energy density and the production costs of the traction battery. The energy density *(EnergyDensity)* follows a logistic growth curve until a technical maximum *(Max_EnergyDensity)* is reached (Wissema 1982). The development of the production costs per kilowatt hour battery capacity *(KWhUnitCost)* is modeled by means of a standard experience curve (Henderson 1984). Both variables are dependent on the cumulated experience, which is approximated by the battery capacity installed in the sold electric vehicles. The battery capacity installed is computed in the agent-based model and transferred to the system dynamics model. Its value is directly written in the stock *KWhProduced* (cf. Figure 3). This way, the integration of the agent-based simulation model with the system dynamics model becomes possible.

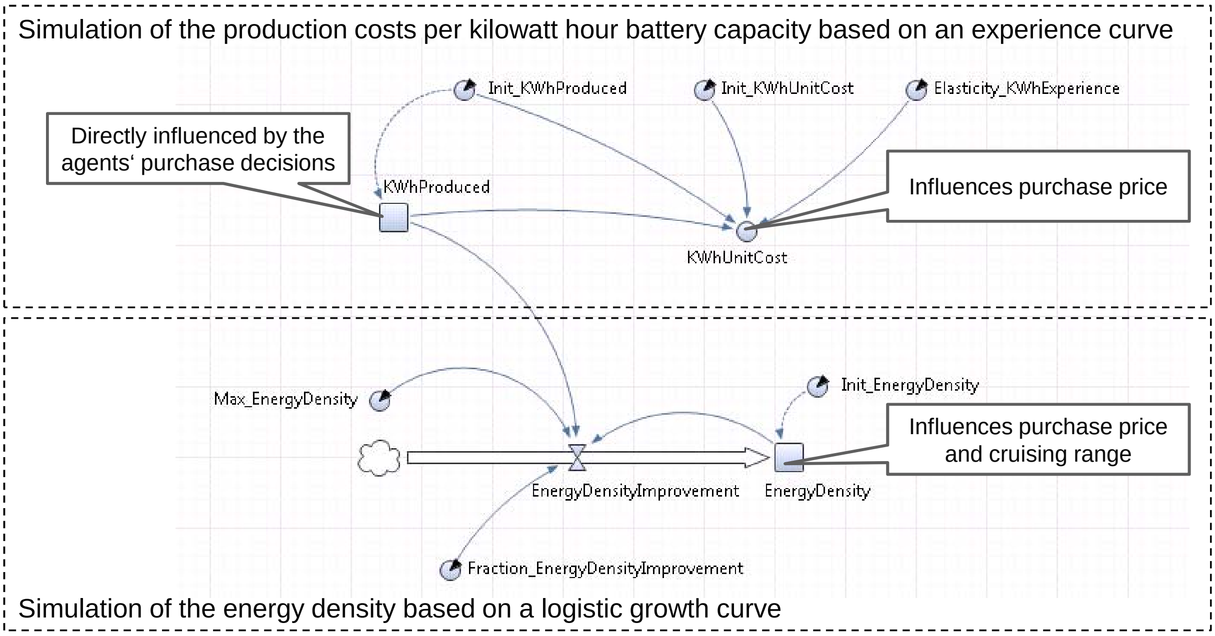

Figure 3: Computation of the production costs and the energy density of the traction battery in the system dynamics model

To compute the purchase price of the battery electric vehicle *(Price)*, the costs of the traction battery *(CostBattery)* are calculated first. These costs are modeled in dependence on the costs per kilowatt hour battery capacity *(KWhUnitCost)*, the energy density *(KWhBattery)*, and the package weight of the traction battery *(PackageWeight)* (cf. Figure 4). The cruising range of the battery electric vehicle *(Range)* is approximated in dependence on the energy density *(KWhBattery)* and the electricity consumption *(ElectricityConsumption)*.

