Limiting motor vehicles' CO_2 emissions – a manufacturer's challenge

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Due to ever stricter emissions regulations the automobile industry struggles to reduce their products' emissions of carbon dioxide. There are several technical options to solve the problem, all of them equally effective. A manufacturer could decide for minimum cost and move on. However, the problem should also be considered from a long-term perspective. Changes in the products' characteristics or the whole product line may lead to unintended consequences. Changing market conditions should be taken into account. A model is presented that has been developed in cooperation with a German OEM. It takes a broad view on the relevant parts of the market and allows structured planning activities.

Keywords: automobile industry, carbon dioxide, emissions regulation

1 Introduction

Transportation's external effects have been discussed for a long time. It is responsible for emitting large amounts of particles and gases that can cause smog and health problems. There are several regulatory measures that have been set up in order to decrease these emissions. During the last years it has been especially carbon dioxide (CO_2) that is focused by new regulations. Carbon dioxide is made responsible for being a main cause of the greenhouse effect which in turn induces anthropogenic climate change. Since the publication of the IPCC[1] report about potential problems caused by climate change and the Stern Review Reports[2] on economic impacts legislative bodies in several countries discuss measures to decrease CO_2 emissions radically. In western countries the transportation sector is responsible for up to 26% of total CO_2 emissions[3] and it is still a growing sector. High economic performance induces a growing logistics industry that enables highly efficient supply-chains and trade commerce that in turn improves GPD. Rapid economic growth in emerging markets like China or India makes incomes rise allowing people to buy more and larger vehicles with more powerful – and fuel consuming - motors. Economic development can be associated with rising travel demand from experiences in the west, and the same pattern can be observed in developing countries today.[4]

Carbon dioxide emissions originate from the combustion process of current drivetrains. It is dependent on the motor's efficiency and the distance driven. Currently discussed regulations

[1] IPCC (2007)
[2] Stern (2007)
[3] EU: 21%, UNFCC (2007a); USA: 26%, UNFCC (2007b)
[4] Dargay et al. (2007)

do not aim at a reduction of driven distances, but want manufacturers (OEMs)[5] to improve the average fuel economy of their new car fleet. The EU, for instance, demands an average of 120 g CO_2 per km for new cars from 2012 on.[6] This is an extremely ambitious target, especially for manufacturers of larger, so called premium vehicles. But even producers of fleets of smaller vehicles will have to take serious efforts to reach this goal. In the U.S. the topic is mainly driven by certain states, California in particular. There, the targets are even more ambitious than in Europe. Besides emission targets for conventional fuel drivetrains, a quota for so-called Zero Emission Vehicles (ZEV) has been introduced in order to accelerate advanced drivetrain and infrastructure development. ZEV do not emit CO_2 during operation. Several other U.S. states have announced to follow California's emission legislation. Countries in Asia closely watch the ongoing developments, too. That shows emissions reduction is a globally advancing process that cannot be ignored by OEMs. The significance for OEMs still grows by the fact that until now none is able to fulfill all the mentioned requirements.

Emission of CO_2 is influenced directly by fuel consumption and the fuel inherent concentration of CO_2. Filters cannot reduce these emissions, so it is the fleet's average fuel economy that has to be tackled by OEMs. There are several technical possibilities to solve the problem, see Figure 1.

Vehicle efficiency	Drivetrain efficiency	Low-emission fuels	Alternative drivetrains
▪ Reduce vehicle size ▪ Weight reduction through new materials ▪ Air resistance ▪ Introduce small cars	▪ Gasoline-Motor o Downsizing o Hybrid ▪ Diesel-Motor o Downsizing o Hybrid ▪ Diesotto	▪ Biofuels ▪ Compressed Natural Gas (CNG)	▪ Hydrogen o Combustion o Fuel Cell ▪ Electr. storage: o Lithium-Ion battery o Capacitator o combined with range extender

Figure 1: Overview over technology improvements that reduce fleet emissions

Decisions have to be made about which of these options to choose and at which range to introduce it. The average fuel economy can be improved in principle in two ways: Either each offered model's emissions are reduced uniformly or a certain number of highly efficient vehicles is introduced that compensate inferior ones. The introduction of alternative drivetrains is even more difficult, since they may be dependent on fuel infrastructure that is not yet existent. Furthermore, the market potential of "green" cars seems rather small until now. In the U.S. the introduction of electric vehicles in the 1990ies was not successful, while in Germany production of two different models consuming only 3 liter of fuel per 100 km was discontinued due to weak demand.[7]

An OEM should thoroughly think about what to do and when. Structured and transparent planning is needed. This contribution's goal is therefore to develop a conceptual model for

[5] OEM = Original Equipment Manufacturer
[6] EU (2007)
[7] That was Volkswagen's 3-liter-Lupo and Audi's A2.

