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Engineers' work on the move: challenges in automobile engineering in a globalized world

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Engineering work in the German automotive industry is currently being dictated by corporate reorganization processes. These are driven by processes of informatization, financialization, and globalization, and evince an increase in the (global) division of labor in product development, as well as an increase in competitive pressures. Being able to deal with information and knowledge is important for coping with these processes at work. In terms of engineers' work, this means that engineers must be able to deal with the increasing amounts of information available in the form of benchmark figures, data, etc., as well as with the challenges presented by work shared in global networks. This paper presents the results of a series of qualitative interviews. The main trends that can be pointed out are the 'enucleation' (removing the core) of engineering work, the loss of autonomy, increasing insecurity, and the changing materiality of the objects worked on. Enucleation processes are increasingly changing older engineers' fields of work. More and more, they are being called upon to take over communication and coordination practices. In connection with increasing insecurity, employees' perception of their own position in the company is changing and, in the end, their strategies of action, as well.

Keywords: engineers'; work; informatization; globalization; financialization; engineering restructuring; enucleation

Introduction

The automotive sector is one of the areas of production where globalization in the past 30 years has created worldwide organizational structures and – especially in engineering – global collaboration based on information and communication technologies (ICTs). This wave of informatization has had profound consequences for engineers' work. The use of modern and new design software is encouraging the evolution of new working methods in areas such as collaborative engineering and of new working spaces as well as places. Computer-supported collaborative working tools are designed to bring people together in virtual spaces. Engineering seems to be becoming spatially flexible: anytime–anyplace organized through an information space.[1] This goes along with organizational changes in automobile engineering leading to a new quality in the international division of highly skilled labor within the context of the restructuring of organizational boundaries.

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[1]Boes and Kämpf, "The Nexus of Informatisation and Internationalization," 193–208.

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Reality, however, is still far from this vision. Our empirical findings show that engineering is still very locally bounded, knowledge-intensive work, although it is no longer possible to ignore the appearance of internationalization and offshoring. Standardization plays a major role with regard to products and processes. Outcomes differ according to the type of enterprise: original equipment manufacturer (OEM) or supplier or engineering service company. Evidence from three case studies is presented to illustrate how working cultures have not hitherto caught up with the dimension of globalized markets. The reason seems to be not only a temporary time lag within a generally concurrent development but also the fact that knowledge work can only be successful in the context of personal collaboration based on relations of trust.

This paper presents empirical evidence of changes in engineers' work triggered by organizational restructuring processes in automobile engineering driven by the globalization and financial integration of the world economy. We examine engineers' experiences and their strategies for dealing with changing working relationships within the context of the German automotive industry that continues to face significant changes. We describe the implications of these changes for work in the context of theories of informatization,[2] standardization, and globalization.[3] Our analysis is embedded in current discussions of how societies transform from post-industrial into information[4] or knowledge societies.[5] Knowledge work[6] or, now that everybody is becoming a knowledge worker,[7] knowledge-intensive work[8] is considered to be both an indicator of the status of social change and a source of transformation in the mode of employment. Technologies play an important role in these transformation processes and are leading to changes in work-related issues, including work organization, workings, industrial relations, and working capacity.[9]

Engineering in the automobile industry is an interesting and relevant site to examine issues around knowledge economy as it is highly influenced by the use of technological innovations and is undergoing frequent and complex reorganizations. Within the landscape of automobile engineering, engineers engaged in product development are especially fertile subjects to understand how work has been fundamentally transformed by the use of modern technologies, i.e. software, ICTs.

Overall, the key question we investigate in the project is *how* the nature of engineers' work changes through the use of new technologies and as a result of the restructuring of organizational boundaries.[10] Since engineers' work is informatized, we will analyze the implications of engineering strategies, processes, and technological innovations for their daily work, as well as how they deal with these challenges. We also look at the consequences of these changes for engineers, which

[2]Schmiede, "Knowledge, Work and Subject in Informational Capitalism," 333–354.
[3]Boes and Kämpf, "The Nexus of Informatisation and Internationalization," 193–208.
[4]The paper presents empirical evidence from the project "Knowledge Work in the Automobile Industry – Topology of Its Reorganization" (Will-Zocholl, 2010) and further work in collaboration with colleagues from Mechanical Engineering and others.
[5]Castells, *The Rise of the Network Society*.
[6]Drucker, *Landmarks of Tomorrow*; Willke, "Organisierte Wissensarbeit" [Organized Knowledge Work], 161–170.
[7]Thomson, *Skating on Thin Ice*.
[8]Huws, *Globalisation Glossary*.
[9]Pfeiffer, *Arbeitsvermögen* [Working Capacity].
[10]Marchington et al., *Fragmenting Work*.

emerge from the (international) division of engineers' work and which trajectories will form the basis for future developments.

These questions have to be answered in order to trace the influence of current changes on daily work: the loss of autonomy concurrent with the spread of responsibility for products and processes used around the world; increasing subjective uncertainty in dealing with the growing complexity of products, processes, and organizations, as well as in dealing with the virtual representation of products and processes, or communication, and referring them back to the 'real world.'

After sketching out some of the essential developments of globalization in organizations, followed by the important distinction between information and knowledge, this paper presents empirical evidence from three case studies. A general overview of the German automobile industry is followed by a description of reorganization processes in the automotive sector focusing on the reorganization of the value chain in engineering and within companies, e.g., new forms of organizational structures and processes. Finally, the case studies are described and findings are presented.