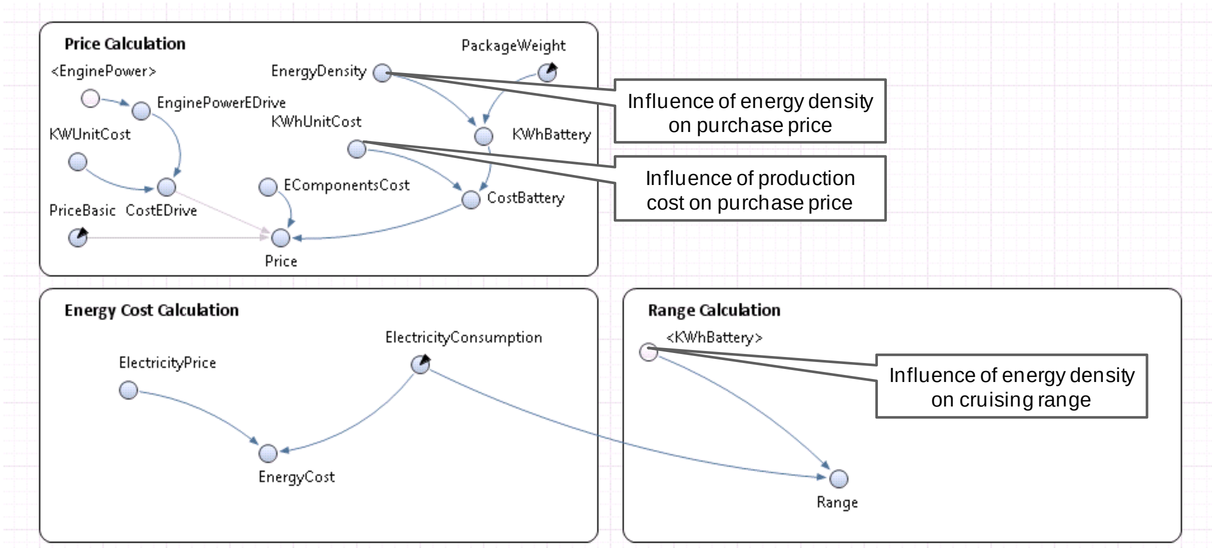

Figure 4: Computation of purchase price, energy cost, and cruising range of a battery electric vehicle in the system dynamics model

(4) Update of the characteristics of the vehicle portfolio

The values of the vehicle characteristics that are simulated in the system dynamics model are used to cyclically update the characteristics of the vehicle models the agents can choose from in the agent-based simulation model. This way it is regarded that OEMs do not adjust their offering continuously. The cycle time for updating the vehicle characteristics (e. g. one year) has to be defined before the start of the simulation run. Additionally, new vehicles can be introduced to the market at these points in time. The adjustment is based on predefined information about the introduction of new vehicle models (e. g. time of introduction, size class, power-train).

(5) Repeat

After the adjustment procedure, the agents can purchase vehicle models from the new product portfolio (cf. Figure 5). The steps (2) to (4) are repeated until the simulation run is terminated. Overall, this procedure allows for integrating the system dynamics model with the agent-based simulation model.