strategic decision support for an automobile OEM enabling the evaluation of temporal allocation decisions of new drivetrain technologies. Customer behavior and relevant market conditions are taken into account. Questions to be asked are: What are the basic underlying principles of the automobile market? In which way will new emission regulations affect the industry, overall demand or driving behavior? How can an OEM develop robust strategies assure future success in the market? From this base scenarios and robust strategies can be developed. In the end there may also be opportunities in the situation that have to be exploited.[8]

2 Problem approach

The problem presented here is complex in a combinatorial as well as in a dynamic way. Possible developments over time are not obvious at first sight, while short-run and long-run consequences will possibly differ a lot. The task gets even more complex, because we adopt an ex-ante perspective. Our problem has not occurred yet, we rather reason about possible outcomes of the new situation and possible ways to deal with it. Focusing on familiar interdependencies between motor vehicle market and the transportation sector – that is in fact vehicle demand, supply, and use – those outcomes are analyzed and evaluated. A certain forecast under which circumstances what will happen is aimed at.

System Dynamics is an appropriate modeling approach for this kind of problem. It focuses on learning and insight into a problem, especially for decision makers.[9] The requirements for empirical data are rather low, compared to other approaches like econometrics. Qualitative values can be captured properly. The method's core lies in coping with dynamic processes and systems. Using variables representing cumulative quantities instead of ordinary differential equation make it easier for non-experts to understand a model's behavior. There is a long tradition in the incorporation of different stakeholders into the modeling process (group learning, interactive strategy development) that is useful in order to apply such a model in a firm.

The initial position of our problem is presented in Figure 2. We find two balancing feedback loops. From a gap between target fleet emissions threshold set by legislation and the currently measured value the desired speed of change of those emissions is deduced with respect to a certain deadline. The time between today and the deadline is the target adjustment time. While the reduction of emissions in a given amount of time may be easy for one manufacturer due to product line and early preparation it may be very difficult for another. The emission reduction pressure is the ratio of desired change of fleet emissions and OEM's emission reduction capacity. The higher this pressure the more resources will be allocated to R&D.

[8] Schelling (1984) mentions product obsolescence due to regulations as a possible sales driver, thus being positive for a manufacturer.

[9] Sterman (1989)

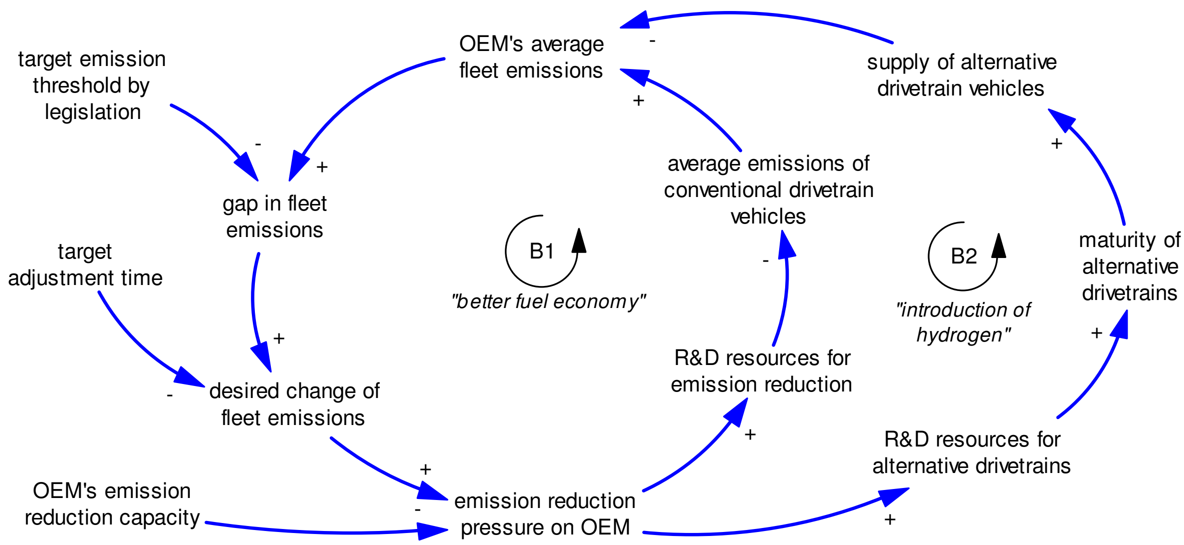

Figure 2: OEM's adjustment to new legislation

This structure implies goal seeking behavior[10] that corresponds well to empirical records.[11] However, the decision between allocating more resources to improvement of conventional technologies and improving new technology is obvious. This is the toehold for basic R&D policies. Both of these reactions lead to lower overall emissions, but mean completely different outcomes in a firm's operations. Figure 3 summarizes operative measures that can be taken. An OEM can in principle reduce weight, reduce air resistance and rolling resistance, and use more efficient transmissions and motors or bundle measures.

