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PROACTIVE DEMAND AND CAPACITY MANAGEMENT FOR AUTOMOTIVE LOGISTICS USING AN EFFICIENT INFORMATION MODEL

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ABSTRACT
The increasing technical complexity of cars and the high number of offered options lead to new challenges in the automotive industry and especially the mid-term demand and capacity management (DCM). This requires a procedural adaptation based upon an efficient information model. In this contribution, the state of the art is analysed for both the DCM process and the underlying information models. Promising concepts for managing the steadily increasing requirements in DCM are deducted, and a modular process kit for the procedural adaptation combined into the concept SmartDCM is introduced. Additionally, a new approach of an efficient information model for managing the increasingly complex information is presented.

Keywords: automotive demand and capacity management, information model

1. INTRODUCTION
Technological developments in the automotive industry are increasingly complex (Nagel 2011). They are influenced strongly by continuous derivatisation and an ongoing shortening of the product life cycle (PLC) (Filla and Klingebiel 2014, Hegner 2010, Romberg and Haas 2005). The resulting technical complexity of cars and the decreasing time-to-market lead to a reduced development time (Filla and Klingebiel 2014, Kuhn et al. 2002). Moreover, the possible combinations of different options, which are offered to customers, often account for more than 10^{32} available variants of middle-class cars - roughly the same number as atoms in the human body (Meyr 2004). The amount of data to handle all variants is considered unmanageable (Liebler 2013).
Over the past 30 years, automotive suppliers have taken power over the automotive manufacturing process (Wong 2017). The share of value-added by automotive suppliers in global automotive manufacturing has increased from 56% in 1985 to 85% in 2015 (Wong 2017). The product complexity, in combination with the reduction in vertical integration, leads to a strong dependence of original equipment manufacturers (OEMs) on their supplier networks (Klug 2010). Foresighted planning is of central importance in a global and resource-optimised value chain. The critical process is the demand and capacity management (DCM): capacities are aligned with demands to avoid later bottlenecks that cause expensive capacity adjustments or production breakdowns (Askar 2008). DCM has to adapt to the changes in external and internal conditions.
This contribution presents the modular process kit SmartDCM supporting a proactive and event-oriented production program evaluation as a key step in the automotive DCM. The concept is based upon a new information model, which effectively transparently unites all required information.
The paper is structured as follows: all relevant terms and concepts, including the automotive DCM process as well as present challenges, are introduced in section 2. The related state of the art and the research gap will be presented subsequently. Section 3 presents a proactive, event-driven approach to DCM and the underlying information model. The paper concludes with the description of the ongoing implementation in industry and an outlook on further research.

2. THE AUTOMOTIVE DCM
This subsection gives an overview of the current management process, the challenges and the state of the art in automotive DCM to deduce the research gap.

2.1. Automotive DCM Processes
Automotive DCM planning process at OEMs can be classified using the Supply Chain Planning Matrix (SCPM): the matrix allocates the planning tasks vertically by planning horizons and horizontally by responsibilities of the OEM departments involved (Dörmer 2013, Fleischmann et al. 2015, Rohde et al. 2000, Schuh and Stich 2012). The automotive planning cycle typically starts with cross-functional strategic network planning. This long-term view typically includes uncertainties (Volling 2009), as the risk of temporary discontinuities in the material supply or the production process tend to make over-deterministic planning unsuitable (Liebler 2013). To handle the increasing number of car models and variants, strategic

decisions can only provide the basis for the subsequent more detailed planning tasks in the mid-term horizon. The target of mid-term production planning is the optimisation of personnel and plant capacities. The primary customer demand for the next 12 to 24 months is forecasted in terms of volumes and customer selectable options (in the form of so-called option quotas). The later customer demand depends on the specific configuration of ordered cars. This aggregation reduces the existing complexity (Dörmer 2013, Volling 2009) and results from the possible forecast quality in the mid-term horizon (Dörmer 2013, Volling 2009). Changes in planned demand are triggered by general trends (e.g. urbanisation), scandals or political decisions (e.g. "diesel gate").