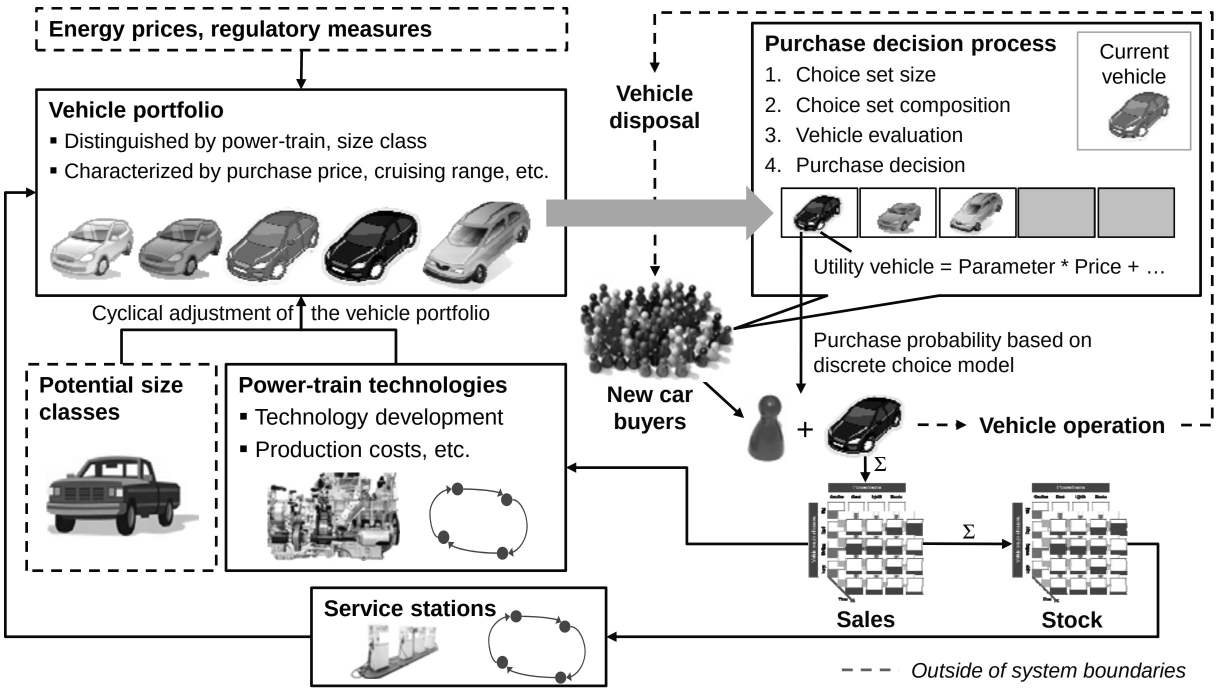

Figure 5: Integration of the agent-based simulation model and the system dynamics model from a process-oriented perspective (Kieckhäfer et al. 2012)

To enable the evaluation of simulation experiments and thus to support strategic product portfolio planning, the model can be executed in two different ways. For a "quick" evaluation of single simulation runs a user interface is provided (cf. Figure 6). Here, the simulation runs can be customized by the user (e. g. definition of the times of introduction of the vehicle models) and the resulting developments of the shares of sales of the vehicle models and the power-trains are directly presented. However, the information content of these results is limited due to the high aggregation level and the stochastic nature of the agent-based simulation model. This is why also, for instance, Monte Carlo experiments can be executed to allow for comprehensive evaluations (e. g. development of the market shares in the consumer segments) of various replications of a simulation run.

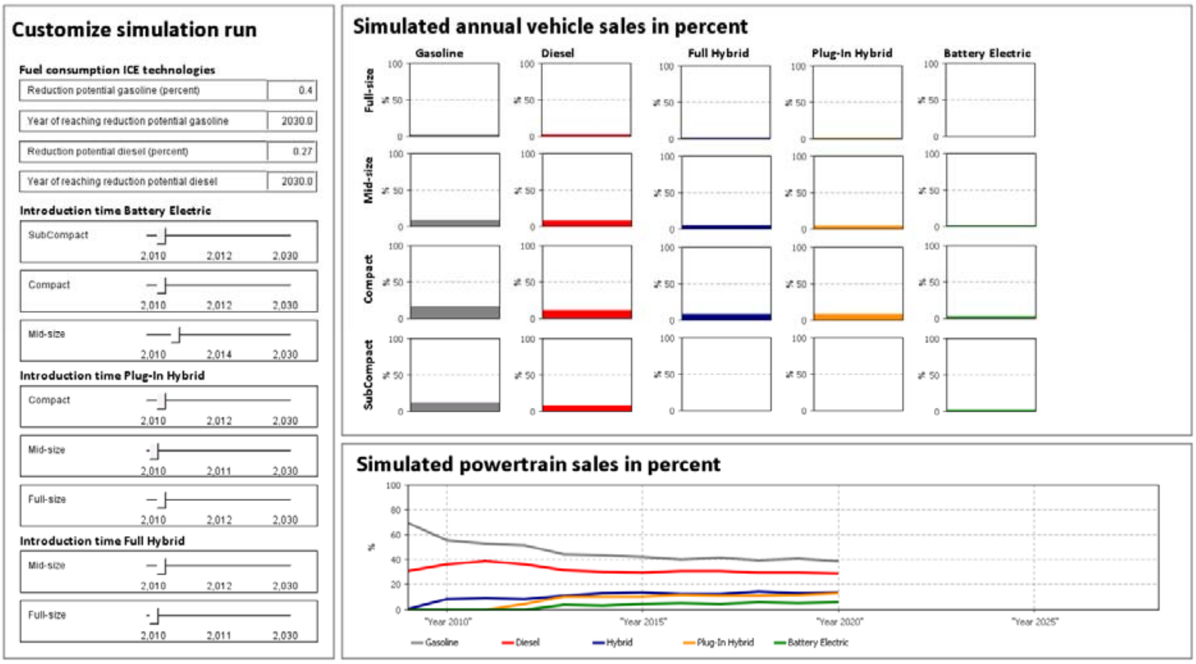

Figure 6: User interface to customize single simulation runs and quickly evaluate the development of the shares of sales of the vehicle models and the power-trains