Short-term	Medium-term	Long-term
▪ Increase tire pressure ▪ Reduce vehicle height ▪ User more efficient transmission ▪ Reduce fuel consumption in idle running mode	▪ User more efficient tyres ▪ Use more efficient power steering ▪ Use automated idle running mode ▪ Improve motor efficiency ▪ Weight reduction by new materials ▪ Reduce air resistance by closing openings in vehicle's front ▪ Lithium battery ▪ Biofuels ▪ CNG ▪ Flexfluel Mild hybrid with NiMH batteries Full hybrid	▪ Total electrification ▪ Hydrogen fuel cell ▪ Battery support ▪

Figure 3: Measures to meet emission targets

[10] Sterman (2000), basic system behavior, s-shaped growth, p. 111
[11] Heavenrich (2006)

3 Literature review

There are a number of streams of literature that are relevant for the question presented. The development of the installed base of vehicles including demand and scrappage is of interest (a), alternative drivetrains' diffusion should be a topic (b), market structure and the interaction of firms and their customers (c), as well as macroeconomic influences like traffic generation and its emissions (d) are to be treated as well.

(a) Modeling the installed base of motor vehicles has especially in the U.S. a long tradition, cf. Mannering and Winston (1985) or Berkovec (1985). While the former treat primarily disaggregate new vehicle demand, the latter also includes the supply side as a manufacturer. Greenspan and Cohen (1999) model scrappage rates in order to estimate total new vehicle demand. Train and Winston (2007) examine the decreasing market share of U.S. manufacturers and find the main reason for these reductions in worse product performance compared to competitors.

(b) The diffusion of alternative drivetrains has been dealt with several researchers during the last years. Brownstone et al. (1994) develop a concept to forecast alternative drivetrain demand on simulation basis. Leiby/Rubin (1996/2000) focus on the transitional process from conventional fuels to alternatives. Christidis et al. (2003), Janssen (2005), Santini/Vyas (2006), Struben (2006), Bosshardt et al. (2007) all focus on the introduction of new drivetrain technologies and the market conditions needed to make the introduction sustainable.

(c) Firms‘ behavior and reaction to new market conditions has been a standard topic in SD modeling since Forrester (1961), coping with cooperation and competitiveness, supply-chain management, project management or human resources management. Sterman (2000) presents a number of examples on how to model market mechanisms. Warren (1999) develops strategies using a resource based view of the firm. SD has been used even for the implementation of interactive market simulation, cf. Hsueh et al. (2006). Besides these more generic examples, there are several more tangible examples of SD usage in industries, cf. Roberts (1978), Lyneis (1980/1998/1999), Sterman (2000/2007) or Schröter (2005).

(d) Modeling economic activity like production and traffic flows and the resulting emissions has been a tool for regulatory impact assessment in the EU for long years. The GAINS/RAINS[12] model focus on air pollution and the emission of greenhouse gases (GHG). TREMOVE[13] map the whole transportation sector of the EU including the total installed base of road, water, and air vehicles, their travelled distance and the resulting amount of fuel consumption. Traffic generation is modeled using models from micro-economics. ASTRA[14] and ESCOT[15] are SD-based macro-economic models to assess decisions in transport policy, and are regarding questions of sustainability.

[12] GAINS (2008)
[13] TREMOVE (2008)
[14] IWW et al. (2000)
[15] Schade/Schade (2005)

Automobile market	Diffusion of alternative fuels	Traffic and emissions	Business models
▪ Mannering/Winston (1985) ▪ Berkovec (1985) ▪ Hensher (1986) ▪ Greenspan/Cohen (1999) ▪ Train/Winston (2007)	▪ Brownstone et al. (1994) ▪ Leiby/Rubin (1996, 2003) ▪ Christidis et al. (2003) ▪ Santini/Vyas (2006) ▪ Welch (2006) ▪ Janssen (2005) ▪ Struben (2006) ▪ Bosshardt et al. (2007)	▪ RAINS (2008) ▪ TREMOVE (2008) ▪ ASTRA ▪ ESCOT ▪ MVSTAFF	▪ Forrester (1961) ▪ Warren (1999) ▪ Sterman (2000) ▪ Hsueh et al. (2006) ▪ Roberts (1978) ▪ Lyneis (1980, 1998, 1999) ▪ Schröter (2005) ▪ Sterman (2007)

Figure 4: Relevant literature

Within the scope of this contribution the core ideas of the models presented above are to be combined and adjusted to the questions of interest. Mapping the installed base of motor vehicles and its change over time is of high interest for assessment of overall impact of policies. The market entry of new products and detailed customer demand is to be analyzed. OEM's and customers' interaction are the basis for market developments. Such analyses are also necessary, in order to analyze possible reasons for adjusting market shares and the estimation of emissions from road transport. The overall model is presented in the next chapter.

