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Are Skill Design Structure Matrices New Tools for Automotive Design Managers?

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1. Introduction

The 2000s have been marked by significant change both in the nature of the vehicle and in its design process. The car satisfies an ever-present need. It longitudinally, autonomously and safely carries a reduced number of passengers and goods. In the future, acceptable vehicles must achieve requirements like reliability, safety, drivability, low gas consumption, minimal environmental footprint, low cost... The satisfactory solutions the designers are expected to offer can not be considered as pure mechanical systems. They integrate coupled functional modules that are embodied in multi-physical components (mechanical components, electronic or electrical devices, embedded software...). Their design requires skills that are "new" from the automotive design managers' viewpoint. The issue concerning the identification, evaluation, building and modelling of skill networks opens promising ways for researchers and practitioners. Thus the purpose of this chapter will be to define the concept of skill network and to explain how it can be mapped by using "Design Structure Matrices" (DSMs) (Browning, 2001).

This chapter will be illustrated with an example concerning a French automaker's design office (Bonjour & Micaëlli, 2010). It aims at developing vehicle organs. These ones concern the powertrain system and the chassis. Their life cycle exceeds two decades. Thus designing them consists in developing a product family compliant with different platforms, models or generations of vehicles. These organs are mass produced. Since 1997, the mentioned design office of over 5,500 designers has been structured according to the systems engineering principles and processes (ISO 15288). Depending on the project, its technical activity partially or totally covers the Vee cycle. In this chapter, we shall not address the issue of skill network identification, mapping and building from a global viewpoint, but from a local one focused on the intermediate layer of the Vee cycle, namely the design of functional architectures. We therefore describe how the skill networks related to this task are restructured.

The remainder of this chapter is structured as follows. Section 2 defines the concept of skill network. It also proposes a conceptual framework including close concepts (job position, profession, core competence...). Section 3 outlines examples of skill networks and the

structuring principles. Section 4 presents the principles that help to identify and structure skill networks. Section 5 describes the proposed method and its application in the case of a powertrain design office and finally, section 6 discusses perspectives concerning the use of this approach for developing specialized knowledge and related skill networks.

2. What is a skill network?

Since Wheelwright and Clark’s work (1992), design managers have considered that matrix management complies with the organization of design activities. A design office is seen as a structure combining a portfolio of design projects and a portfolio of skills. Project managers bundle several teams in a given project and different skills in a given team. It has also become usual for researchers to develop sophisticated methods optimizing design project scheduling or team building. Little work has been done to explicit the concept of skill. Authors have most often an impoverished vision of this notion. A skill would be a stock of “commodities” corresponding to the knowledge workers store in their brain (Gherardi, 2007). The project manager would pick up required skills in this stock, as does the consumer to a supermarket shelf. The project manager would have in mind a good deterministic model. For such a project, for such a list of requirements, he/she perfectly knows the kind of tasks, teams, skills, internal designers or providers required to achieve it. He/she would behave as an “arbitrageur” (Lachmann, 1986). He/she would balance the value and the cost of each skill and assess the ability level of his design office. If a given skill has a poor value, if the design office ability is low, and if the “transaction costs” (Williamson, 1985) are low, then he/she will outsource it. Otherwise, he/she will behave in miser. He/she will consider the skill as a core competence. He/she will protect it the best he/she can. Table 1 represents the project manager’s alternatives that extend the 'make or buy' choice. It shows an option in which he faces with a dilemma. Another option is also very difficult to manage. It concerns the situation in which co-design and long-term partnership with a supplier is required. This situation tends to become dominant in the automotive industry.

Design Office ability	Value of the skill	
	<i>Low</i>	<i>high</i>
<i>low</i>	If the transaction costs are low, then outsource the skill (buy)	If the transaction costs are low, then co-develop the skill
<i>high</i>	Dilemma	Develop the skill (make)

Table 1. Project manager’s make or buy choice.