Subsequently, DCM processes ensure the availability of materials and resources for the mid-term production plan, even if specific material requirements are difficult to be determined from the aggregated planning volumes (Pawlikowski et al. 2017). If necessary, DCM proposes and initiates capacity adjustments to minimise costs for production, warehousing and human resources (Stadtler 2004). Like this, DCM acts as an essential interface between market demand, production and supply chain capacities (Arnold et al. 2008, Krog et al. 2002). Demand and capacity asynchronies are identified, and appropriate countermeasures are implemented in a reasonable time frame (Pawlikowski et al. 2017).

Then, internal negotiations are usually held in monthly sales meetings to adopt the production program to still necessary changes (Herold 2012). The aggregated procurement plan, production and transport capacities are derived from the identified production demand (Rohde et al. 2000). The result is a plant-dependent production schedule for volumes of defined product groups for each production week in the planning horizon (Dörmer 2013). Economic aspects should be taken into account in these processes (Barthel 2006), but feedback on the economic viability of capacity adjustments is not considered in the mid-term planning (Dörmer 2013).

In contrast, the later following short-term production planning uses customer orders. This deterministic primary demand can be used for the first time for a detailed demand calculation (Liebler 2013).

2.2. Challenges of the Automotive DCM

When central processes, structures and resources are fragmented and geared towards decentralisation, agility and speed (Gehrke 2017, Hompel and Henke 2014), production planning needs to become more flexible, too. For example, the current DCM process is no longer able to cope with the large number of planning impulses and the complexity of demand and capacity information. There is a need for a proactive and event-oriented evaluation of automotive production programs which shall be detailed in the following.

A highly complex set of technical rules describes the compatibility of car models and their potential options. Most of these options can be selected by the customer. Others are driven by marketing considerations, legal and political country-specific requirements and internal restrictions. The technical rules can prohibit or force options for certain models (e.g. no sports seats for a basic model). Because of dependencies among the options, the smallest change in the planned production program may affect greatly the part requirements and associated capacity utilisation of suppliers and other resources.

Moreover, after 125 years, car and drive concepts are fundamentally changing (Kampker et al. 2013). Alternative powertrain technologies are designed to reduce emissions. Electric mobility leads to changes in car architecture and product structure. Additional car variants are introduced within the short to mid-term period to react to changing market demand. At the same time, cars are increasingly connective and become more and more digitised by assistance systems (Gärtner and Heinrich 2018). Especially, the integration of intelligent assistance systems leads to a radical increase in the complexity of parts and car variants (Kampker et al. 2016, Krumm et al. 2014), resulting in a new complexity in the automotive DCM process.

Automotive product life cycles (PLC) amount to about seven years. Assuming a development time of three years, technologies used at the end of the PLC are ten years old (Kampker et al. 2017). Considering the rapid technological development of electronic components, PLCs in the automotive industry are far too long and will have to become shorter (Bundesregierung 2018). The developed markets are increasingly demanding customised products and solutions (Ehrenmann 2015) that adapt to new technological developments during the automobile PLCs. Today, OEMs are incentivised to upgrade electronic functions, components, parts or include numerous new parts within the PLC. In some cases, relationships with new supply chain partners arise (e.g. Apple or Google). On the one hand, the car is continually being redefined as a product, and the entire value chain must continually adapt to these changes (Kampker et al. 2013). On the other hand, it results in greater market dynamism and less predictable customer requirements in the mid-term. A significant flexibilisation of the entire value-added network is required to cope with these challenges.

The processing times for feedback on a production plan or a change within are currently in the range of several weeks. The current DCM process is only slightly automated today and characterised by many participants, iterative planning rounds and data distributed across many systems (MS Excel, SQL-DBs, flat files, etc.). The result is an increasing overload of the responsible human planners, an increasing frequency of bottlenecks as well as the associated costs. The example of a BMW bottleneck in 2017 illustrates how great the threat of a loss in quality and the associated loss of image is (Tagesschau 2017). In sum, the current DCM process is too static, too poorly digitalised and too slow for future automobile production. A more proactive, flexible and fast DCM process and a suitable DCM IT support are necessary.

A suitable degree of automation combined with the support of intelligent planning procedures allows the human planner to plan quickly and validly in an environment of high uncertainty. Today, as a result of the long planning cycles, there is no iterative feedback loop installed between the production plan based on the sales forecast and the production program planning in the mid-term. A real-time capacity check of planned production programs (like a pre-audit) will improve the quality of mid-term production planning by proactively identification of critical capacities.