4 Model overview

The purpose of our model is to evaluate an OEM's policies aiming at meeting new emission legislations' targets. A lot of research has been done to develop and evaluate technical solutions being able to reduce emissions. These efforts were successful insofar that there are a variety of options available now that can solve the OEM's short term problem. But so far, no one has analyzed the consequences of choosing one of those options or another not to mention the long term technology paths. From a policy maker's point of view this "operational" problem is not this important, because the outcome will be fewer emissions from vehicle operation. For a manufacturer, each decision ties resources and therefore reduces the number of future courses of action. This is how competition then can lead to a company's survival or death.

Endogenous parameters	**Exogenous parameters**	**Not included**
▪ Installed base of motor vehicles ▪ Number of vehicles per capita ▪ New vehicle sales, market shares ▪ Discards of old vehicles	▪ Number of potential customers ▪ Income ▪ Unemployment ▪ Preferences	▪ Different vehicle segments ▪ Different customer segments

- Vehicles’ attributes
- Emissions
- Production capacity
- Delivery delay
- Travel demand
- Fuel demand
- Population
- Retail
- Product pricing

Figure 5: System boundaries in the model

Since the situation is completely new and demanding, we are interested in a variety of effects, so we choose broad system boundaries. Given the conceptual strength of SD – incorporating models from different scientific disciplines – we are able to investigate different links between the automobile industry and close-by stakeholders. This way we incorporate important interactions between the manufacturer and the market. Following this holistic view the company’s activities are integrated into a basic model of the automobile market. We differentiate basically five sub-systems:

1. Manufacturing and retail in terms of an OEM and a generic retail structure,
2. The installed base of vehicles that is actually responsible for today’s emissions,
3. People, being OEMs’ customers as well as vehicle product users (= drivers),
4. Demand of travel and following vehicles and fuels,
5. Infrastructure being able to accommodate travel and fuel demand.

These modules are complemented by a small number of exogenous parameters which are chosen primarily due to reasons of simplification. For instance, the political process of regulation development shall not be treated here; therefore emission regulations in terms of threshold values or quotas are given exogenously. Income is more or less given by the overall economic situation, even though the automobile industry has a large impact as employer and tax payer. Discarded vehicles are not tracked. We assume that, if they leave the installed base they are completely out of order or cannot return. The amount of emitted matter is counted to get an impression of the overall environmental effectivity of a policy. All of the modules and parameters are linked by various causal relationships explained in more detail later on. The model structure is shown in Figure 6. A description what the modules contain follows.