The globalized, informatized economy

The following are the central ideas of the analyses of today's globalized and informatized capitalism, with emphasis on Castells' theory: with the world economic crisis of the mid-1970s, which only at first glance seemed to be an 'oil crisis,' the long age of mass production based primarily on the division of labor and standardization – marked by a Taylorist and Fordist technological and organizational basis, as well as by an enduring Keynesian-based intervention of the state into the economy – reached the end of its development possibilities. What aspects justify calling this the dawn of a new age? There are two answers to this crisis – unrelated to each other intentionally, but complementary in a practical sense and in respect of their consequences: globalization, and the informatization of society and the economy. Although – or because – globalization is a common catchphrase these days, it is worth making an effort to identify its most important dimensions. Since the late 1970s, we have been able to observe clearly intensified competition in markets worldwide, which has resulted in pressure on national markets for goods and financial services.

Apart from this external dimension, which is directed toward national and international markets, there is a second, internal, and equally important effect of globalization impinging on companies and organizations. The first clearly visible and publicly perceived step in this change was the spread of lean production and lean administration models. This refers on the one hand to decentralizing aspects of labor and company organization: a shift in the scope of flexibility, but also a shift in responsibility toward the single worker, the team, or the department. Its equivalent is the thinning-out of the middle levels of hierarchy, which helps create more direct chains of information and decision-making. This system already included direct, constant comparison with parallel processes to increase transparency and stimulate competition for the most efficient methods. Continuous quality control has since become common practice for a large number of companies.[11] The last of these

[11]On lean production in Europe see, e.g., Wickens, *The Road to Nissan*; Bratton and Beynon, *Japanization at Work*; Jackson, *Turing Japanese*; Collard, *Total Quality*.

elements is the purposeful reorganization of logistic chains, orientating them toward the optimization of the processes of the dominant companies, in the words of a popular managerial slogan, 'concentrating on core competencies.' Following this guideline, there emerged both a new international division of labor with strongly differentiated, specialized, flexible markets, and new forms of the division of labor in product markets and in lines of industry, taking the form of company networks, network or virtual companies, i.e., 'horizontal'[12] organizations.

However, these organizational aspects of decentralization do not tell the complete story. Centralization is ongoing when we consider capital concentration, financial control, or the economic and political power of the companies. In a certain sense, the finance-capitalist origins of globalization again catch up with the sphere of real production and services, and structure them: the orientation toward the short-term goals of shareholder value makes corporations dependent upon global capital flows. The centralization of financial and finance policy, often operationalized in the form of being ruled by quarterly finance balance figures ('financialization'), together with organizational decentralization, is typical of globalized companies. The company's limits are of a virtual, financial nature, they are no longer the traditional factory walls or fences. The recent crisis of 'finance capitalism,' with its severe consequences for the worldwide economy, financial or real, has demonstrated this dimension, throwing serious doubts on the future ability of top management to steer their companies in a long term, strategic way.

Informatization – the second answer to the world economic crisis of the 1970s, signaling the end of the age of Taylorist and Fordist mass production – means not only, and not even primarily, the ubiquitous spread of digital ICTs but first and foremost a qualitative increase in their significance. Information technologies have accompanied capitalism right from its beginnings. But what then is new about digital ICTs? What gives us the right to speak of a new kind, or even a new period, of informatization as the technological basis of informational capitalism?

First, computer technology is different from preceding technologies, all of which were auxiliaries for solving particular tasks, i.e., they were special machines, whereas the computer is a 'universal machine,'[13] which, because it is program-controlled, may be used for any task. As it is the objectification of a general, symbolic machine, it can also operate on the universe of symbolic models and worlds. Although this machine needs input from the real world and must give back its output to the real world to fulfill its purpose within the context of the system as a whole, within this second self-referential world of working on and processing symbols, it is free of these limits and open to any step of work.

The second fundamental feature of ICTs is that they are no longer primarily tools for supporting solutions located outside of their tasks, but are instead a part of a whole process, of a system. For just this reason, they offer gigantic new potential for productivity: in the symbolic world of information, a growing number of material processes can be modeled, calculated, simulated in all their variants, and calculated with regard to their mechanical, chemical, biological, or electronic effects. Increasing portions of the work involving changing and designing in the real world are being shifted to the world of information, where they are then carried out virtually. What

[12]Castells, *The Rise of the Network Society*.
[13]Krämer, "How Computers Change Our Use of Symbols"; Heintz, *Die Herrschaft der Regel: Zur Grundlagengeschichte des Computers* [Regulation Governance: History of Computers].

is new is the technology-based, media-mediated ability to change knowledge. The complete technologization of knowledge in its informational form is a step from conventional mechanization toward informatization.[14] The strategies of productivity competition, which is still the economic basis of capitalist production, have shifted from material production toward this world of virtual product development[15] and product planning, where at the moment things are changing.

The third specifically new feature of the ICTs is their effect on space and time. Informatization enables information and communication networks that are able to operate globally and in real time. Globalized socio-technological systems – as the tendency can be summarized – have been created, which generate, communicate, and process information, and do so in real time. Furthermore, in principle, these systems enable worldwide access to any content, but they are also the technological basis enabling ICTs to become reflexive, as mentioned in the second point.

Information and knowledge

A brief yet more detailed discussion of the role of information and knowledge in the informatized economy and society would seem to be in order here, because that is where the decisive conditions for the constraints as well as the freedoms confronting working subjects can be found. *Information* is merely a raw material for work, knowledge and organizational processes: abstracted, shaped, and thus formalized content. In contrast to the data of technical communications models, information must not only be technically understood by transmitter and receiver but the content it transports must also be syntactically understandable. Information is always positively determined and must always be so, since it is only possible to create technical models of objects and relations that are clearly defined, and be it defined in a statistical sense. At the same time, however, this limits the reach of information in principle, for positive determination can only be reached by disregarding variety, i.e., by means of abstraction. Thus information always includes designed and formalized excerpts of reality only, i.e., excerpts cleared of disturbing conditions and complexities.