An integration of continuous iterative feedback loops may increase the economic outcome of the production program when bottlenecks can be identified and avoided proactively. When determining costs for the capacity adjustment, it must be ensured that only the relevant costs are taken into account (Gottschalk 2005) which result from the comparison of planning scenarios (Ewert and Wagenhofer 2008). Costs of capacity adjustments include costs directly related to the provision and use of capacity flexibility (Gottschalk 2005). Additionally, opportunity costs must be considered (Kilger et al. 2012), as a possible profit could probably have been achieved if the capital employed for the measures had been used for a purpose other than that (Gottschalk 2005). An example is the lost contribution margin of car options of which the share decreases as a result of a supply bottleneck (Maiworm 2014). For decision support in medium and short-term sales planning, price limits (Kilger et al. 2012) can be applied for the acceptance of additional orders.

But DCM processes can only be accelerated if the relevant information is fully available in real-time. A prerequisite is the consistency and transparency of all DCM-relevant information.

2.3. State of the Art of the Automotive DCM

A review of relevant literature regarding automotive production program evaluation in the mid-term horizon has been conducted. The aim was to deduct the research gap clearly and understandably using a structured method by Webster and Watson (2002). The research has been based on the keywords "production planning", "capacity planning", "planning systems", "optimisation", "flexibility", "supply chain management", "the automotive industry" and "production and logistics". A total of 43 relevant publications have been identified. The concepts have been allocated to the planning concepts of the SCPM and been classified into the different horizons. Figure 1 shows the resulting classification of concepts.

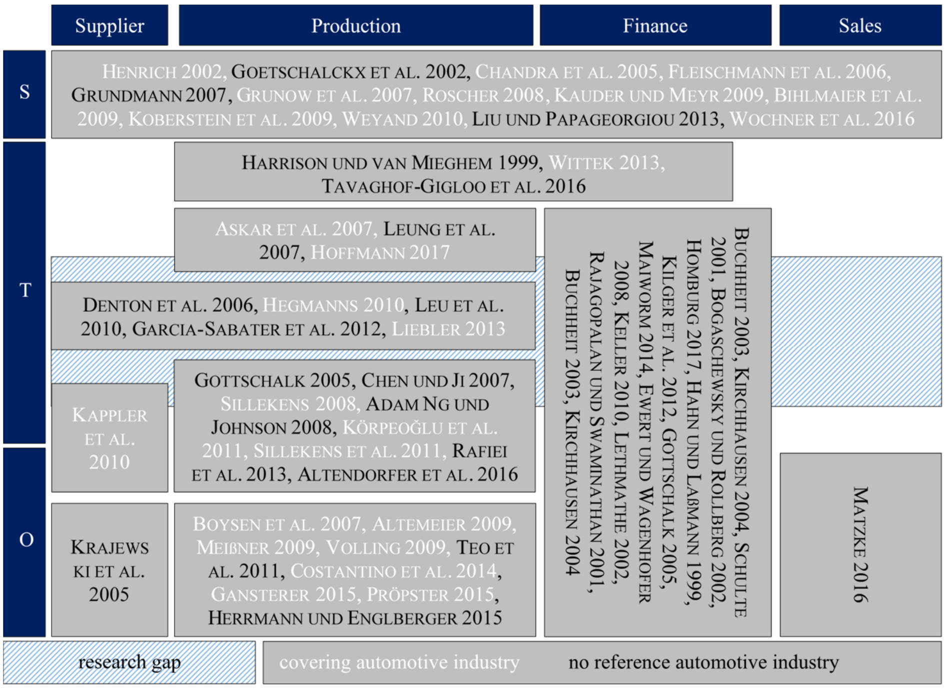

Figure 1: Research gap from the DCM in the mid-term horizon

13 of the 43 authors have been assigned to the strategic horizon, where distributive and capacitive factors of the cross-functional strategic network planning and product allocation are focused. The authors Grunow et al. (2007), Bihlmaier et al. (2009), Koberstein et al. (2009), Liu and Papageorgiou (2013) and Wochner et al. (2016) investigate the collaboration of distribution and production. Goetschalckx et al. (2002), Fleischmann et al. (2006) and Kauder (2008) examine a more holistic perspective and integrate all business areas except sales. Henrich (2002) presents an automotive model for strategic planning for an entire supply chain. The production in the strategic horizon is the focus of the publications of Chandra et al. (2005), Grundmann (2007), Roscher (2008) and Weyand (2010). The authors in the mid-term horizon mainly focus on the OEM production. Only Kappler et al. (2010) work on suppliers and sales by presenting a robust calculation method for determining part requirements using ranges (Kappler et al. 2010). Denton et al. (2006), Leung et al. (2007), Leu