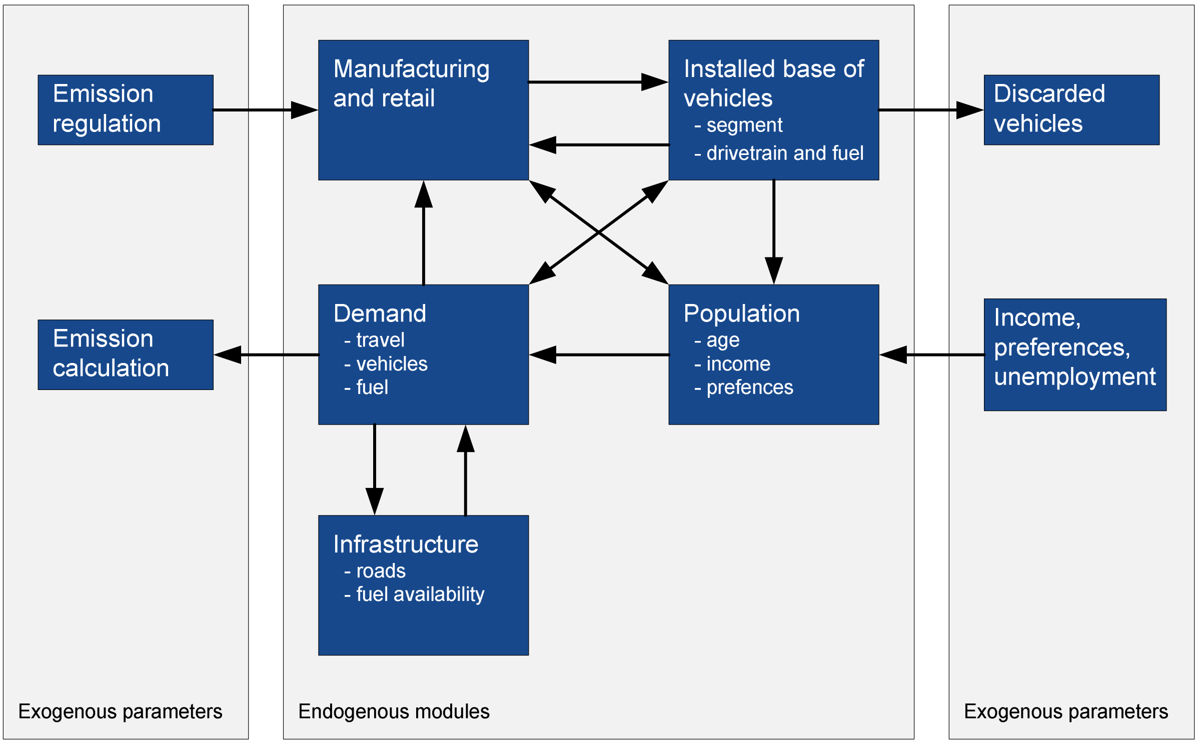

Figure 6: Model structure

4.1 Population module

Describing the population in a market is of special interest. Its structure determines demand of goods and services. OEM's potential customers and motor vehicle drivers are considered here being the same people and therefore modeled as one cohort of people. It makes sense to differentiate people that are not yet allowed to drive (the youngsters), and the ones not capable anymore (the elders). These three age-dependent cohorts form the most aggregated aging-chain still reflecting the population inherent age structure relevant for car ownership and usage. Age is in fact an indicator for annual mileage using motor vehicles.[16] Furthermore, income and personal preferences towards purchase decisions are incorporated, applying so called co-flows.[17] This way any attribute can be assigned to any age-cohort.

4.2 Installed base of vehicles

Since the amount of motor vehicles in use is the objective of all legislation aiming at emission reduction, it is a crucial task to model their aggregated structure in detail. The installed base of vehicles is modeled as a co-flow aging-chain[18], in order to track vehicles together with their attributes over their useful life. Vehicles are subdivided by segment, drivetrain technology, fuel, and age. Vehicle characteristics are tracked in order to estimate overall emissions and fuel consumption. The former allows control of the achievement of the legislation's goals, the latter is important for economic development and especially the development of new fuels such as ethanol or hydrogen.

Using such an aging-chain structure permits analyzing age-dependent effects. Obviously, the number of discards is such one. The older a vehicle gets, the more probable grows its discard.

[16] Litman (2008)
[17] Sterman (2000)
[18] Sterman (2000)

We differentiate between “engineering scrappage” and “cyclical scrappage”.[19] The former depends on wear and tear dependent on usage product quality. Empirical results from the U.S. as well as Europe show that newer model years have a longer lifespan.[20] One possible reason for this could be learning effects and the growing competition that makes quality an important purchasing argument. Cyclical scrappage is influenced by the general economic situation. Greenspan and Cohen (1999) select the unemployment rate as a proxy for this. Discarded vehicles leave the vehicle stock and are treated any further. Scrappage is a rough estimate of overall demand in saturated markets with low variation in population numbers. If these conditions are not met, a more detailed approach is needed.

4.3 Demand module

When people come into contact with cars they seem to get dependent, at least as long as they are able to afford it. This is even so in cities where public transport is available.[21] A growing population induces growing demand of travel and – depending on their income – a growing number of vehicles that pushes fuel demand. The demand module treats all these three demand endogenously. Demand for travel with motor vehicles is primarily function of income and cost.[22] There price and economic situation play a role. Beyond that, it is limited by road capacity. This is important to capture extreme conditions, such as extreme growth of population that would lead to a larger installed base of vehicles, given equal income.

Demand for fuel is dependent on the installed base and its average fuel consumption. Empirical results show that newer automobiles are drive more than older ones.[23] This effect is captured by the structure of the installed base model. Price elasticity of fuel is rather low; fuel is a rather inelastic good. However short and long term elasticity differ.[24] So price jumps have a larger effect at first until drivers adjust their driving behavior to the higher price. The relative inelasticity of fuel demand can be modeled as a reference price effect.[25] People react on a price change dependent on the ratio between the new price and the one they consider being fair. This reaction is highly elastic. After some time they get used to the new price, i.e. it becomes their new reference price.

Vehicle demand is modeled as the difference between desired vehicle ownership and the current installed base. Vehicle ownership is estimated by a Gompertz-function with per-capita income as dependent parameter.[26] The saturation level is a function of urbanization and population density.[27] Besides total demand of vehicles, an OEM is obviously interested in market shares as disaggregated total demand. They can also be considered as aggregated individual purchasing decisions.[28] Regarding the given situation the introduction of new vehicles – especially the ones with innovative technology – is of special interest. In the marketing literature aggregate diffusion models of product innovations are often used to

[19] Cf. Greenspan/Cohen (1999)
[20] Greenspan/Cohen (1999), EEA (2002)
[21] Cullinane/Cullinane (2003)
[22] Dargay et al. (2007)
[23] Hughes et al. (2006)
[24] Espey (1996)
[25] Fibich et. al. (2005)
[26] Dargay et al. (2007), Christidis et al. (2003)
[27] Dargay and Gately (2007)
[28] Train (2003)

model the developing market share of product innovations.[29] Though being able to map empirical purchasing patterns these models do not allow analyzing the reasons for the purchase decision. They do not allow, for instance, specifying the product in detail. It is possible to model that a product has been purchased from an ex-post point of view, but not why. For an ex-ante analysis of possible future developments purchasing behavior must be explained by causal relationships.

