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Asking for the moon
Or model-based coordination in distributed design

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Abstract. This paper reports on a study of practitioners in engineering design striving to transform their work practices so as to be able to cope with complex interdependencies across global production networks. As a key feature of these budding coordinative practices, practitioners are trying to build computational 'models' of the 'design space' of their enterprise. The paper examines the difficulties they face in developing these models.

Introduction

Ongoing changes in the global political economy seem to be accompanied by concomitant changes in the organization of cooperative work in enterprises and institutions. This transformation is, perhaps, particularly pronounced in manufacturing.

For most of the 20th century, the activities of engineering design and production in manufacturing were typically organized within the framework of vertical corporations controlling more or less the entire process from extraction of materials to final product assembly and from design to production (Chandler, 1977). By contrast, the process is now — increasingly — 'fragmented', to use the expression adopted by economists studying the phenomenon (Arndt and Kierzkowski, 2001; Cheng and Kierzkowski, 2001). The pin-making process described by Adam Smith (1776), in which the craft work of manufacturing pins had been decomposed into a dozen of specialized activities each of which were allocated to a particular workman, has, so to speak, been disassembled and dispersed over a range of specialized enterprises in different locations. Consequently, a large and steadily increasing part of (national and international) trade consists of trade in (simple or composite) components as opposed to final products. That is, on one hand the entire manufacturing process is now being distributed over multiple — sometimes thousands — of enterprises. On the other hand, the constitutive units become increasingly specialized. What emerge, then, are global production networks (Arndt and Kierzkowski, 2001; UNCTAD, 2002; Berger, 2005; UNCTAD, 2005). The topologies may vary; some may look like 'supply chains', others like hierarchies of thousands of small enterprises controlled by a transnational corporation, and others again like proper networks.

A variety of motives are of course at play in this transformation process. In many cases the driving motive is that of reducing the cost of labor by outsourcing to countries with substandard labor conditions. However, other motives, less transient and more sustainable, are also involved, such as the advantages of increased specialization, economy of scale, etc., made possible by the radically reduced costs of transportation and communication (cf., e.g., Harris, 2001; Levinson, 2006).

Whatever the motive, the 'fragmentation' of the design and production process — *i.e.*, its increasingly distributed character — raises acute coordination problems for the participating cooperative ensembles.

The reasons for this are rooted in the nature of design work. In his classic analysis of design work from 1964, Christopher Alexander argues that 'What does make design a problem in real world cases is that we are trying to make a diagram for forces whose field we do not understand' (Alexander, 1964). That is, design is a 'wicked problem', to use the term suggested by Rittel and Webber a few years later: 'In order to describe a wicked problem in sufficient detail, one has to develop an exhaustive inventory of all conceivable solutions ahead of time. The reason is that every question asking for additional information depends upon the understanding of the problem — and its resolution — at that time. Problem understanding and problem resolution are concomitant to each other [... The] process of solving the problem is identical with the process of understanding its nature' (Rittel and Webber, 1973).

Christopher Alexander went on to claim that 'more and more design problems are reaching insoluble levels of complexity' (Alexander, 1964). If this was not obvious when he wrote it, it is evident now, as networks of industrial enterprises struggle to master distributed product design: 'These complexities are compounded drastically when solving a "wicked problem" involves multiple actors, in that different aspects of the problem are addressed by different designers and the interdependencies among these aspects, and hence between the actors, emerge and change as the design project unfolds' (Schmidt, 1998). When design work becomes distributed over global networks of specialized enterprises, the problem becomes malicious.

Our study focuses on describing this challenge to engineering practitioners in production networks and how they try to cope with it.

The study

We ground our arguments in extensive fieldwork carried out in two companies in the automotive industry: *Newcars*, an automobile manufacturer, and in particular *Carparts* on the supplier side. We engaged with these two companies as part of EU Project MAPPER whose objective it was to develop, introduce, and evaluate an approach to 'model-based adaptive product and process engineering'.

In this paper we focus on *Carparts*, which belongs to the 2nd tier suppliers of the Automotive Supply Chain. It produces 'seating systems' (climate control, motion controls, etc.) as well as head restraints, control cables, and gear shifts. It faces problems in managing myriads of highly interdependent tasks in a distributed network of suppliers. It also seeks to improve its 'process of innovation', with a view to developing and evaluating design alternatives for its products.

Empirical material was collected at *Carparts* during two field visits, each lasting several days, in November 2005 and March 2006, with the purpose of trying to ensure that technical requirements be grounded in actual work practices and needs at the user site. During these field visits we had the opportunity, through ethnographic methods, to study a series of activities related to advanced engineering in the company. During our first visit we were able to observe how projects are managed. We followed co-located and distributed meetings, project meetings as well as design reviews, and ongoing work at a series of workplaces in design, testing, and purchase. During our second visit we focused on practitioners' interactions with external suppliers and on the company's ways of managing projects set up specifically for product and process innovation. In addition to this fieldwork, we engaged with various staff in a series of interventions. One of the authors also participated in a number of modeling sessions carried out by the MAPPER modelers with project responsibles from *Carparts*. Our final involvement with *Carparts* was a validation event in November 2007, where we, among other things, were exposed to an approach to product modeling which the internal project manager for MAPPER had developed. On that occasion, we also observed a modeling session dedicated to the creation of a model of collaboration with suppliers including a demo of model-support of customer-supplier design collaboration.