et al. (2010), Körpeoğlu et al. (2011) and Rafiei et al. (2013) analyse the make-to-stock production. The authors Gottschalk (2005), Chen and Ji (2007), Adam Ng and Johnson (2008), Altendorfer et al. (2016) focus the tactical production planning but lack the specifics of the automotive industry. The authors Hegmanns (2010), Garcia-Sabater et al. (2011) and Liebler (2013) provide a holistic view on the mid-term horizon and, in addition, consider production, distribution and suppliers. Askar et al. (2007), Sillekens (2008), Sillekens et al. (2011), Hoffmann (2017) and Tavaghof-Gigloo et al. (2016) focus on the capacities of a production line.

Eleven authors have been assigned to the operative horizon. They focus on the production area of the company and deal with ascertained customer orders and not with demand forecasts or plans. Only Gansterer (2015) and Herrmann and Engelberger (2015) do not rely on orders but examine the transition from tactical to operational horizons. The authors Boysen et al. (2007), Altemeier (2009), Costantino et al. (2014), Pröpster (2015) and Matzke (2016) deal with the capacities of assembly teams. Krajewski et al. (2005), Volling (2009), Meißner (2009) and Teo et al. (2011) evaluate capacity adjustments.

Literature shows that it is not possible to deterministically validate demand plans within the mid-term production planning since the secondary demand can only be determined precisely with specified customer orders. However, for reasons of economy, sales and mid-term production planning are being carried out with a high degree of aggregation. Based on the literature review, there is a need for a new procedural concept which supports the event-oriented review of the production program. The literature review revealed no such concepts. Against the background of increasing market dynamics and globally linked supply networks, it is necessary to present a more integrated and dynamic concept for DCM. Therefore, an integrated, efficient information model is needed. Thus, the following section analyses the state of the art of automotive information models.

2.4. State of the Art of Automotive Information Models

Today, relevant data of automotive logistics is typically kept in several systems using relational data structures. However, a transparent and efficient information model is the key for DCM processes to assess the availability of automotive components. This information model has to depict all dependencies between parts, components and car features in a structured way (Fruhner et al. 2018). An elemental part of this information model is the product structure, which represents a structured form of the product and its components (Schuh and Riesener 2018). However, information on the dependence of planned model volumes, option quotas and material items is also needed as DCM processes synchronise market requirements with capacities and constraints of the supply chain and production system. A detailed analysis of information models in the automotive industry has been conducted in Fruhner et al. (2017). The analysed information models have been evaluated against these requirements which have been identified based on future challenges in the automotive industry: *Integration of new dependencies*, *Integration of cross-functional Information*, *Modularity*, *Management of Comprehensive Data*, and *Transparency* (Fruhner et al. 2017).

The literature review showed that approaches based on relational data structures quickly lead to poor transparency and redundancies as the data is distributed over several database systems (Bockholt 2012). A Design Structure Matrix (DSM) as proposed, for example, by Deng et al. (2012) or Kashkoush and ElMaraghy (2016) could support the representation of complex multidimensional and cross-functional automotive data. However, a DSM only allows to illustrate simple one-dimensional relationships. It is not possible to append additional cross-functional data, as its tabular structure easily becomes intransparent (Kissel 2014). Only similar relationships between two components can be mapped by semantic networks. No kind of hierarchy or at least an overall view can be integrated. Therefore, in complex data environments, the transparency is limited (Yang et al. 2012). Tree structures which have, for example, been presented by Kesper (2012) and Schuh (1988, 2018) do not offer modularity natively. However, an approach with evolving part/product families has been introduced by ElMaraghy et al. (2013). Moreover, it should be noted that tree structures can become very complex (Kesper 2012). With its hierarchical concept, the approach of Vegetti et al. (Vegetti et al. 2011) is a promising development. Two or more components can be joined together and form a more complex (sub-) assembly within the more general graph structure (Luo et al. 2016). Modularity is also supported in this way. Riggs and Hu (2013) introduce a precedence graph for disassembly, which is an especially enhanced graph structure.