3 Potentials and limitations for practical use

3.1 Potentials

The simulation approach shows various potentials for practical use. Obviously, it fulfills many of the stated requirements and might thus be helpful for its original purpose to support strategic product portfolio planning. The development of market shares of various power-trains in different vehicle size classes could be simulated subject to the vehicle portfolio offered to the market. Individual and heterogeneous consumer behavior, technology development as well as aggregated developments in the business environment can be accounted for. Furthermore, the model is founded on widely used scientific theories and incorporates expert knowledge from industry. Based on data for the German market that is partly provided by industry and partly taken from publicly available sources, the model shows a quite reasonable behavior within validation tests. On the one hand, the market shares of conventionally powered vehicles in the last few years can be reproduced (Kieckhäfer et al. 2012). On the other hand, model behavior, specifically the development of the market shares of alternatively powered vehicles, stands in accordance with diffusion theory. These results are achieved without calibrating the model by using the broad empirical data base. This provides a starting point for building confidence in the model, which is a crucial point for its application in practice.

An additional potential of such a model is the possibility to store expert knowledge that is normally spread over the company. During meetings and workshops, this knowledge and the mental models of the experts from different divisions and disciplines can be brought together, discussed, and used to build the model. Thus, the modeling process itself might support the interdisciplinary and interdivisional cooperation in the company. Once the model is built and the expert knowledge is incorporated, the model can easily be adjusted to execute simulation runs.

Another possibility to apply such a simulation model in a company might be to use it as a tool for gaining a deeper understanding of the behavior of the automotive market in management and in further steps as a training tool for strategic planners. The simulation model allows analyzing the main feedback loops between the vehicle portfolio offered to the market, consumer choice, consumer awareness, development of powertrain technologies, and service station availability. This way, a broader basis for the strategic product portfolio decisions could be ensured.

With regard to external communication the simulation model could be used in the discussion with other stakeholders like policy, NGOs, and journalists. Especially the application of the simulation model in the field of regulatory impact assessment seems to be promising. Here, for instance the model can be used to analyze the impact of different policy and technical measures on the reduction of CO_2 emissions in the automotive sector (e. g. Herrmann et al. 2012, Meyer 2009, Walther et al. 2008; 2010). The results can then be discussed to improve accuracy in the design of regulatory measures and raise their effectiveness.

3.2 Limitations

Despite its potentials, the presented simulation model is not yet used in practice. Up to now, it remains an academic solution for practical requirements and is so far only in use at the university. To support the application in practice, the confidence in the model and the user acceptance still has to be raised to a large extent.

The confidence in the model depends strongly on choosing the right model scope and structures as well as on using the right data. Even though the model was developed based on various workshops and discussions with decision makers from industry there is still no consensus about these aspects. The reasons for this are on the one hand heterogeneous opinions of the stakeholders. This heterogeneity is not only due to the fact that the stakeholders stem from different disciplines, but also due to their specific expertise and previous experience in model building. On the other hand model scope, structures, and data cannot be treated independently of each other. For instance, it is still an open question how to model consumer behavior adequately. As in science, a lot of opinions exist in practice which consumer behavior model is most suitable to explain the purchase decisions of the consumers. The discussion on this topic ranges from selecting the best model from various existing discrete choice and conjoint models to incorporating completely new insights from neuroscience into the model. From this discussion the main data issues originate. At best, a widely trusted consumer behavior model has to be found that explains the individual purchase decisions on the basis of company internal data. However, even if agreement on one consumer behavior model is reached, it is not always guaranteed that internal data for this model exists. Furthermore this data is usually confidential, so that, if at all, only aggregated internal data can be incorporated into the model as long as it remains an academic solution.