The long-term collaboration with personnel at *Carparts* (which was further strengthened in project meetings of all sorts) allowed us to acquire substantial knowledge of the ways of working in this company and its problems. But we also need to emphasize the limitations of our fieldwork with regard to the use of the modeling approach promoted by MAPPER. The models we will describe are constructed as part of experimentations and have not yet been deployed. They were developed over the course of almost one year by practitioners (in different professional and organizational roles) in collaboration with modelers (consultants, researchers, as well as in-house specialists in modeling). We were not able to actually observe the day-to-day process of modeling but rely on presentations of this process by the internal project manager. However, we have witnessed some the difficulties of those involved in producing these models and the numerous conflicts surrounding this process. Hence, when we refer to ‘modeling’ in this paper, we do not describe an already existing practice. What we look at (and document) are practitioners’ attempts to develop such a practice and the associated techniques as well as their problems with doing so.

A view from the top

The automotive industry launched on a large engineering outsourcing activity in the late 1990’s. This had strong implications for the integration and coordination of knowledge and competencies on the one hand, for the organization of product development on the other hand. Companies such as Toyota, Renault or Fiat implemented the concept of ‘platform’ – units that are based on a core team formed by several professional profiles who follow the whole life cycle of a product. Hand in hand with this a modular product architecture was introduced (Bonazzi and Antonelli, 2003). The strategy was, and still is, to separate component design from developing the concept for a new vehicle. Component design starts well before the concept design for a particular car and involves a panel of what is called 1st tier suppliers. These are strategic partners who are actually involved in co-design and substantially contribute to product innovation (Midler, 1995). Another category of suppliers are those of parts with an influence on styling and where also a high innovation rate is expected – lights, seats, windows, electronics, hydro-forming, etc. This engineering outsourcing activity has been described as a move towards the car company becoming a ‘systems integrator’ (Becker and Zirpoli, 2002).

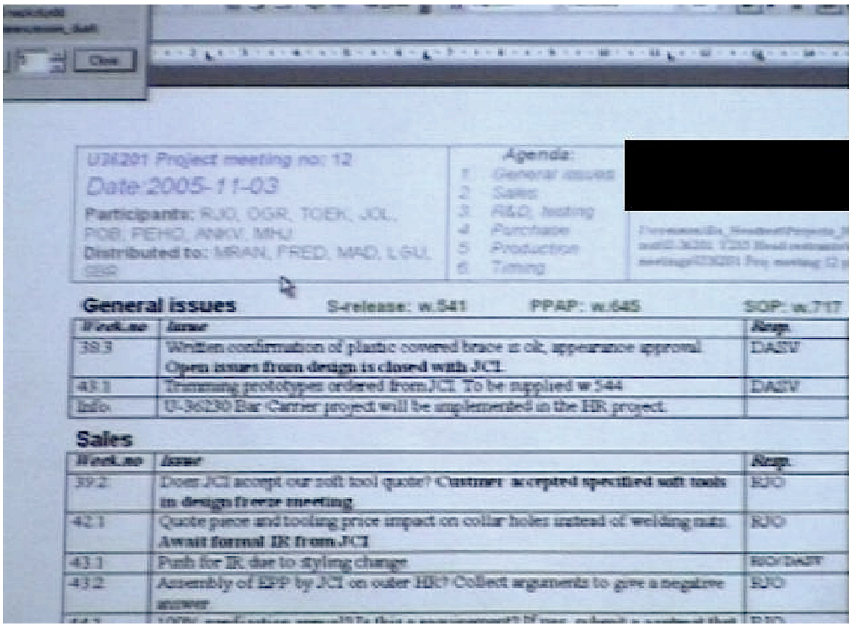
Our case study at *Newcars* focused on one central phase of cooperation with suppliers, the so-called ‘target setting process’. At the beginning of the development of a new car there is the ‘vehicle concept’. As part of this, desired product properties or ‘targets’ are formulated on the basis of a market analysis, interviews with customers and/or a focus group, an evaluation of the competitors, etc. The aim is to identify the main features of the product in terms of security, comfort, sportive performance, price range, climatic comfort, etc. This is also called the ‘voice of the customer’. A ‘performance tree document’ is created which lists the features starting with top-level requirements. Target setting is led by the marketing people in collaboration with engineers. Qualitative criteria for each feature have to be translated into technical criteria and parameters, e.g., system efficacy, or air distribution. Also the price has to be set for each of these features. Different types of engineers are involved: ‘performance engineers’, most of them with a background in Computer-Aided Engineering and virtual testing, have to set targets and perform the first analyses, in collaboration with engineers responsible for systems of physical components (‘RdS engineers’), who have to decide whether these targets are feasible. The negotiation of performance is a complex process involving a large number of suppliers with whom targets are discussed and if necessary modified. The aim is to have modifications fixed in the early phase, since the cost of engineering changes increases as development advances. This is a process of optimizing performance and integration over all vehicle systems and parts. There are often conflicting targets and always conflicts with cost targets.

This process is supported by a range of IT systems. The PLM system (Product Lifecycle Management) contains pertinent information concerning product development (engineering Bill of Materials, CAD drawings, a digital mock-up environment for virtual testing, a specification of the formal process of engineering changes, and so forth), but it only supports the engineering aspects of target setting and not the requisite communication and coordination with the supplier. In fact, within the *Newcars* Group different PLM systems are in use. Similarly, the system for managing the performance tree is proprietary and thus not shared with suppliers, only the SSTS or Sub System Technical Specification system is. Not surprisingly, updating the State of Requirements document after each target modification process takes time. Hence, while formal communication is mediated by the SSTS, day-to-day interactions with suppliers are done by email, phone and, if this is possible, through shared CAD documents. The complexity of this process together with the high dependency with suppliers, many of whom are chosen by Purchasing, creates huge management problems for *Newcars*.