Due to the findings of the literature review, a concept based on graph structures (including approaches of ontologies and semantic networks) is most suitable, as graph structures meet the requirements best.

3. INTRODUCTION OF AN APPROACH FOR PROACTIVE AND EVENT-ORIENTED PRODUCTION EVALUATION

A simplified but digitised, proactive DCM planning process is needed. Moreover, an efficient information model, which contains all relevant information, is required. Only the combination of both concepts might exploit the full potential. This section gives an overview of the concept SmartDCM and the new approach for an efficient information model.

3.1. A Modular Process Kit for SmartDCM

The developed qualitative research design addresses the empirical research gap in the automotive DCM and serves to derive the process modules needed for a proactive automotive DCM. It is based on data analysis of 48 guideline-based expert interviews at a plant of a German OEM with private and business customer segments which applies triangulation by combining two methods: the deductive category assignment is supplemented by inductive category formation. According to Mayring (2016), this triangulation improves the quality of research results compared to only one methodical approach. Transcribed text passages of the interviews that could not be assigned to a deductive category have been grouped into inductive categories according to predefined criteria. Three encoders have ensured the quality of the data evaluation in the deductive and inductive coding process. The need for a fast assessment of mid-term production programs to secure the supply of parts and incremental financial change has been validated. In short, it was revealed that an iterative feedback loop between the sales department and capacity providing departments dramatically increases the reaction time. To develop a holistic approach, the processes from literature have been enhanced by the identified requirements of entrepreneurial practice. It could be deduced, that the central vulnerability of today's DCM is reflected by the program approval that is not based on a detailed capacity check: the determination of requirements takes mostly place afterwards. Valuable empirical findings contribute to an application-oriented development of an event-oriented mid-term evaluation of the automotive production-planning program. Table 1 shows the developed modular process kit.

The process kit is divided into three thematic clusters: production program planning, capacitive evaluation and monetary evaluation.

The first thematic cluster production program planning contains nine process modules. The identification of the market requirements takes external parameters and trends into account. The internal requirement identification focuses on the existing restrictions within the OEM's internal production network. Subsequently, the primary requirements planning is carried out as proposed in literature. A comparison is made between the market requirements and the internal requirement identification to determine the production oriented sales planning. The process module for enriching the mid-term primary demand is an alternative to the forecast-based rough planning of resources. It provides the basis for the detailed capacity check of purchased and manufactured parts, containers and OEM internal resources for the mid-term horizon.

The second thematic cluster capacitive evaluation contains eight process modules. The determination of the secondary demand is a relevant process step as proposed by literature. The production requirements planning contains the process steps procurement model assignment, inhouse production planning and external procurement planning. The detailed capacitive evaluation includes capacitive checking within the OEM's internal production network as well as balancing of capacities for purchased and manufactured parts and containers. The capacitive adjustment evaluation relies on relevant information such as marginal cost and capacities, lead times and throughput times for all known measures. If a capacity adjustment is not possible, customer demand may be controlled by demand management. To enable the iterative feedback loop, the capacitive feedback from these processes must be reintegrated into primary demand planning. Finally, the assessment of the overall security of supply summary of the production program takes all capacitive adjustments into account.

Table 1: Modular process kit for a proactive DCM

category	required process modules			
production program planning	PM1	external requirement identification		
	PM2	internal requirement identification		
	PM3	primary requirements planning		
	PM4	analysis of existing restriction		
	PM5	determination of production oriented planning		
	PM6	event-driven production program changes		
	PM7	production program enrichment		
	PM8	production program summary		
	PM9	production program release		
capacitive evaluation	PM10	secondary requirements planning		
	PM11	production requirements planning		
	PM12	interplant capacity evaluation		
	PM13	detailed capacity evaluation	a	internal production plant
			b	purchased parts
			c	manufactured parts
			d	container
	PM14	capacitive adjustment evaluation	a	internal production plant
			b	purchased parts
			c	manufactured parts
			d	container
	PM15	demand management	a	internal production plant
			c	manufactured parts
	PM16	capacitive feedback		
	PM17	security of supply summary	a	internal production plant
			b	purchased parts
			c	manufactured parts
			d	container
monetary evaluation	PM18	contribution marging determination		
	PM19	capacity adjustment costs determination		