Knowledge, on the other hand, remains bound to the knowing subject in principle, for it is always context-related, dependent on interpretation, and understanding. It is always – as Michael Polanyi has termed it – 'personal knowledge.'[16] There are no stocks of knowledge that are not communicated by the thinking subject's mind. Without being worked on by the mind, this knowledge remains lifeless material. As in the case of other technologies, this conversion of information into knowledge may be supported by means of production but it can never be replaced, or at most only partially. In a certain sense, therefore, knowledge is 'information critique.'[17] Thus one cannot simply transform implicit knowledge largely into explicit knowledge, as stated by naïve concepts of knowledge management, but

[14]Spinner, *Die Architektur der Informationsgesellschaft* [The Architecture of the Information Society] 63–75.
[15]Anderl, "Produktentwicklung in der Automobilindustrie" [Product Development in the Automobile Industry], 37–52.
[16]See further: Schmiede, "Virtuelle Arbeitswelten, flexible Arbeit und Arbeitsmärkte" [Virtual Working Environments, Flexible Work and Labor Market]; Willke, "Die Krisis des Wissens" [The Crisis of Knowledge], 10–47; Polanyi, *Personal Knowledge*.
[17]Gamm, "Wissen und Information" [Knowledge and Information], 192–204.

must provide space for processes that do indeed make it possible for tacit knowledge to have an effect.[18]

This clearly shows that knowledge is closely connected to genuinely social processes in that it not only requires an appreciation of the contents themselves but also of the knowing individual (as the English term 'acknowledgement' signifies). To support and foster the development and dissemination of knowledge, one has to create the social conditions for the processes of collaboration and communication by which knowledge workers can transfer or gain new knowledge in acts of doing and sharing their experiences. In engineering work in the automobile industry, the observer comes across exactly this constellation.

The automotive industry

After the systemic crisis of the European automobile industry in the 1990s and the rise of Japanese car makers, as seen in the triumph of Toyotism, European car makers began to enjoy business success again at the beginning of the new millennium. The European comeback was based on a better use of the skill potential on the shop floor, modularization, and increasing outsourcing of engineering and production including an increasing international division between low- and high-cost value chains as well as increasing innovation activities.[19]

In the past few years, German automakers have on the one hand managed to sell more cars than ever before, while on the other hand, new competitors have emerged, increasing the pressure on German (and European) automakers. Their problems are still much the same as those of the 1990s: their high-cost structure and quality problems, as well as an orientation to short-term shareholder value.[20] While production costs are being cut by shifting production plants and forcing suppliers to produce more cheaply, the costs of research and development have risen by 256% in 10 years as a consequence of the focus on innovation strategies and the fact that return on investment decreased owing to a larger variety of models and shorter model cycles.[21]

At present, automobile companies are trying to drastically reduce engineering costs.[22] Companies are trying to reduce costs by focusing on common components, modularization, and platform strategies, such as had been adopted in the lean production and lean thinking concepts of the 1990s[23] and at the same time staying innovative. A new level of cooperation between OEMs, suppliers, and engineering service providers is emerging.

Engineering outsourcing as a core strategy

The scope of engineering is being restricted by outsourcing more and more engineering units to suppliers, or by contracting out to engineering service providers. It is practiced in national and international contexts, leading to collaboration

[18]Polanyi, *The Tacit Dimension*.
[19]Jürgens, "An Elusive Model," 411.
[20]Becker, *Ausgebremst: Wie die Autoindustrie Deutschland in die Krise fährt* [Braked out: How the German Automobile Industry Drives into the Crisis].
[21]Stifterverband für die deutsche Wissenschaft, *Facts*.
[22]VDA, *Future Automotive Industry Structure (FAST) 2015 Study*.
[23]Womack et al., *The Machine That Changed the World*.

between the different players. The increased transfer of engineering contingents by suppliers enabled the major suppliers to move up the value chain.[24] Figure 1 shows the hierarchical, pyramidal-oriented network of players in automotive engineering as it has been carried out in the studies of Bernd Rentmeister.

These collaboration processes are supported by several collaboration tools used at the interfaces. Global and local engineering networks are emerging between OEMs and system and module suppliers, between OEMs and full or specialized engineering service providers, as well as between OEMs and suppliers of systems, modules, parts and components, or specialized engineering service providers.[25]

While collaborative engineering has become a popular working method in multinational and national companies, global engineering is supposed to be the next step forward in the future of engineering. Global engineering is the glittering vision of efficient and optimized engineers' work, of engineers all over the world collaborating to work nonstop on a single component of a product.[26] Concepts of global engineering suggest that engineering is going to become spatially flexible, and this has optimistically been adopted by the management of companies, organizations, and even at universities.

Organizational restructuring in engineering

The new level of informatization and globalization reached by the companies which have gone global has led to permanent reorganization processes. In the case of

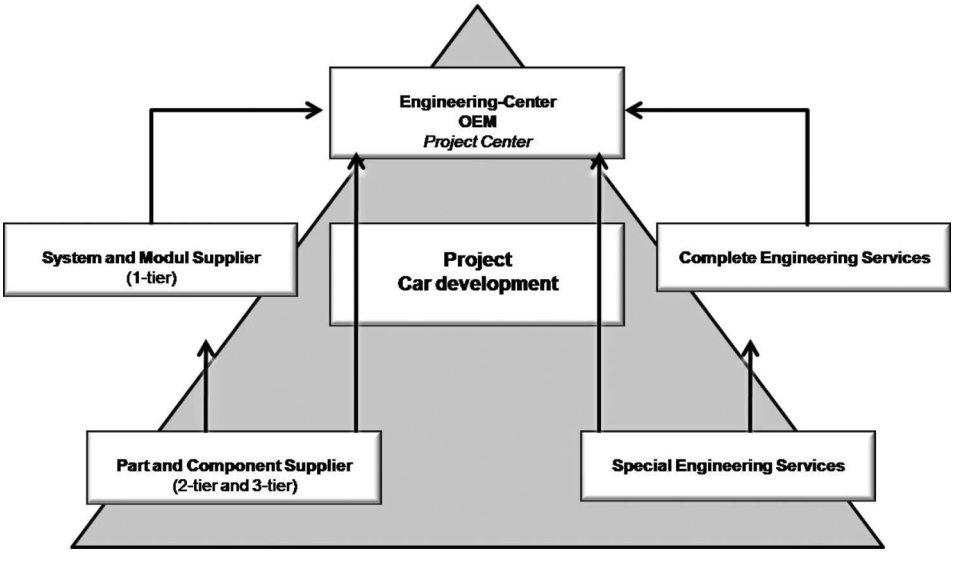

Figure 1. Automobile engineering network.
Note: *Source:* Rentmeister 2002.