A view from the middle …

From the point of view of a particular work organization in the middle of the network, or rather enmeshed in the middle of multiple networks, the whole thing is even more complex. On the one hand it produces components for a range of customers, often-large corporations, and on the other hand it is itself a customer of a network of suppliers. When components are highly standardized items, commodities, this position is classic and does not pose a particular challenge. Nor do very stable ‘supply chains’ pose a major challenge to participants. The challenge arises and becomes a major one when component designs are not standardized and stable; that is, when customers request different and varying design configurations. The enterprise-in-the-net is then exposed to conflicting force fields. From its customers it is presented with requests and requirements with respect to its products that it will have to find economically viable solutions to: ‘Can we do this at all?’, ‘Do we have a design we can modify?’, ‘Do we have to open a new product line and could we then reuse the new design for other purposes in some modified form?', and in any event: 'What will it cost?' and 'Can we meet the schedule?'. And conversely, as far as its own suppliers are concerned, the enterprise-in-the-net of course poses the same requests and requirements. (New design options may of course flow in the opposite direction, 'up stream', just as legacy design options may disappear from the pallet, for instance for reasons of environmental protection).

Coordinating with these different stakeholders is difficult. It involves, for example, negotiating specifications with several suppliers while routinely resolving the problem of aligning different part-code naming standards, and so forth. Moreover, standards in manufacturing differ across national boundaries and we have witnessed several meetings at which such mundane differences created severe problems.



U36201 Project meeting no: 12
Date:2005-11-03
Participants: RJO, OGR, TOEK, JOL, POB, PEHO, ANKV, MHU
Distributed to: MRAN, FRED, MAD, LGU, OBR

Agenda:
1 General issues
2 Sales
3 R&D, testing
4 Purchase
5 Production
6 Timing

[redacted]

General issues S-release: w.541 PPAP: w.645 SOP: w.717

Week.no	Issue	Resp.
38.3	Written confirmation of plastic covered brace is ok, appearance approval **Open issues from design is closed with JCI**	DASV
43.1	Trimming prototypes ordered from JCI. To be supplied w.544	DASV
Info.	U-36230 Bar Carrier project will be implemented in the HR project.	

Sales

Week.no	Issue	Resp.
39.2	Does JCI accept our soft tool quote? **Customer accepted specified soft tools in design freeze meeting**	RJO
42.1	Quote piece and tooling price impact on collar holes instead of welding nuts. **Await formal IR from JCI**	RJO
43.1	Push for IR due to styling change	RJO/DASV
43.2	Assembly of EPP by JCI on outer HR? Collect arguments to give a negative answer	RJO

Figure 1: Issue list.

At present, managing this complexity relies heavily on documents that have been pre-defined for each project stage and that are meant to ensure 'best practices' as well as accountability. For each stage in the project, the project needs to pass a 'gate', at which point the project manager is supposed to have the required documents ready. This is checked manually by the Steering Committee coordinator and there is a formal signing-off of each 'stage gate'. The standard format for documenting technical information is Excel files. In these documents information is arranged in the form of lists of parts, materials, or tasks organized according to different principles. These lists are produced and used by engineers and their project managers.

A key document in the hands of a project manager is the so-called 'issue list', which is central to handling the weekly project meetings (Figure 1). Each issue list has a header with the project name, meeting number, date, the list of participants, the list of people to whom the list is to be distributed, and the agenda. The form of an issue list ensures that issues are addressed in a particular way. For each issue the list specifies activities, responsible persons, and deadlines. Issues are identified by the number of week in which they have been addressed and a short text. Starting with general issues, most lists we encountered represent, in a rather loose way, a certain order of priority and/or different actors (e.g., R&D, purchase, sales) and/or project stages (e.g., quoting, testing, releasing). There is a particular meeting dynamics around issue lists. At the beginning of the meeting the project manager opens the issue list. S/he addresses each issue, step by step, asking for status information, changing parts of the task description or the deadline when relevant. S/he may also introduce additional issues, specify actions, and so on.

Issue lists are at present the main means for evoking and advancing open issues in a project at *Carparts*. It is also the main means for dealing with uncertainties in as much as the issue list allows practitioners to project complex and difficult issues onto separate and linear tasks, expressed in terms of concrete and simple steps. The list also ensures accountability in that commitments are specified and can be traced as it is made transparent which week a decision on which issue was taken. We can say that the main function of the issue list is to document issues and the related decisions for purposes of awareness, reference, control, and accountability (Jacucci*, et al.*, 2007).

However, there are numerous problems with this ‘document-driven’ way of managing work. Since there is a host of documents ‘behind’ the issue list that needs to be aligned, updated, and shared within the network, much cross-checking, for example, has to happen in the process of negotiating specification parameters with multiple suppliers. To put it bluntly, as it is now the material specification process is unbelievably cumbersome and tedious.

For example, Jill is working on the specifications for a heating wire, a new product. She has improved the specifications step-by-step, consulting with the supplier. She now finishes the third release of the specifications for wires of different width to send it off for signatures to Design and Production. To register a new issue she has to pick an issue number from one of the folders located in the main building. This is a serial number that is totally unrelated to the part number or specific task. Jill signs and enters the date. At the moment she, in consultation with the supplier, specifies the ‘bare single diameter’ because this is a piece of information that the design department needs. For this purpose she examines repeatedly an email sent by the supplier who has specified the nominal weights of enameled products for her. She also changes various text strings such as ‘bunched and reinforced’. At various points she brings out her calculator, checking a value. Jill has to go through each single line in the five documents describing five wires with different width (and part numbers), checking carefully. She then creates a PDF file, inserts ‘sign this document’ and crosses out the part number on a small hand-written list. It takes her almost five minutes to attach all the documents to be sent off: she opens each document to see if it is the right one, even though the file names indicate the part and issue numbers.

To better deal with processes such as the one we have described, *Carparts* has initiated the introduction of a document management tool (PLM), but the introduction is already delayed and has resulted in much frustration with what personnel at *Carparts* perceive as a pressure to produce more and more documents 'for others'. In parallel practitioners started experimenting with modeling as a way of capturing complex interdependencies and, eventually, making processes, such as material specification work, more efficient.