The third thematic cluster monetary evaluation includes the financial evaluation and total feasibility check. For a financial comparison of a production program with its predecessor, the respective contribution margins are offset against each other after deduction of relevant costs incurred. To determine the contribution margin, the net cost of sales must be compared with the actual revenue of the planning period by summing up all product types (Hahn and Laßmann 1999, Kilger et al. 2012). Changes in the model mix, option mix or market distribution of the car volumes to be produced can have a positive or negative impact on the contribution margin of the production program.

Figure 2 visualises the proactive DCM process based on the modular process kit. The validation of the process kit is based on workshops to verify the research outcome with the interviewed experts. The workshops took place within each interviewed department at the OEM to ensure the correctness of the process modules within the process kit and to derive requirements for an efficient and user-friendly application development. Underlying requirements are, for example, appropriateness for the task, self-descriptiveness, identification and elimination of faulty customizability and controllability (Deutsches Institut für Normung 2008, Schneider 2008). The appropriateness for the task helps users to do their job effectively and efficiently. The self-descriptiveness ensures that each dialogue step is immediately understandable and that it is explained to the user on request. It is necessary to ensure the identification and elimination of faulty inputs with minimal correction effort as some data is entered by the users themselves (Krcmar 2015). The customizability allows adapting to user-specific needs, such as the choice of the preferred language or the reading direction from left to right. The controllability allows the user to initiate the dialogue process and to influence its direction and speed. To ensure the device-independent applicability of the SmartDCM, a web-based implementation has been recommended.

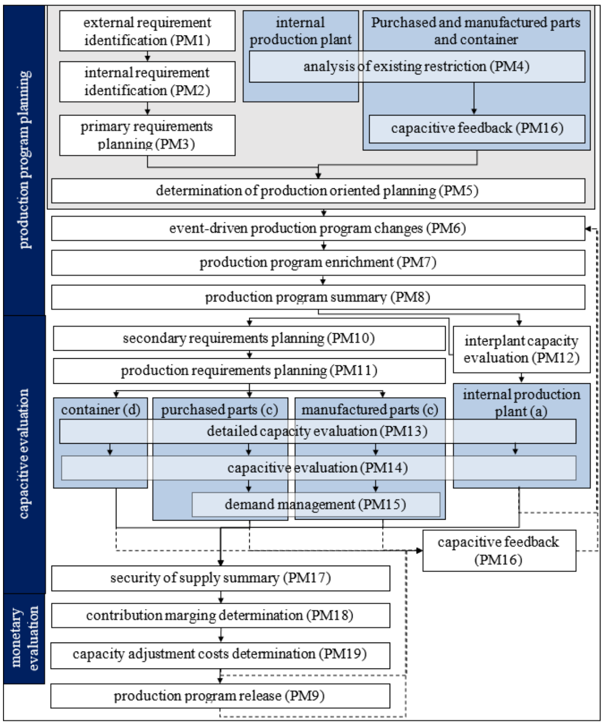

Figure 2: Process for a proactive DCM

3.2. Information Model for Automotive DCM

To implement the described new SmartDCM process, a new information model is needed, which holistically depicts the required information. The literature review revealed that DSMs, even if valuable in development, are not eligible for DCM and its complex cross-functional information. Especially semantic networks, tree structures and generalised graph structures have proven to be promising candidates for a new generation of information models. A graph structure has been chosen as the basis for SmartDCM, as it fulfils the requirements for a future-oriented information model (e.g. parallel component development).

As a next step, it was necessary to analyse what the information model used in the SmartDCM has to contain. For this purpose, data of two middle-class series of a German OEM have been analysed.

Each model of both car series can be sold in several markets, where each market has its own legal rules and customer preferences. Therefore, it is important to differentiate not only between models but also between model-market-combinations.