To ensure user acceptance in industry, the applicability of the simulation model is of great importance. This is a big challenge due to the complex model structure as well as the variety of methods and data incorporated in the model. Expert knowledge is required to adjust the model structure, the data base, or the evaluation options of the simulation runs. This is why such a model can currently be handled nearly exclusively by the researchers from university. It cannot be granted that the designated users of the simulation model also possess the necessary knowledge.

3.3 Implications for future work

The presented simulation model can be considered as an innovation with regard to strategic product portfolio planning in industry. Future work has to ensure that the model is adopted by industrial decision makers and diffuses into the company to increase the possibility that its discussed benefits are exploited in industry. Analogously to the Bass model, effective advertising and word-of-mouth are required for this. The key to success is to identify innovators in the company that can act as disseminators and ensure their confidence in the model and user acceptance. Once they are convinced of the new approach, they can promote it within the company.

Thus, the question remains how to build confidence and raise user acceptance in a way that industrial decision makers are convinced of such an innovative and complex simulation model. Obviously, further comprehensive validation tests have to be carried out to build confidence. Within these tests only industrially collected and proved data should be used. Based on this data, the simulation model, of course, has to provide reliable and verifiable results that are easily traceable for industry. However, this seems to be nearly impossible. Reliability and verifiability are hard to obtain because of manifold opinions in the company about the right model and the uncertain future development of the automotive market. The complexity of the model impedes traceability of its results.

To nevertheless build confidence into the model, future work should focus on the following issues. (1) It is of great importance to avoid false expectations of the industrial decision makers. It has to be clearly communicated, that the simulation model, just like the scenario technique, does not strive for point predictions. (2) The model has to be successfully applied to exemplary real world case studies, like in Walther et al. (2010) for the Zero-Emission Vehicle Regulation of the state of California. (3) Sensitivity analyses with regard to complete sub-modules of the simulation model seem to be very promising, as done e. g. in Whitefoot et al. (2011). For instance, different consumer behavior models could be incorporated in the simulation model to demonstrate the impact of these models and compare the simulation results. Based on this comparison one or maybe more widely accepted consumer behavior model(s) could be agreed on and used in the simulation model to actually support strategic product portfolio planning.

As stated, a further prerequisite for the user acceptance is the usability of the simulation model. To make the model applicable for non-experts, an interactive and hands-on user-interface has to be provided. Here, the design of a management flight simulator that allows for a user-friendly manipulation of selected model parameters as well as the evaluation and visualization of selected results seems to be promising. At best, the flight simulator also allows for easily changing complete sub-modules (as discussed above) that are predefined by the experts. This way not only the execution of the simulation model would be simplified, but also the adjustment of the model structure.

In any case, educating students in university to become experts in modeling and analyzing complex and dynamic socioeconomic systems and diffuse into the company could be advantageous.

4 Conclusion

In this contribution, we report how agent-based modeling and system dynamics can be used to support strategic product portfolio planning in the automotive industry. These approaches provide the opportunity to estimate the development of the market shares of different vehicle models which are one important input for the evaluation of different product portfolios. Especially the integration of system dynamics and agent-based modeling enables meeting various practical requirements. We show this potential by presenting a simulation model that was developed in cooperation between university and industry. The simulation model integrates a system dynamics model to consider aggregated system behavior with an agent-based discrete choice model to consider individual consumer behavior. Herewith it is possible to support strategic product portfolio planning by simulating the market share developments of alternatively powered vehicles taking into account different vehicle portfolios. Thereby various factors from business environment, technology, and consumer behavior, whose developments and influences on the market environment are analyzed in the scenario process, as well as their interdependencies can be taken into account.

The presented simulation approach shows various potentials for practical use, such as supporting strategic product portfolio planning, enhancing the understanding of the automotive market, and storing knowledge of experts from various divisions. However, some limitations for its practical application have been identified. Here, the main tasks lie in building confidence in the model and raising user acceptance, which thus has to be trageted by future work. Further comprehensive validation tests and sensitivity analyses can be used for building confidence. To enhance the applicability of the simulation model and thus raise user acceptance, a hands-on user interface e. g. in form of a management flight simulator should be developed and implemented.

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