Modeling the design space at *Carparts*

An enterprise-in-the-net such as *Carparts* may, over time, wind up in a quagmire of proliferating product models and variants that will completely neutralize the benefits of specialization and economy of scale. To counter that, such enterprises need to 'map out' the design space, that is, the extant product portfolio (models, variants, alternative components and materials), the design parameters for each product model (i.e., that which can be changed), and the interdependencies of the different design parameters, e.g., 'If you do this, then you also have to change that'.

This mapping effort is a daunting task. It is a cooperative effort of significant complexity, as it involves engineers, designers, production managers, marketing people, etc., who obviously represent different professions, different conceptual worlds, different economic and organizational interests, etc. This would in itself make such cooperative mapping effort of interest to CSCW. But not only that: it is an effort that in the eyes of practitioners themselves might benefit greatly by computer support based on computational representations of interdependencies of design decisions and design tasks, that is, computer support of a kind that is central to CSCW's concerns. This issue was on the agenda of CSCW from the very start and has been pursued under labels such as 'common information spaces' and 'organizational memory'. For good reasons much of this research has focused on the domain of technical design (cf., e.g. Conklin and Begeman, 1988; Subrahmanian, *et al.*, 1994; Subrahmanian, *et al.*, 1997).

What we have observed, however, is that practitioners have, in a strictly experimental manner, actually begun building computational design space maps, or 'models' as they term it.

Now, *modeling* is a concept that is fundamental to engineering competencies but that is apt to mystify the uninitiated, as vividly described by Pepper White in his account of his miserable student years at MIT: When a teacher explains that 'before you can control a system, you need to control the performance of a system', but 'once you know how to model things, you can model anything', White, perplexed, thinks to himself, ‘Model. Model. Model. Eventually I’ll be able to use that word without blushing’ (White, 1991, p. 121 f.). Ultimately, however, White begins to understand the concept: ‘Model. Key word. So an abstraction is like a model. And a model of a system may be composed of linked models of smaller systems, or subsystems’ (p. 218). — No surprise then that engineers, faced with the challenge of configurable design in production networks, would approach the problem as one in need of ‘modeling’.

While a ‘key word’ in engineering culture, the term ‘model’ is a source of ambiguity in that different stakeholders use the words ‘model’ and ‘modeling’ differently. Models of different kinds in fact abound in the industrial world, typically engineering models (energy flow models, mass transfer models, etc.), but also process and product models and models of organizational structure, workflows, etc. Professional ‘enterprise modelers’ on the other hand talk about ‘powerful’ models in support of collaborative business networking. The models we talk about here and that practitioners at *Carparts* are now asking for, are not engineering models and so on but models of the *design space*, that is, computational models that may reduce the cost and effort required to manage the design space, including design options, costs, process of innovation, etc. as well as the concomitant *workflow models*.

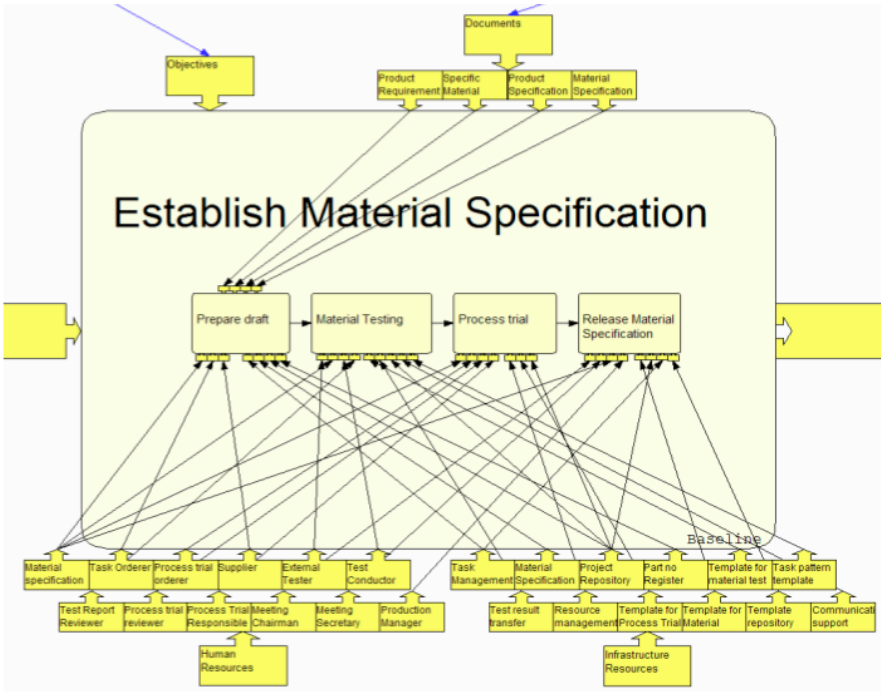


Figure 2: An example of a task pattern: material specification (fragment).

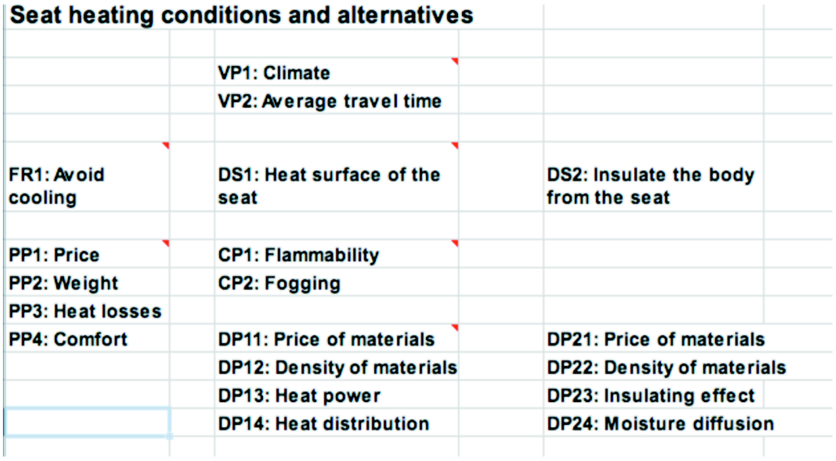
The ‘modeling approach’ was introduced at *Carparts* in a situation of increased pressure for ‘innovation’ (several projects had been set up to ‘improve the process of innovation') and it competed from the start with the not yet implemented document management system PLM.