[24]Ramioul and De Vroom, *Global Value Chain Restructuring and the Use of Knowledge and Skills*.
[25]Schamp et al., "Dimensions of Proximity in Knowledge-based Networks," 607–624; VDA, *Future Automotive Industry Structure (FAST) 2015 Study*.
[26]Bichler, "24-Stunden-Entwicklung" [24-hour Development].

automobile engineering, an example of decentralization processes would be the distribution of competences and responsibilities by outsourcing engineering units to autonomous engineering centers, some of which take overall functions, such as human resources, budgeting, and purchasing. In contrast, centralization processes often go hand in hand with decentralization processes, as when functions are again sourced in central units, or functions situated in every department are concentrated in central units, as when one central human resource department begins delivering services to the whole company. On the one hand, companies are being structured to comply with market conditions,[27] while on the other hand, an internal market is created in which corporate units compete. Market principles are replacing hierarchical control as a new mode of surveillance and regulation has appeared. 'Indirect regulation'[28] is a keyword for this development, which means managing a company by business ratios and head counts, better known as management-by-objectives.[29] This form of regulation plays an important role, since vehicle development is organized in projects.

Automobile engineers' work

The implications of organizational restructuring could be found in manifold changes in engineers' work organization. Because engineers' work is informatized work, tendencies toward standardization play an important role. The use of modern technologies has fundamentally transformed the work of engineers engaged in product development processes in the automobile industry.

Engineering methods have changed from step-by-step procedures to much more modularized simultaneous engineering. The various phases of the product development process overlap the preceding and the following phases, with more opportunities to change the product in shorter time generating lower costs and improving quality. This means that engineers are responsible for different components, parts, etc. of different car projects in various phases of the product development process. One crucial condition for realizing simultaneous engineering was the digitization of product data and as a consequence the product development process is on the way to becoming completely virtualized. Models are no longer designed on the drawing board, but created and simulated by using digitized 3D models to create digital mock ups that can be taken to simulate future functions of the individual components and the complete product as a virtual prototype. Even test procedures can be simulated and vehicle handling tested on a PC.[30] Data can be stored in product data management systems and exchanged easily across great distances. This is leading to the evolution of new working methods in areas such as collaborative engineering, and new spaces as well as places of work. Engineering seems to be becoming spatially flexible: anytime–any place.

A Fraunhofer IAO study[31] found that creative design tasks were increasingly being replaced by communication and coordination tasks. In addition,

[27]Moldaschl, "Changing Organizational Structures," 67.
[28]Sauer, "Corporate Reorganization, Human Resource Management and the Flexibilization of Work and Employment," 2.
[29]Drucker, *Landmarks of Tomorrow*.
[30]Anderl, "Virtuelle Produktentwicklung in der Automobilindustrie" [Product Development in the Automobile Industry], 37–52.
[31]Bullinger et al., *Automobilentwicklung in Deutschland* [Automobile Engineering in Germany].

documentation tasks have increased as a consequence of distributed work. Cooperative working contexts lead to a significant increase in managerial tasks like project management or other coordinative functions.[32] This could mean that requiring engineers to be knowledgeable in the fields of economics and management is pushing their traditional qualifications into the background.[33] Former studies discussed questions of autonomy of work and deskilling tendencies.[34]

To know more about these mechanisms, the following questions have to be answered: What are the challenges in engineers' daily work and what are the strategies for action which are emerging? How do they feel about their personal situation?

Toward globalized engineering work?

We have chosen a qualitative research approach to illustrate the field of engineering, which has not been researched in this way recently. Three case studies were conducted to attempt to answer these questions and in order to picture the German automobile industry and its strategies of dealing with the increasing pressure due to globalization; we drew upon a series of 45 expert interviews with managers and engineers in automotive engineering.

Methodological approach

Empirically, the research is based on case studies in automotive engineering and pursues a multimethod approach. An analysis of statistical data and documents is combined with 40 qualitative, guided interviews targeting engineers. These were working in the development and product development departments of two OEMs (MassCar and PremCar) as well as at an engineering center of a system supplier (FirstTier). Persons managing engineering processes and strategies were interviewed, as were engineers on the operational level, who fulfilled various roles in the product development process, from December 2006 to February 2007 and from November 2008 to February 2009.

Although companies in the German automobile industry range from one-person engineering offices to OEMs employing more than 360,000 people, we will focus on three large, internationally operating companies. These companies employ between 5000 and 8500 engineers in car development processes. Their engineering departments – especially the core areas such as design, prototyping, and engineering processes and strategies – were selected to investigate general issues of engineers' work and to point out striking developments in the different types of companies. Interviews were conducted in the period between November 2006 and spring 2009. We took into account the fact that the last session of interviews was held in the aftermath of the financial crisis.

The interviews were recorded digitally and transcribed word by word. We took a content analysis approach[35] using WinMax software. The interviews, corporate

[32]Stefan, "The Boundaries of 'Marketisation'," 231–252.
[33]Kurz, "Nicht nur Techniker sein" [Being More Than a Technician], 59–106.
[34]Braverman, *Labor and Monopoly Capital*; Whalley, *The Social Production of Technical Work*, 66.
[35]Mayring, "Qualitative Content Analysis," 139–148.

documents such as annual reports as well as job advertisements were all taken into account in the final analysis.