In order to capture the causal relationships of the purchasing decisions we use utility model from discrete choice theory[30], cf **Fehler! Verweisquelle konnte nicht gefunden werden.**. A product is then evaluated by a customer based on the products characteristics and the customer's preferences. Since purchasing decisions are never purely deterministic there is also some stochastic noised included in the utility calculation. In fact we use the so called logit model-family with independent and identically distributed stochastic terms. These are the most widely used model class in this area.

The overall product range is regarded by customers and the purchasing decision is then based on the product features. Automobile are durable rather expensive good. When purchasing a car customers make a multicriterial decision. Assuming utility maximizing but partly stochastic behavior discrete choice theory can be applied to model such a decision Train and Winston (2007) find in their study that purchase choice is basically dependent on brand loyalty, automobile dealerships and the following product attributes: Price, size, power, operating cost, transmission type, reliability, and body type.

Considering especially new technologies a purchase is not only influenced by a product's utility but at least as much by the customers' awareness that it exists. After market introduction marketing measures will boost awareness for a while, though it will not reach all potential buyers. After the product is bought by some early adopters, it will attract attention on the road due to its newness.[31] Together with word-of-mouth effects, product adoption can turn into a reinforcing feedback-loop that is constrained by a maximum possible market share,

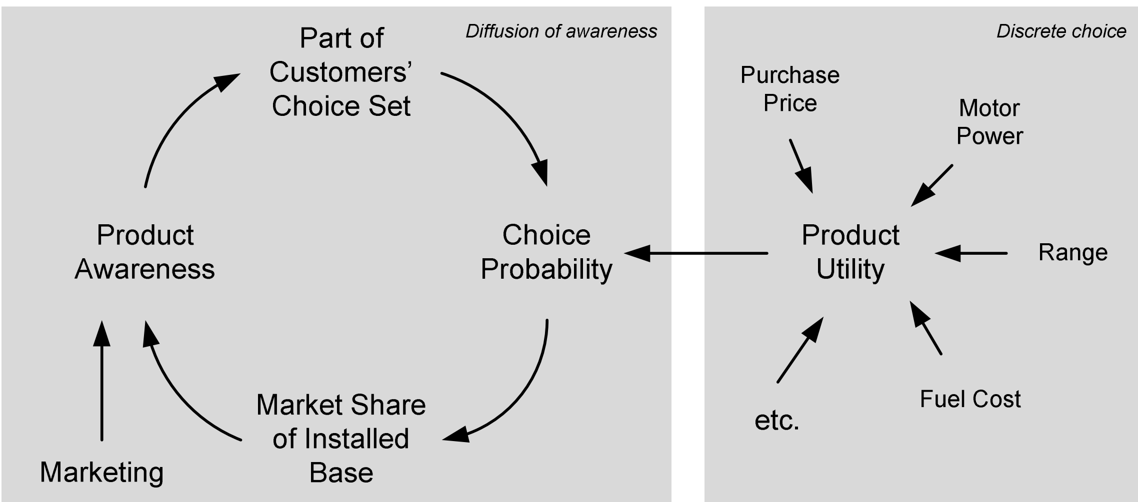

Figure 7: Purchasing decision based on product awareness and utility

[29] Bass (1969)
[30] E.g. McFadden (1974)
[31] Kalish (1985)

Two examples will exemplify these mechanisms. Volkswagen offered a small passenger car consuming only three liter fuel for 100 km. It was quite famous for this extremely good efficiency, media attention was high. But its rather negative image as “eco-car” and the rather high purchase price compared to other vehicles of its size reduced its formal utility following in low purchasing probabilities. Market share stayed low so that production had to be finished. Diesel driven passenger vehicles, on the other hand, faced hard times for a long period. Though being advantageous in many ways, especially for long range drivers, low profile made it impossible to attract customers. Improved technology has lead then to better reports and better sales figures for the last years.

4.4 Infrastructure

Roads are the most obvious infrastructure needed to operate motor vehicles. Their capacity determines a limit of motor vehicle utilization. The higher the capacity the faster vehicles can drive. On the opposite, if there are too many vehicles on roads, congestion will occur, i.e. speed will slow down so other modes of transportation may get more attractive. While in developing countries much road capacity is under construction due to the growing number of vehicles, in developed countries stagnating capacities can be observed.[32]

The development of fuel stations is especially interesting for the introduction of alternative drivetrain technologies. Their opening depends on future expected demand for this fuel that is dependent on current market shares. In order to spread alternative fuels, both vehicle base and fuel availability have to develop simultaneously.[33]

4.5 Manufacturing and retail

Several parameters can be directly influenced in order to reduce fleet emissions: the new product supply in terms of product attributes and volumes, product quality, production capacities, production rates, and retail price. An OEM produces what he perceives as being probably successful in the market. The only constraint is legislation setting product characteristics and cost. Information about purchase decisions can be collected at the point of purchase (at the retailer) and will be fed back into the OEM deciding afterwards in which segment to produce, how many different models to offer and what configuration those should have.