An approach to 'enterprise modeling' named Active Knowledge Modeling (AKM) was presented to the project team at *Carparts* - 'knowledge sharing' computational platform and associated 'methodologies' designed for the purpose of mapping relationships between products, organizations, processes, and systems of an enterprise (Lillehagen and Krogstie, 2002). The team at *Carparts* created several models using AKM during the first two years of the project. These resulted in so-called 'task patterns' for, e.g., the material specification process, which we briefly described (Figure 2), but also for more generic activities such as preparing and conducting a meeting. However, working with these task patterns in a small pilot trial did not convince practitioners. Not only was the tool difficult to handle due to a not well-designed user interface; but working through highly detailed sequences of tasks proved cumbersome. After a long debate it was decided to focus on product modeling and at the same time to provide a new interface called Configurable Virtual Workplace (CVW). The main idea was to connect product with process descriptions and to support practitioners in arranging tasks and subtasks connected to their own specific activities, such as design or production, around the product-in-attention.

Modeling a product requires what in modeling jargon is called 'externalization of product knowledge'. This can be done on different levels: by expressing concept and solution principles, properties and parameter structures, functions and services, systems and capabilities, forms and features, material and appearance, location and spatial relations, environmental aspects, costs and economic concerns, legislation and standards, production and maintenance, life-cycle and end-of-life considerations (Carstensen*, et al.*, 2008). A 'complete' product description, or so runs the argument, facilitates working with 'views' that focus on the aspects needed for the current work, while ensuring consistency across views in a comprehensive manner.

While the general ideas behind this approach seemed clear, it took practitioners at *Carparts* some time to 'discover' how to build useful product models and what to do with them. The experiences we describe are the outcome of a process that was driven by the 'use-case manager'. We call him Paul. Finding the initial modeling sessions within MAPPER unsatisfactory, he was delighted when he came across a PhD thesis on product modeling for configurability in manufacturing: he scrutinized every page and began producing small conceptual models, first with Excel, later with the MAPPER modeling tool. He set up a small user group, including a CAD technician and two interns, and they began working, undertaking on average one modeling session per month. The idea was to create a complex product description by decomposing the product into Configurable Components (CC) as well as material 'requirement components', and to attach to each of these components a set of validated variant parameters, product properties range, and interface requirements (Tellioğlu, 2009).

The team decided to start with simple examples and to work their way bottom-up to more complex product descriptions. They chose to work with seat heating and first spelled out the seat heating conditions and alternatives for the requirement ‘avoid cooling’ (Figure 3), systematically listing all relevant parameters. Paul describes how difficult it was to agree on the parameters that define product variants: ‘*We have been spending a lot of time [trying] to identify what in the product variation should be modeled as a performance parameter [PP], what should be modeled as a design parameter [DP], what should be modeled as a constraint parameter [CP], and what should be modeled as a variant parameter [VP]. And there were no real guidelines of what is what*’.



Seat heating conditions and alternatives

	VP1: Climate	
	VP2: Average travel time	
FR1: Avoid cooling	DS1: Heat surface of the seat	DS2: Insulate the body from the seat
PP1: Price	CP1: Flammability	
PP2: Weight	CP2: Fogging	
PP3: Heat losses		
PP4: Comfort	DP11: Price of materials	DP21: Price of materials
	DP12: Density of materials	DP22: Density of materials
	DP13: Heat power	DP23: Insulating effect
	DP14: Heat distribution	DP24: Moisture diffusion

Figure 3: Product description in spreadsheet document created by Paul at *Carparts (fragment)*.

The next step was to create a model of ‘seat heating’. When designing a seat heater, materials have to be chosen for the carrier, the assembly glue, and the seat heating conductor (see Figure 4). As regards the carrier material, the team identified elasticity, environmental footprint, and cost as the main factors, and polyester fabric plus foam and polyester felt as the currently available materials. Having gone systematically through these requirements and confronting them with the currently available choices, their conclusion was that there was a missing combination of properties on the market – ‘PUR free and highly stretchable’ - and that *Carparts* might have found a carrier material they could sell, since none of its competitors uses it.

Paul’s story goes on with the modeling of other components, such as the glue material and the heating wire. For the latter, the heating wire, requirements or properties (electrical, mechanical, failure modes, cost), design parameters (conductor material, thickness of strands, surface layer, fiber reinforcement) were defined, and the option of serial versus parallel circuits was identified as an additional parameter influencing the choice. In this case the choice was between sinus wires and alloyed wires. Here their conclusion was that 'very thin copper strains with fiber reinforcement would be ideal'. However, constraints of production have to be taken into account: '*… but in reality we are using the alloyed wires, because [of] the constraints in production: the wire layout with the fiber enforcement wire is not doable. And if you add in PVC and insulated wire then there are constraints in peeling insulated wires; so then you will damage the wire*' (Paul). He took this as evidence for the fact that design choices are interdependent and may have repercussion for production: '*So this [is] why we say that the configuring of [a] product should be extended also to configuring the production*' (Paul).