Organizational settings in the companies analyzed

The US-based mass automaker (MassCar) aggregates more than 10 brands worldwide. The company is organized globally from the United States and follows a platform strategy.[36] It runs engineering centers in four global engineering regions, three of which are within the European region, with the focus being on the German site. The second OEM (PremCar) is a German premium car maker with two consolidated brands. It has eight engineering centers distributed around the world focusing on specifications and country-specific applications. The German engineering center is the head of the company's engineering strategy. The third enterprise used as a case study, a system supplier (FirstTier),[37] is organized in a global engineering matrix. Responsibilities are delegated to the different regional engineering headquarters depending on the location of customers' businesses. For instance, when working for an American automaker, the head of engineering would be based in the US, whereas the German colleagues would attend to adaptation and production in Germany or in Europe, respectively. The German engineering center is responsible for European customers and for the company's near-shore engineering centers in Eastern Europe.

The analysis of the three case studies resulted in the differentiation of three types of reorganization processes: 'intensified globalization,' 'persistent centralization,' and 'accelerated offshoring.' All three reorganization processes are closely connected to the division of labor that emerges among globally operating companies or other actors in the field of engineering, such as suppliers or engineering service companies.

Reorganization processes at MassCar could be described as intensified globalization. An international engineering strategy is being pursued, which integrates all captive engineering centers in the company's four engineering regions of the world. Every car development project has its home region for engineering; nevertheless all regions are involved in creating new models. Work labeled as 'brand identity building' is distributed among the company's several engineering centers. Due to its international engineering structure, MassCar is organized in a matrix that has a global and a regional axis. Concerning the company's restructuring efforts, the global standardization of processes takes center stage. The global management board decides which processes are to be standardized globally and which processes are to be adapted locally. Interviewees from the German engineering center

[36]Platform strategy: Cars of the same size (vehicle class) are built on the same platform (chassis), with different bodies. From the outside one cannot recognize that it is the same car with a different external design. OEMs try to save engineering costs as well as improving purchasing conditions.

[37]Tier-1 classifies the supplier as a direct supplier to the OEM. Suppliers delivering Tier-1 suppliers are classified as Tier-2 or Tier-3. The numbers denote the rank in the value chain. About the classification as Tier-1 for the researched supplier company it needs to be mentioned that Tier-1 supplier is valid for the research area. The company itself could also operate as Tier-2 in other contexts. A different classification of supplier companies would be to distinguish by competencies: e.g., system and module supplier, part and component supplier or complete and special engineering services (Rentmeister, ''Einbindung und standörtliche Organisation von Ingenieursdienstleistern in der Automobilentwicklung'' [Organization of Location of Engineering Service Companies in Automobile Engineering]).

described these processes as an 'Americanization' rather than internationalization. The American processes were taken as global guidelines. MassCar's main focus in engineering is evident: reducing costs. Processes are arranged very consistently in order to maximize the benefits from using platform and common component approaches. Being a mass car producer achieving a lower return on investment due to rising engineering costs on the one hand and on the other hand due to declining sales prices for cars as well as decreasing number of sales during the crisis, the company has enhanced its efforts to avoid redundant processes.

MassCar outsources its engineering to a high degree. It avails itself of the opportunity to distribute work among the captive engineering centers around the world and to use offshore service centers in India. This makes it possible to do 'standardized work' in engineering, such as calculations and simulation processes. Attempts to get MassCar's global engineering center to cooperate cannot be regarded as a success. The release of the first platform was carried out under the direction of MassCar's European engineering center. The project united all regions in one joint project. Although this appeared to be a kind of cooperation among the engineering centers of one and the same company, the severe competitive atmosphere between these different sites could not be concealed. One region literally struggled to protect its intellectual property against other regions. Although installing an internal clearing center attenuated the issues obstructing a successful outcome, they did not cease to exist completely. There is still fierce competition for jobs between the intra-company sites. Outsourcing to external engineering partners is preferred to distributing work internally. Furthermore, MassCar prefers collaborating with German suppliers located near their European engineering center rather than having in-house cooperation throughout the world.

PremCar's reorganization processes can be characterized as persistent centralization. The company pursues an engineering strategy that concentrates on a German engineering research and development center. The product development process requires collaboration with external suppliers and engineering service providers located nearby, in Germany and Austria. 'Brand identity building' components are handled only in their German research and development center. The company's organizational structure is still very centralized and hierarchical, even though car developing projects are organized in a project matrix. PremCar has also tried to standardize processes, but not as consistently as MassCar. This has not been so important for PremCar with respect to financial aspects. The focus on reducing costs has emerged as a new issue only in the last decade, while the main focus continues to lie on the engineering of innovative products. Issues of quality and innovation are very important to the company's self-conception.

PremCar also outsources its engineering to a great extent. The company heavily relies on its partners along the value chain, apart from an engineering center in India. Concept engineering is done in-house while series development is very often outsourced to external engineering partners. In addition, PremCar has modules or components engineered by suppliers and engineering service companies. The company highly values the physical presence of its partners. Hence many suppliers or engineering service companies locate their subsidiaries close to the OEM or send resident engineers to work on-site. PremCar also places high value on the possibility of intervening in the external partner's actions in the engineering process, even though this is more expensive. Temporary employment also plays an important role in PremCar's engineering center. The employees are under constant strain because temporary

employment contracts were extended or renewed or – in the worst case – were not renewed. Furthermore, employees had to accept time restrictions as well as short-time work at the peak of the financial crisis. Both OEMs try to reduce the overall engineering time and save engineering costs. However, whether they really save money is questionable given the additional expenses for technological systems (e.g., video conferencing), new software and data systems, higher travel expenses as well as solving communication problems occurring in intra- and inter-organizational project teams.