The production volume is assumed to depend on forecasted demand with regard to regulatory requirements regarding fleet emissions. Production capacity must be adjusted for each segment. The forecast based target capacity is incorporated after a delay. The market is not assumed being in equilibrium, so under- and over-capacity are allowed. Variable and fixed production costs are considered, being dependent on production capacity and production rate incorporating learning effects and economies of scale. Prices are adjusted due to the desired capacity utilization, the target sales rate, and compensations for producing expensive highly efficient cars, but it will not be set less than variable production costs.

[32] Litman (2006)
[33] Struben/Sterman (2007)

Since customers usually buy at retail stores this part of the supply-chain is incorporated in the model, too. The retailer orders due to current sales figures and adjusts the product price if stock is too high. On the other hand, customers will not wait for a product if it is not available.

5 Model validation

Validation is a crucial aspect in any modeling approach.[34] Besides assuring the model quality we can gain first insights into our work. Since empirical data is not available we focus on validation of structure and behavior.[35] Structural validity is assured by asking experts, decision makers, use empirical analyses of the causal relations or literature studies. The parameters have their equivalent in reality.[36] State and flow variables have to be chosen carefully depending on the overall goal of the study. We follow a rather theoretic approach, so variables are also checked by literature review. The model's reactions have to consistent with several inputs. So called stress tests give a good overview of reasonable stock behavior. We found no discontinuities or during these tests, the direction of reactions followed our expectations. Low product awareness lead to low purchase probabilities, for instance, even if product attributes are competitive. Variation of utility parameters had seemingly correct effects, too.

6 Basic strategies of emission reduction

As demonstrated CO_2 reduction is to be tackled by OEMs directly and without waiting any longer. The EU's new legislation (fleet average reduction), allows for a lot of options. The two most basic ones are reducing emissions of each offered model equally and introducing extremely efficient eco-models. Both can have the same effect on average emissions but the process of introduction and the consequences for the firm's operations differ a lot.

The automobile market is highly segmented and large OEMs offer several models per segment.[37] If each offered model is to get more efficient there is an equal number of development tasks to be done. This drives cost that can hardly be compensated. Economies of scale help to decrease costs, but for some time each model's margin will be low depending on the segment the model is offered. Emission goals on the other hand are certainly achieved, since the desired reduction percentage is solely dependent on the OEM, not on sales numbers. The overall efficiency gain may also be advantageous facing rising fuel prices. The customer does to have to decide explicitly for a "green" product in this case, but only considers normal preferences.

In order to avoid the efforts of changing the whole product line "green" models of extreme high efficiency can be developed. In a simple case it is one such model per segment. If this model is sold in certain numbers it will influence the fleet's average emissions. Introducing explicitly efficient models works in many ways differently that the first approach. One single eco- model may serve as technology testing platform. Its costs can be compensated by the

[34] Sterman (2000), Barlas (1996), Coyle /Excelby (2000)
[35] Liehr (2004), Sterman (2000)
[36] Barlas (1996)
[37] Becker (2005)

other non adjusted models that margin is still high. Furthermore, a positive "green" image caused by such a model may spillover on the brand's whole product line. Difficulties can be expected from the more uncertain planning situation. Expanding the product line means more complexity in production operations, boosting costs. Marketing efforts are needed, at first to introduce the new model that may be considered inferior to the in-house competitors (at least as long as motor power is wanted more than fuel efficiency). After that sales numbers have to be generated to achieve the emission goal always considering that a too high market share would cut margins that should be compensated by the conventional models. If customers really like the new product more than expected demand would exceed production capacity leading to long waiting times that may be bad for reputation. Capacity would have to be adjusted and in the end prices for the other models could decrease, because production capacity is fixed in the short run. Another model competes against all the others in the product line effectively.

7 Implementation and outlook

A generic motor vehicle market model has been presented with a broad focus on manufacturer's activities. This model can be in principle adjusted to any market, allowing an OEM flexible use of it. It has been developed in cooperation with a German OEM in order to investigate consequences of latest EU emission regulations. Basic adjustment strategies to latest emission regulations were tested. The influence on several stages of the supply chain like production capacity utilization or marketing measures have been tracked and visualized. Analyzing effects on purchasing behavior as well as on internal processes we developed a deeper understanding of the challenges the manufacturer faces.

Against the background of a dynamic, complex, and unstructured problem with numerous causal relationships, feedback, non-linearities and delays to be considered SD is an appropriate method to get better insight into the problem. Several enhancements are underway. Different customer segments will be represented to see how their reaction interacts and interfere. Furthermore, the OEM's research and development activities will be taken into account.

8 References

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. System Dynamics Review, Bd. 12, Nr. 3, S. 183 – 210.

Bass, F.M. (1969). A New Product Growth For Model Consumer Durables. Management Science. Vol. 15, No. 5. pp. 215-227.

Becker, H. (2005). Auf Crashkurs - Automobilindustrie im globalen Verdrängungswettbewerb. Springer.