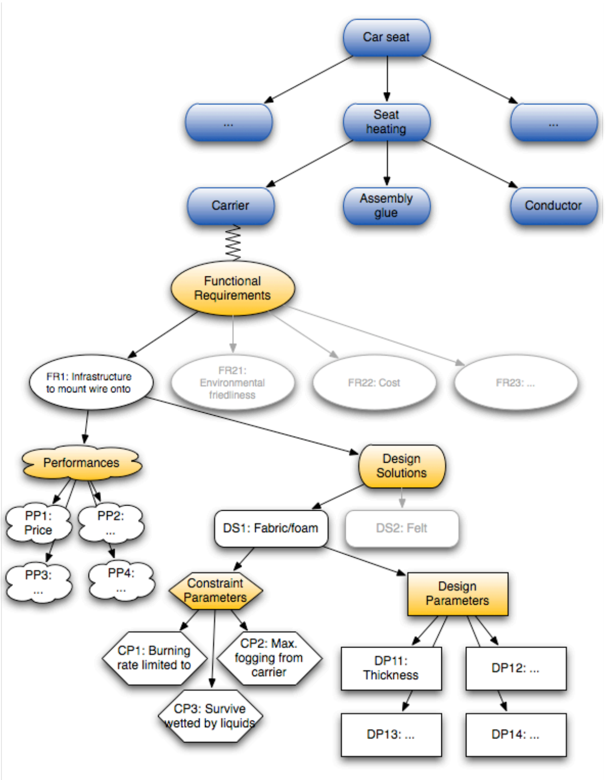
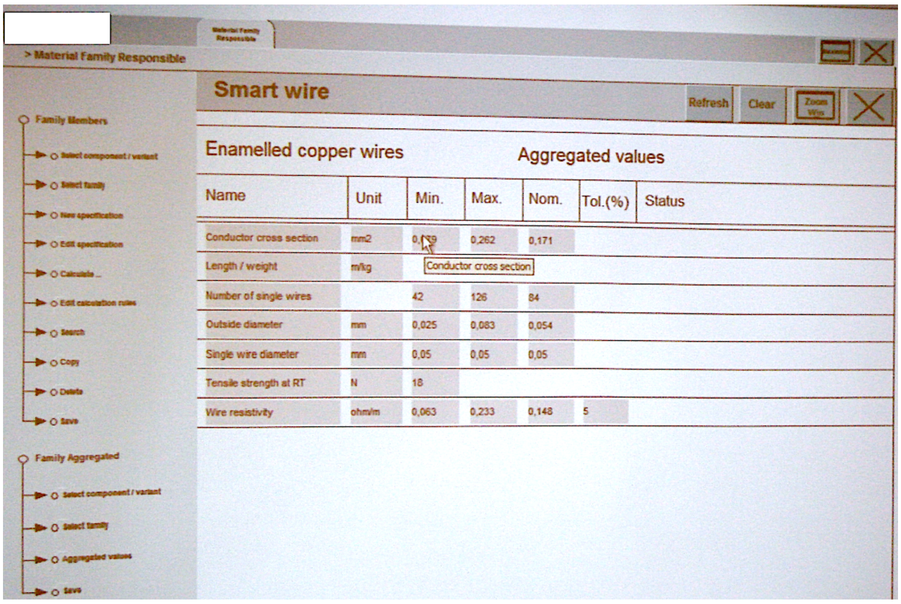


Figure 4: Model of the product part 'carrier' at *Carparts* by using Configurable Components (CC)

These more conceptual exercises motivated practitioners to take a step further. The simple product model was enriched with a small executable part that should help them probe how to support their collaboration with suppliers (Figure 5). The scenario was the following: Jane, the responsible for material specifications at *Carparts,* opens the graphical workspace of the modeling tool, searches for a specific wire and enters a specification for resistivity. As a result, the customer responsible at the supplier involved is notified; he edits his own specifications in his own Excel file, and Jane then receives and reviews the result. In this way a specification document is built, turn by turn, both parties seeing exactly the same data while the 'secrets' of each party (ownership of data and formulas) are safeguarded. In this scenario the responsible for a specific family of materials can also see the aggregated values and compare them to the customer request.



Smart wire

Enamelled copper wires

Aggregated values

Name	Unit	Min.	Max.	Nom.	Tol.(%)	Status
Conductor cross section	mm2	0,[illegible]9	0,262	0,171		
Length / weight	m/kg					
Number of single wires		42	126	84		
Outside diameter	mm	0,025	0,083	0,054		
Single wire diameter	mm	0,05	0,05	0,05		
Tensile strength at RT	N	18				
Wire resistivity	ohm/m	0,063	0,233	0,148	5	

Figure 5: Editing specifications in distributed teams at *Carparts*.

Other practitioners saw this simple executable model as a good checklist: '*you can see the status [of the specifications] and can highlight the risks from the beginning*'. They were not only interested in adding more details to the model but pointed to the value of implementing design rules – '*there are so many rules around wires – so as to be able to replace the [spreadsheet] tools we are working with now*'. They could also imagine using the model for prioritizing sales options: '*Sales is very impatient, even for early quotations; if they have the tool they could see for themselves*'.

The importance of managing complex design decisions within *Carparts* in relation to its numerous suppliers was also highlighted by a quality problem that had come up the year before: it seemed a 'hot topic' at that time but got forgotten when the responsible employee left the company. The problem had to do with the quality of the lamination between two foam layers and had been noticed by one of their customers. Thorough analysis of this case had made it apparent that there had been a failure on the side of *Carparts* in communicating certain material specifications to one of its suppliers, which had several repercussions. Paul used this example to propose a model that captures the status of requirement specifications with different suppliers.

Paul comments: '*This is an important lesson for the product modeling [effort]. If we don't catch the product requirement, then we will not catch the business agreement either. Once it comes to things, once it appears false in the deliveries, then you must know whom to blame. And these specifications are the basis for* *[deciding] whom to blame. So I mean, if we have a better specification of the products, then we are safe in our business agreement.*' His idea was that 'alarms' for missing requirements could be built into the model (e.g. 'no action needed' (green), 'start negotiate the requirements' (yellow); 'request missing requirements' (orange); 'start develop new solution or don't quote' (red)).