The central moment of the reorganization processes at FirstTier can be identified as accelerated offshoring. FirstTier has two operative business segments. Each consists of three hybrid and independent departments (divisions). The departments are located around the globe. Engineering units are globally cross-linked and responsibilities concentrated in strategically important engineering centers. The position of the German engineering center is powerful due to the fact that the company's central engineering department is located in the same area and that FirstTier's head office is in Germany, too. Today, near-shore engineering sites play an increasingly important role in the face of economic crises. The near-shore engineering centers were set up primarily to take over standard tasks, such as design work, simulation, or calculation. Recently, they were either upgraded or on their way to taking over increasingly complex tasks. These sites are used to draw a scenario of outsourcing highly skilled engineering work to low-wage areas. Inside the company, these actions are said to be its current strategy. Furthermore, the proportion of temporary employment at FirstTier was very high before the crisis struck. Similar to PremCar's strategy during the crisis, FirstTier also discharged its temporarily employed workers.

Up to now, global engineering strategies in the sense of 24-hour engineering of one component around the world do not play a role in the companies studied. Interviewees mentioned that they do not believe that this could be enforced for several reasons: product development processes are highly creative actions and thus cannot be standardized, given all the remaining ambiguities. According to their opinion, vehicle engineering cannot be done piecemeal. The materiality of the parts to be developed cannot be arbitrarily reduced. For example, some components have to be engineered in one piece and cannot be divided into independent parts to be engineered in particular. The product development process could be divided functionally, however. Calculations, for example, could be extracted and done based on the division of labor. If two or more engineers worked on the development of one part simultaneously in the same place, they could constantly share their ideas and thoughts, whereas if they were forced to work one after the other on a piece due to different time zones, they would have to negotiate indirect forms of communication and explain the individual steps of their work in detail, which would be time consuming and complicated. To organize these procedures involving complex products would require enormous amounts of standardization leading to 'robot's work' – as one of the interviewees at MassCar put it. Moreover, the technological prerequisites are not even sufficiently developed to implement the on-time transfer of the huge data quantities involved. Internet technology could allow the required exchange of masses of data, but not necessarily in a secure manner. The existence of huge information systems could not guarantee similar working processes. Engineers gain access to masses of information but cannot always process it as knowledge. And if they do process it as knowledge, this will be closely connected to their personal experiences, so called tacit knowledge.

MassCar is on the way to unifying its large data stock into one 'super system,' a broad product management system with one database to work with, including virtual team spaces, communication tools, calculations, drawings, etc. If every engineering center used this system, it would be easier than before to transfer and work simultaneously on similar items. Conducting global engineering in the sense of working 24 hours straight on a similar item by passing on work steps around the globe still remains a 'vision.' The companies apply the 'follow-the-sun-approach' to arrange simulations, calculations, etc., to be done in India. Due to the time difference between Germany and India, Germans send out data to India in the evening, which is then processed by Indians and sent back to Germany the following morning. German engineers then continue working on it without losing anytime waiting for the results from India. Problems occurring in the context of global engineering are brought down to the technical and/or cultural level. This means that technical reasons, such as too little data transfer capacity, tend to be given when difficulties appear in global engineering or when projects fail. However, cultural differences are also mentioned as obstacles. But especially the complaint about cultural differences can be seen as a general issue of globalization. As the world grows together, the ability to deal with these developments becomes increasingly important. To be successful in globalizing work, companies need to create a corporate climate with an open-minded atmosphere where intercultural exchange is possible. In times of growing competition among engineering centers of multinational companies, every trifle can serve as a welcome pretext to claim that it is impossible to work together successfully with people belonging to other cultural contexts.[38]

Changes and challenges for engineers' work

The organizational changes sketched in the above and increasing worldwide competition lead to changes in engineers' work. Six issues of changes and challenges could be pointed out in the following section: enucleation of engineers' work, autonomy of work, increasing insecurity, the issue of responsibilities, increasing complexity, as well as transformations in the materiality of engineers' work.

First, the changes in the work organization of engineering, including the contents of the work, could be described from the engineers' perspective as the 'enucleation'[39] of engineers' work. The core of engineers' work, such as design work, is becoming increasingly marginal – this was observed at both OEMs, in particular. Other tasks, such as communicating, coordinating, and traveling, as well as administrative duties, are becoming more important. Companies intensify these developments by outsourcing design work to engineering sites abroad, to engineering partners, and to engineering service companies. Automakers aim to reduce the variety of components used in the vehicles or to facelift older types of components. These actions lead to a loss of innovative design work. PremCar engineers complain about the loss of creativity caused by the standardization of components and processes, the enormous cost restrictions, and the outsourcing of engineering. At the OEMs especially, the interviewees characterized their work as administrative rather than creative, as this MassCar project manager describes it,

[38]Downey et al., "The Globally Competent Engineer," 107–122.
[39]Lat. "enucleo" (German: "*Entkernung*"): "Enucleation" explains removal of original engineering tasks such as design work.

> It has developed into an administrative job. It really has, I'm sorry to say. That is why many engineers do not want to work for large corporations. I mean, somebody who becomes an engineer has certain ambitions. He would like to do a bit of research, fiddle around with things, try things out, you know? Why does it work like this and not like that? You don't get that here. You don't have the time for it here. You can't do it at all. It's not what you get paid for. It didn't used to be like that, though.
>
> (MassCar 6)

This is even worse if the company management puts a higher value on project management tasks and collaboration than on the design work itself. If employees want to get ahead, they need to leave behind the core areas of engineers' work and settle for doing more administrative work, etc. In contrast to discussions about job enrichment or job enlargement, engineers working under these conditions experience the replacement of original engineering tasks as a loss. In their understanding as technicians, this work is very important to them.