Each option is typically assigned to an option family (O-Family). This helps, for example, to avoid invalid configurations (e.g. two radios). In DCM processes, the planned volumes of car models and quotas of options are analysed to rule out asynchronicities. In case of a shift in demand, typically model volumes and option quotas are modified in synchronity. So, it is necessary to integrate the volume for model-market-combinations into the information model. All allowed options and the associated option families must also be mapped as well as the planned quota information. The technical and market-specific buildability of any car configuration is a key aspect for the validity of a production program. The highly complex set of technical rules (TECRule) must be integrated as well into the information model to account for this aspect. A car *Type* is divided into several *Models*. Furthermore, each *Model* is connected to several *Markets*. Moreover, within each *Market,* several *Models* can be sold.

For each *Option,* a *Quota* is necessary to anticipate customer orders. The *Quota* is based on the ratio of the occurrence of the *Option* in its *Option-Family* and is considered to be different for each *Market*. Therefore, each *Option* is connected to an *Option-Family*, a *Quota* and a *Market*. The same argumentation is valid for the relation between *Models* or *Model-Market*-combinations and *Volumes*. Furthermore, the *Options* and *Markets* are associated to the *Technical Rules* as those rules might block or force *Options* due to a specific combination of *Options* or *Market*-specific limitation.

The resulting data objects needed can be summarised as follows: *Type*, *Model*, *Market*, *Volume*, *Option Family*, *Option*, *Quota* and *Technical Rules*. Figure 3 shows the identified attributes transferred into a graph structure.

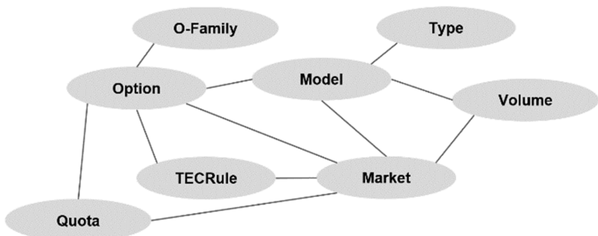

Figure 3: Efficient information model for SmartDCM

For the application, the introduced graph structure has been instantiated at a German OEM. Figure 4 shows the resulting class diagram in the Unified Modeling Language (UML). The model was supplemented within this step by the concept of variant cluster (VCluster). VClusters describe subsets of permitted variants with common characteristics. Each variant cluster inherits all the characteristics of its higher-level cluster. As a result, the model contains an efficient hierarchically linked cluster structure of variants. Thus, an effectively transparently representation of all the required information is given. First tests show that a production program evaluation can be performed efficiently using the developed information model.

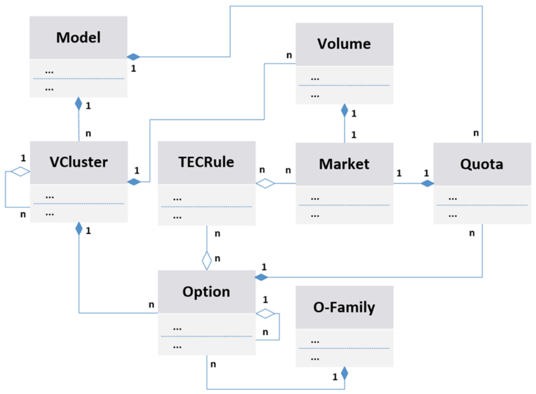

Figure 4: Instantiation of the developed graph structure

4. SUMMARY AND OUTLOOK

Digitisation in the automotive industry and the increasing number of variants are major challenges for future automotive DCM. Additionally, shorter life cycles and development cycles also increase the planning complexity. To overcome these challenges, this paper presents a modular process kit for a proactive automotive DCM which implicates a procedural change and an approach for efficient information model. The SmartDCM modular process kit provides an event-driven capacitive evaluation of an automotive production program that contains country-specific car models and options. The capacitive feedback includes restrictions from manufactured and purchased parts, containers and internal production plants and is communicated to the sales department in iteration loops. To be able to manage the increasingly complex information, the attributes required in the SmartDCM have been identified first. Afterwards, the developed information model, including the required attributes, has been introduced and an instantiation for the prototypical implementation of SmartDCM at a German OEM has been performed.
Currently, a software-suite is being developed, combining both the SmartDCM and the efficient information model. The implementation uses a service-oriented architecture to react as flexible as possible to potential future changes in the DCM process or technological changes (e.g. new deep learning methods). In the next steps, the information model will be extended to include capacity information and especially the new and changed dependencies in automotive products which result from the increasing digitalisation of the car.

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