Paul's story describes a progression from, at first simple, 'conceptual' product models to, still also quite simple, executable models based on these product models. It also indicates a diversity of open questions. A key question is which properties of a product to make visible. As the small examples show this is dictated by practical concerns. What the relevant design parameters of the heating wire are – 'conductor material, thickness of strands, surface layer, fiber reinforcement' – results from the current practice at *Carparts*. But it also depends on where *Carparts* thinks they can innovate, or where they think one of their suppliers could contribute something, or on new requirements, such as the EU directive concerning lead-free components. When building such models the critical issue is to capture the relevant permutation options: to which extent can practitioners rely on the completeness of these product descriptions in a model that has been constructed for specific design purposes?

CSCW research has quite early pointed out that 'the cooperative ensemble reproduces the multiplicity of its environment in the form of the multiplicity of "small worlds" of professions and specialties' (Schmidt, 1991, p. 6). Hence the challenge of bringing multiple, incommensurate perspectives together. As Paul described, it is this incommensurability that is so hard to resolve: 'where he [a modeler] used variant parameters, he should have been using performance parameters', and so forth. For example, addressing the question of how many configurable components to define and on which grounds to decide this, Paul observed that a supplier has other ideas about what to maintain as configurable than has a car manufacturer for whom it is the car part as a whole that is of interest. All these decisions are by no means arbitrary, but they become exceedingly difficult when multiple perspectives are involved.

The issue, we find, is that selecting parameters depends on the particular perspective that practitioners apply and the context for which it is needed: 'there is no best model', somebody remarked. In the sciences and in engineering, modeling is a (typically quite systematic, sometimes rigorous) procedure of abstraction for creating useful representations of aspects or sections of the world. It is purposive, therefore internal to a specific practice. No model of a given section of the world is 'true' or 'false' in splendid isolation from the practices to which it belongs. Rather, models are 'useful for the purpose', or 'not so useful', as the case may be. — 'Useful for the purpose', but for which purpose? Different practices (e.g., concerning production and procurement of insulation, wiring, adhesives, fibers, as well as sales) are characterized by different concerns; they address different aspects or sections of the world with different structural and dynamical characteristics, and they thus conceive of the world differently, apply different criteria of importance, success and failure, etc. Consequently, when it comes to modeling, practitioners of different branches of engineering design have different perspectives that in turn indicate a notion of central object or 'unit of analysis' as well as criteria of what to 'foreground' and 'background' in modeling.

Moreover, even within a given perspective, relevant trade–offs dictate preferences in modeling commitments. The top level trade–off is 'what' in the entire world to include or not include in the model's explicit representation, depending on the costs of handling (gathering, eliciting, validating, maintaining) the requisite information in the model, versus the advantages gained by using the model. Other crucial trade–offs exist in structuring the model, especially in the choice of level of 'granularity' (level of detail) and of 'specialization' (depth first) versus 'multiplicity' (breath first).

These concerns run deep and cannot be dealt with once and for all. They are here to stay. However, there are also severe limitations with current modeling notations and techniques that may, conceivably, be resolved or amended.

Existing modeling notations are quite generic. There are first of all difficulties with expressing modeling primitives and relationships at the appropriate semantic level, that is, in categories such as, e.g., 'part/whole', 'cause/effect', 'pending/decided', etc., as opposed to the highly abstract categories of the object-oriented paradigm such as 'object', 'class/member', etc. To overcome these limitations, modelers have introduced the notion of 'templates'. As opposed to the generic notation of object-oriented modeling, 'templates' offer a specialized notation and a library of specialized objects and relationships that have been predefined in a 'meta model': 'the specification work can be significantly reduced by describing the manufacturing or logistics system by a re-usable template, and store it within a library for later use […Structuring] the templates in an object oriented class structure saves modeling effort and at the same time supports additional transparency as well as some standardization' (Rabe and Jaekel, 2002). Behind the 'templates' are different 'approaches', such as POP* (Process, Organization, Process and System), ICOM (Input, Constraint, Output, Mechanism) and CPPD (Collaborative Product and Process Design). (For an informative review of 'process modeling languages', cf. (Mili*, et al*., 2003)).

The choice of template obviously determines what kinds of relationships (hence perspectives) can be modeled (hence expressed). For example, during another modeling session in the project a modeler explained: '*Part of planning and setting up a modeling environment is to select the right kind of modeling template, the right kind of modeling languages. But [most] likely, since you can add new things later, depending on the needs as they arise, it is rather flexible as well. You can start modeling using simple templates and add as things go along*'. Choices were formulated in terms of template names, such as 'in this case I think we will use ITM [Information Technology Management] or BPM [Business Process Modeling]' or 'so we should use a BPM template and not a CPPD template'.

More debilitating, however, existing modeling approaches implicitly presume hierarchical topologies and thereby seduce users to artificially try to enforce orthogonal distinctions onto other forms of relationships. This makes it exceedingly difficult to express complex interdependencies. This limitation may be related to the presumption that relationships necessarily must be represented in the form of two-dimensional graphs in order to be 'user-friendly'. This assumption may turn out to be a prejudice.

Finally, given the enormity of the challenge of building computational design space models, whence the rush? We have no way of answering the question. But some explanations seem likely. Firstly and obviously, there is the competitive pressure that permeates everything that goes on in manufacturing and engineering design. It may, on the ground, foster irrational behavior and unsustainable solutions, but it is institutionalized in budgets, in annual and quarterly targets, in performance measurement systems, etc.