The increasing demands placed on communication are a result of a greater division of labor. Despite all the new collaboration technologies, the interviewees attach a special value to face-to-face meetings, even though time-consuming traveling makes it even more difficult to fulfill their ambitious working objectives. For them, this seems to be the most important way to successfully share their experience. New collaboration technologies, such as virtual team spaces, etc., have not yet replaced the old ones, like telephone conferences and face-to-face meetings. The new technologies are regarded as neither flexible enough nor suitable for simulating face-to-face communication. This option seems to be based on the existing skepticism toward computer-supported visualizations and on the lack of informal structures in virtual contexts. Therefore, communication tools are not used as intended.

Secondly, the *autonomy* of engineers' work, which had been at a high level in the past, is seriously eroded by cost-saving strategies and working guidelines dominated by financial business criteria, although the situations of the engineers at the various companies studied evinced strong differences. At MassCar, cost pressure and the strategies dominated by the American headquarters come together to increase standardization, and promote restrictive policies governing actions. Process orientation dominates product orientation, as a MassCar engineer mentions,

> Then it is less a matter of the product itself than of the processes, and behind each process there are people who are tracking these processes, who watch the project engineers to see that they keep to these processes. This is not always good for a product, because it sometimes gets neglected and that is one of those problems [. . .] too many processes.
>
> (MassCar 5)

Hence the process becomes the dominant factor, thereby limiting the autonomy of engineers' work and leading to frustration among engineers and, what is more, even to a disregard of internal guidelines like a project engineer describes,

> Very little latitude [. . .] the processes are just there, you have to keep to them. Of course, you can bend them a little, yes, but in the end there is nothing you can do but follow them. And that has changed hugely in the past few years. These processes in particular really hurt engineers, the real engineers who would like to concentrate on their products but spend most of their working hours simply looking at processes and numbers and filling in forms, I'm afraid that's how it is.
>
> (MassCar 5)

PremCar has had a long-term success story with no redundancies in engineering in the past. The aim of the engineers is primarily the 'quality' aspect. At the time of the interviews, however, they were not allowed to do their best at work because of a reduction in working hours. The engineers experienced this as if their way of working was being dictated to them. Their autonomy has been reduced to a much larger extent than at MassCar. Due to the international organization inside the company, the engineers working in product development have to take more issues into account and cannot make decisions as independently as before. This situation made them feel much more under pressure because they did not have enough time for the simultaneous engineering concepts and all the additional tasks needed to organize the distributed work.

Crucial to the third issue, *increasing insecurity*, is the fear of possible or actual job loss. MassCar engineers experienced one bout of mass layoffs in their engineering department several years ago – an experience that has substantially lowered their frustration barrier. The anxiety of job loss was found to be a central issue in the interviews at MassCar. At FirstTier, the situation is affected by the demand to outsource engineering tasks to the near-shore engineering centers. The pressure increased after the temporary staff was laid off at the beginning of the sales crisis and the internal staff had to take over their work. The engineers we interviewed were confronted with new competitors in near-shore sites within the same company and were shocked and annoyed as a result. They were expected to teach their Eastern European colleagues as well as do their daily work. They were unable to make management realize that the near-shore engineering centers would not deliver the same benefits and quality. A project manager of FirstTier argues, 'And then, of course, we German engineers say ''You get what you pay for, obviously. They are cheap and they give it to you on the cheap'' (FirstTier 2).'

The management keeps on expanding the Eastern European engineering centers. And the engineers have no basis for negotiations. They ask themselves whether the company is honoring their work or not and experience a feeling of being dispensable as if it were a point of inflection. At this point of analysis, it is not important if there is an objective threat of job loss or if the engineers merely feel threatened by the general economic situation or the companies' globalization strategies.

Furthermore, the question of *responsibilities* is important in cooperative working environments. Who is responsible for what? This is not easy for the engineers to solve because it is not always clear who to contact in constantly changing contexts and who is to be informed in complex matrix structures. This leads to another issue: the problem of being inundated with information via e-mail. Because it is so easy to distribute information through technological systems, and because it is not so easy to know exactly who should really receive the information, it is dispersed very broadly. As a consequence, a great deal of time is spent sorting the important from the unimportant. Another facet of the topic of responsibility is that the same components are used all over the world. For one thing, this means that someone must be found to assume the overall responsibility, to approve and monitor further developments, while at the same time, all the engineers working on such components must be aware of the fact that changes can have far-reaching consequences and be very costly if their importance is discovered too late.

The fifth feature quite often mentioned by engineers is the increasing *complexity* of their work. This is related on the one hand to the above-mentioned cooperative working environments, as well as the fact that more tasks have to be done in parallel,

and on the other hand to the increased complexity of the product itself. Components are made up of different parts, engineered in various fields outside of mechanical engineering. Interdisciplinary cooperation is needed between electrical and mechanical engineering (leading to new fields of study like mechatronics) as well as software engineering. The interdisciplinary issue is seen as a special challenge. A PremCar engineer describes the recent development,

> Suddenly things you had never thought of are crosslinked and causing problems in software and electronics development. You know, that never used to happen. [...] And these electronic processes, for instance, they have a completely different timing. They are totally different. They have much shorter innovation cycles, for example. You know what I mean. Your home computer is ready for the scrap heap after three or four years, first-class quality. A four-year-old car is still in good shape [...] Whether mechanics or electronics, it doesn't matter to the customer why a breakdown has left him stuck on the roadside. [...] The actual character of a problem is different in electronics. There is this lack of transparency. So it's the complexity of the whole functional network. There is a fault somewhere no one can explain, and you can look around forever before you finally find it.
>
> (PremCar 3)

Sixthly, the *changing materiality* of engineers' work caused by a proceeding informatization has to be singled out as another central theme. The virtualization of product development processes and of the products themselves is making engineers' work more abstract. This level of abstraction, which is highest in simulation or 3D-CAD design, must be brought back down to the level of real conditions and references, however. The engineers in the interviews made a point of mentioning how experience in the 'real world' is needed to accomplish this sort of translation exercise. If this is lacking, more work has to be done on physical prototypes and there is a danger that things no one had considered can turn up on a larger scale.