Christidis, P.; Hidalgo, I.; Soria, A. (2003). Dynamics of the introduction of new passenger car technologies: The IPTS transport technologies model. Online: http://www.jrc.es/publications/pub.cfm?id=1107 (2008/03/15)

Coyle, G.; Exelby, D. (2000). The validation of commercial system dynamics models. System Dynamics Review. Vol. 16, No. 1, pp. 27-41.

Cullinane, S.; Cullinane, K. (2003). Car dependence in a public transport dominated city: Evidence from Hong Kong. Transportation Research Part D 8:129-38.

EEA (2002). TERM 2002 33 EU – Average age of the vehicle fleet. Online publication: http://themes.eea.europa.eu/Sectors_and_activities/transport/indicators/technology/TERM33%2C2002/TERM_2002_33_EU_Average_age_of_the_vehicle_fleet.pdf

Espey, M. (1996). Explaining the variation in elasticity estimates of gasoline demand in the United States: A meta-analysis, Energy Journal. Vol. 17, no. 3, pp. 49-60.

EU (2007), Reducing CO2 emissions from light-duty vehicles, Online unter http://ec.europa.eu/environment/co2/co2_home.htm (2008/03/01)

Fibich, G.; Gavious, A.; Lowengart O. (2005). The Dynamics of Price Elasticity of Demand in the Presence of Reference Price Effects. Journal of the Academy of Marketing Science, Vol. 33, No. 1, p. 66-78

Dargay, J.; Gately, D.; Sommer, M. (2007). Vehicle Ownership and Income Growth, Worldwide: 1960-2030. In: The Energy Journal, Vol. 28, No. 4, 2007 (forthcoming), online: http://www.econ.nyu.edu/dept/courses/gately/DGS_Vehicle%20Ownership_2007.pdf (2008/01/03)

GAINS (2008). Model description. Online: http://www.iiasa.ac.at/rains/gains/model%20description.html (2008/03/01)

Greenspan/Cohen (1999). Motor vehicle stocks, scrappage, and sales. The review of economics and statistics

Heavenrich, R. (2006). Light-Duty Automotive Technology and Fuel EconomyTrends: 1975 Through 2006, U.S. EPA. Im Internet: http://www.epa.gov/otaq/cert/mpg/fetrends/420r07008.pdf

IPCC (2007). Fourth Assessment Report. Available online: http://www.ipcc.ch/ipccreports/ar4-syr.htm

IWW, TRT, ME&P, CEBR (2000): Endbericht des Forschungsprojektes ASTRA (Assessment of Transport Strategies) im Auftrag der Europäischen Kommission. Karlsruhe.

Kalish, S. (1985). A New Product Adoption Model with Price, Advertising, and Uncertainty. *Management Science*, Vol. 31, No. 12. , pp. 1569-1585.

Liehr, M. (2004). Komponentenbasierte Systemmodellierung und Systemanalyse – Erweiterung des System-Dynamics-Ansatzes zur Nutzung im strategischen Management. Deutscher Universitäts-Verlag / Gabler Edition Wissenschaft

Litman, T. (2006). Changing Travel Demand: Implications for Transport Planning, ITE Journal, Vol. 76, No. 9, pp. 27-33.

McFadden, D. (1974). The Measurement of Urban Travel Demand. Journal of Public Economics, 3, pp. 303-328.

Schade, B.; Schade, W. (2005). Evaluating Economic Feasibility and Technical Progress of Environmentally Sustainable Transport Scenarios by a Backcasting Approach with ESCOT, in: Transport Reviews, Volume 25, Number 6, Number 6/November 2005 , pp. 647-668.

Schelling, T.C. (1984). Choice and consequence - Perspectives of an errant economist, Harvard University Press, 1984.

Sterman, J. (1989). Modeling managerial behavior: misperceptions of feedback in a dynamic decision making experiment. Management Science 35/3, S. 321-339.

Sterman, J. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill

Stern (2006). *Stern Review on the Economics of Climate Change.* http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm (2008/03/19)

Struben, J.R.; Sterman, J. (2007). Transition Challenges for Alternative Fuel Vehicle and Transportation Systems. MIT Sloan Research Paper No. 4587-06. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=881800 (2008/03/10)

Train, K.E. (2003). Discrete Choice Methods with Simulation. Cambridge University Press.

Train, K.E.; Winston, C. (2007). Vehicle choice behavior and the declining market share of US automakers. In: International Economic Review, Bd. 48 Nr. 4, S. 1469-1496

TREMOVE (2008). Model documentation on the project website. Online: http://www.tremove.org/documentation/index.htm (2008/03/14)

UNFCCC (2007a). Emissions Summary for European Community (15). Im Internet http://unfccc.int/files/ghg_emissions_data/application/pdf/euc_ghg_profile.pdf (2008/02/20)

UNFCC (2007b). Emissions Summary for United States of America. Im Internet http://unfccc.int/files/ghg_emissions_data/application/pdf/usa_ghg_profile.pdf (2008/02/20)