But there is also a certain ethos in the engineering approach to modeling which was nicely expressed when Pepper White's teacher at MIT said that 'once you know how to model things, you can model anything. It does not matter whether it's a mechanical, fluid, thermal, chemical, electrical, or biological system. The concepts of modeling are the same' (White, 1991, p. 122). Given such an approach, rushing in would be the norm. It would also make one inattentive to the incommensurate conceptualizations of, say mechanical, electrical, and organizational systems.

This rather rush approach to modeling is also reflected in the observable proclivity to extend the object of modeling from the factual (e.g. work processes and products) to the not so factual (e.g. contractual arrangements, trust, knowledge), as we can for example see in the conclusion Paul draws from the example of the not specified requirements: '… if we don't catch the product requirement, then we will not catch the business agreement either'. And then from static object structures to evolutionary dynamics, assuming causal dependencies in people's actions and disregarding intentions, encountering vast opportunities for disaster.

Asking for the moon

When visiting Cuba shortly after the revolution, Jean-Paul Sartre had a conversation with Fidel Castro. At one point in the conversation Castro said that the revolution would get people whatever they requested, to which Sartre raised the sensible question: 'What if they asked for the moon?' Castro thought for a moment and replied: 'We may not be able to get it for them, but we would understand that they *need* it.' (Sartre, 1961)

When workers at *Carparts*, *Newcars*, and many other enterprises are engaged in developing and tentatively pursuing a strategy of constructing computational models of the enterprise–wide design space, in order to find a way of coordinating internally and with other enterprises in global production networks, they may indeed be 'asking for the moon'. What they do may eventually turn out to be impossible but that does not discount the obvious need.

Trying to meet the different and varying requests and requirements of their large customers in the automobile industry and at the same time trying to sort out their network of suppliers, the practitioners at *Carparts* are engaged in a very demanding exercise. The received ways of doing this, relying on a network of (passive) documents and a flow of documents is seen as increasingly inadequate. They *need* 'active documents', that is, facilities that can automate their work of keeping track of design interdependencies.

These conceptual and practical problems exemplify what Bittner (Bittner, 1965), in his brilliant essay 'The concept of organization', wrote about organizational rules, arguing that the sense of a organizational rule (and, *a fortiori*, a model) is relative to the practice for which it has been devised. This is reflected in his suggestion to 'attain a grasp of the meaning of the rules as common-sense constructs from the perspective of those persons who promulgate and live with them' [p. 251]. Interestingly he refers to the role of organizational rules in linking affiliations between entities (people, tasks, parts of a complex product, and so forth) that 'are too remote for contingent arrangement'. Organizational rules help people link those entities into 'coherent maps or schedules' where 'each link derives its meaning not so much from the specific rule that determines it, but from the entire order of which the rule itself is a part' [p. 252]. That is, organizational rules (or models) are constructs members of a particular organizational unit or profession define in order to connect with elements that are outside the scope of their own direct influence. How these rules are understood and evoked depends on the situation, practice, and perspective of the involved actors. With this argument Bittner points to the fundamental ambiguity and openness of rules but also to their power in linking things that are remote — geographically and socially, but also conceptually.

A way to conceptualize *the specifics* of the kind of budding practice we have observed would be to discuss it under the perspective of the concept of 'boundary objects' (Star and Griesemer, 1989). This term was introduced and is being used to denote artifacts that, at the boundary between different local practices, facilitate loosely coupled collaboration between these communities. In the words of Bowker and Star:

'Boundary objects are those objects that both inhabit several communities of practice and satisfy the informational requirements of each of them. Boundary objects are thus both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use and become strongly structured in individual-site use.' (Bowker and Star, 1999)

The models under tentative construction at *Carparts* were obviously conceived of as something akin to boundary objects, in as much as the models were deliberately designed to be far less detailed than the CAD models of products and parts already in use. Practitioners at *Carparts* and modelers thus made an interesting distinction between CAD drawings and product models. The product model provides a simplified view of each part of the product, hiding much of its complexity. Contextual knowledge can be added, as well as information on pending issues and on related tasks and responsibilities. That is, each model is not just a drawing; it has property sets.

Anyway, whatever their current status, what workers at *Carparts* are trying to construct goes beyond boundary objects in that the product model is obviously intended to regulate local action in a rather strong sense. This, then, poses the problem they are struggling with: they are trying to construct one integrated and overarching model for heterogeneous practices, not a family of related models representing different perspectives. In other words, what they are up against is that representations are local and temporary closures (Gerson and Star, 1986).

Now, building one integrated and overarching model may very well be the only viable approach. But it might just as well be a prejudice, if not on the part of practitioners at *Carparts,* then a prejudice on the part of developers of notations and tools of modeling. That is, perhaps a family of related models would be more feasible: more appropriate for a bottom-up process of model construction; more appropriate for involving, expressing, integrating multiple perspectives.

Modelers within MAPPER were principally aware of these problems but they were also convinced that they had the right approach to addressing them in efficient ways. A modeler at *Newcars,* for instance, demonstrated his acute awareness that a multiplicity of models is required when he talked of his approach as a war room: *'The idea is that for each wall of this room you have different models representing different domains. You have an expert for each of these walls and when you are in the middle, you just can give a look to all these models and try to see the connections between process and organization, product and system'*.

While reproducing the myth of an omniscient observer who can instantly see and grasp all the connections (when placed 'in the middle'), this proposal also, albeit implicitly, demonstrates that current modeling technologies are deficient when it comes to expressing the relatedness of perspectives and thus supporting the interconnectedness of heterogeneous practices and leaves it to practitioners to figure that out themselves, as they have always done.

Existing technologies of modeling are very flexible when it comes to building models in a piecemeal fashion and then connecting them, just as they offer the flexibility of choosing different modeling approaches and notations. However, the current modeling environments are lacking when it comes to expressing the relatedness of models from different perspectives.

That is, there is definitely a room for CSCW research to fill this gap between monolithic models and disconnected models. In fact, there is not only a room, there is a need.

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