In summary, it can be said that the pressure on engineers with regard to time, scope of work, and mental stress has increased enormously in the past decade. The scale depends on the type of company they are working for. In former times, German engineers felt important in their company and the importance was well paid and honored with respect from the management. Today they are losing their prominent position by experiencing their dispensability. They never had aims comparable to those in the information and communication (ICT) industry,[40] where software engineers understood themselves as a kind of co-management. They saw and still see themselves as employees, not managers. Their aim is to create products, not organizations. But they feel they are no longer receiving the attention they got in the past. They are feeling less valued as virtualization and informatization commodifies their work. Make no mistake, engineers are still in quite a comfortable situation compared to other groups of employed persons. They earn good salaries and their jobs are relatively secure. Nevertheless, substantial changes are taking place.

The interviews with engineers working in product development in all the companies included in our case studies showed that engineers are trying to deal with these issues and the strategic guidelines of their companies in their own way. The strategies for dealing with these challenges in all three of the companies we studied are largely similar but different in respect of one dimension. The 'work-to-rule option' could be found in all three cases. This means that engineers are doing only

[40]Boes and Kämpf, "Offshoring and the New Insecurities," 104–119.

what is assigned. Frustration is the reason for this strategy. With regard to the permanent changes in organizational structures and the feeling that their ideas for restructuring are going unnoticed, quite a few of the engineers did not feel that they and their work are being adequately accepted. Reorganization strategies, such as the intensified globalization at MassCar or the accelerated offshoring at FirstTier, seem to encourage this response among the engineers employed by these companies, endangering their identification with the company and with their own work. Because of the insecure working conditions at MassCar, and the pressure of offshoring work at FirstTier, more and more employees seem to see this option as appropriate. They compensate for the praise they are missing at work by extending their free-time activities. If they cannot accomplish this, there is a risk that they may turn to inner resignation or withdrawal.[41]

Apart from this similar pattern, however, the 'exit option,' which means leaving the company and looking for another job, was already an alternative to the frustration option even before the crisis, especially at FirstTier. Today everybody seems to be happy if they can keep their job. Anecdotal evidence shows that even temporarily employed engineers at engineering service companies do not want to change to an OEM because of the insecure situation – especially at MassCar. At PremCar, where the identification with the company is still high, another option is 'being on the lookout for career chances inside the company,' in other departments, for example. This means trying to advance one's career by climbing up the ladder and finding a job that seems to be more secure.

The reorganization processes described here vary in their degree of internationality and division of labor in product development. The higher the level of division of labor in the organization of product development work, i.e., the more the development work was outsourced, the greater was the role played by the issue of enucleation and frustration-generated alienation in the companies or in the departments specifically involved. The number of interviews only allows hints of this; further investigations will be necessary to place this conjecture on a solid basis. Moreover, increasing insecurity in view of the increase in global references in the work was noticeable, whether due to cooperation with international locations or the nascent issue of offshoring in engineering. Confronted with the crisis, engineers see their negotiating power decreasing more than they would have ever thought. This may lead to a cancellation of internal agreements between highly skilled employees and the management in automobile firms.

Conclusions

Changes in engineers' work are closely connected to reorganization processes in the companies studied. Globalization processes are being driven by the increasing use of modern ICTs, which create an information space or possibility space, in which engineering work becomes reorganized.[42] The virtualization and informatization of product development processes can be considered additional conditions favoring this occurrence. As a consequence, the materiality of engineering work changes. It is only possible to cope with this qualitative change with the aid of tacit knowledge.[43] This is

[41]Coyle-Shapiro and Parzefall, "Psychological Contracts," 17–24.
[42]Boes and Kämpf, "The Nexus of Informatisation and Internationalization," 193–208.
[43]Polanyi, *The Tacit Dimension*.

also necessary to deal with the complexity of products and processes, and may replace the use of large IT systems and ever newer tools and databases that merely serve to file information without generating knowledge. Attempts at reducing complexity by standardization and building up huge documentation systems have not been successful so far.[44] As described above, it has proved impossible to extract knowledge from people's minds onto technological systems, thereby enabling a global distribution of knowledge. This tacit dimension of knowledge explains its renewability, and the fact that we are able to experience new issues as new and to deal with them on the basis of our previous knowledge at the same time. Because knowledge changes when passed onto somebody else, it can only be experienced in the collaboration of people themselves.

The presence of this kind of knowledge was able to reduce complexity in cooperative contexts and could not be replaced or mediated through technological systems or tools.[45] This can be seen as a reason for the (local and regional) 'spatial fixes'[46] of engineering, e.g., in cluster centers or the on-site locations surrounding the OEMs' engineering centers.

The coordination of work based on the division of labor and on networks involves additional challenges. The range of individual engineers' responsibility grows; there is less room for autonomy. In the end, activities arising from a changed work organization change engineers' perception of their work. They describe a process of enucleation in which the core of engineers' work undergoes a change that many of the persons interviewed described as a loss. Here it does not matter whether the new coordinative activities are strongly related to the product, or if they involve filling IT systems of ordering office supplies. This feeling can be interpreted by those interviewed as an anachronistic idea of engineering work or as a problem of masculinity, as the loss of work references capable of supporting a masculine identity.[47]

Finally, enucleation and the effects of an increase in the global division of labor are causing engineers to become insecure with regard to their position in the company, as well as with regard to their job security. The realization that their work is being commodified is reinforced by a lack of recognition in the company. As a result, the innovative potential of the employees is not fully exploited, which could cause engineering work to become less attractive in the long term.

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[44]Pfeiffer, *Arbeitsvermögen* [Working Capacity].
[45]Schilcher, "Tacit Knowledge and Its Implications for Knowledge Management," 25–30.
[46]Jessop, "Spatial Fixes, Temporal Fixes and Spatial-Temporal Fixes," 142–166.
[47]Mellström, "Engineering Lives," 169.

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