The vision of the project manager as arbitrageur is based on three implicit assumptions: 1- the designed product is modular, 2-the content of projects, tasks and teams’ work can be completely defined, 3- skill is a static entity. According to the pattern described above, a bundle of skills develop a single module, and this module satisfies an isolated set of requirements. Therefore, the project manager can easily define the required skills and coordinate them. If the product architecture is “integrative” (Sosa et al., 2003), then the

organizational problem he/she copes with is more complex. Skills integration in design projects does not consist in buying and using separated skills. The project manager must create and implement workplaces facilitating intra-team and inter-teams learning. His main question is not: what skills to buy? But: how to facilitate shared “exploration” (March, 1995) of the design problem and cross-learning between teams or skills (Lester & Piore, 2004)? What is important then for him/her, is not the static attributes of the skill (what is made for? Who possesses it?? What is its level of expertise?), but its evolutionary ones (what is its potential of learning? How to change it during the project? By linking with what other skills?). This list of questions leads the manager to rethink the notion of skill. It can no longer remain ill-defined. The way we suggest is to define a set of separate entities closed to the notion of skill:

- a skill is defined as a functional concept. It consists in specialized knowledge "owned" by a design actor, who can be a designer or a design manager. Its main attributes is its function,
 - a profession is understood as an evolutionary concept. It can be seen as an evolving set of specialized knowledge possessed by individuals, shared by a working community (or skill network) – socially recognized –, and re-built due to long-term processes. The profession gives them a common and perennial identity. They see themselves as a set of peers,
 - a job position defines the workplace in which the design actor performs his/her “working activity” (Engeström, 1987) in a given organization called design office, project team or design department,
 - a skill network is both an evolutionary and a functional concept. It consists in a community within which expertises are developed. The boundaries of a community may be contained in those of the firm (bounded community) or be more extensive (boundless community),
 - a professional path describes the potential transfer from one job position to another one.
- Every organizational entity of a design office can be seen as a skill network. Thus a design actor may participate to three skill networks: the project team, the department, and the “community of practice” (Wenger et al., 2002). The design manager can formalize a skill network as a functional department and as a project team. The project team is an organizational entity that has a limited life. Its goals are operative. They are focused on short or medium term. The department is a perennial organizational entity. It can support a “design core competence” (Bonjour & Micaëlli, 2010). The life of a community of practice may exceed that of a team or a functional department. This structure is also less hierarchical and fuzzier than a formalized organization (Wenger et al., 2002), e.g. a project team or a design department.

The design manager can bundle designers within these different skill networks by using various criteria (see later). DSMs promoters underline the fact that this tool can be used to structure the design office (Sosa et al., 2004). They pay their attention to the operative level. Each designer has a job position corresponding to a role he plays into a project team. Therefore an Organization_DSM can be used to map the expected flow of data between job positions. It is helpful to bundle job positions within a same team and reduce coordination costs within the project. A job position is also responsible for performing expected tasks. A Process_DSM can model the precedence between tasks within a design process. This last variety of DSM can minimize the feedback loops in the project. A design task contributes to

the design of a given component. A Product_DSM can represent the interfaces between components. One clusters them into modules in order to minimize the interfaces within the system. These three types of DSM have been commonly studied in the research community working on the DSMs (Browning, 2001).

Fig. 1 depicts the conceptual framework we propose to better understand the concept of skill network. This framework is presented by means of the Unified Modeling Language (UML) class diagram. The left part of the figure shows the cognitive, communitarian and organizational entities previously mentioned (profession, job position, skill, skill network, community of practice, design office, project team, department...). Its right part contains the design management domain (design manager, DSM...).

Until now, DSMs have not been used to cluster specialized knowledge according to their cognitive proximity, in order to identify relevant skill networks. The design manager can use the results provided by these tools in at least three ways. Firstly, he/she may decide to perpetuate the identified skill network as a functional department. Secondly, he/she may encourage experts to build a community of practice to explore a particular problem. Thirdly, he/she may suggest his/her company and its suppliers to consider the institutional conditions for recognition of a new profession. In all cases, he/she does not act directly on the knowledge 'owned' by individuals. He/she structures their future working activities. Table 2 can help him/her to identify the skill networks within the design office he manages. This table reuses the entities of the “model of the activity” proposed by Engeström (1987).

Question	Entity	Current Case Study
Who possessed the skill?	Design actor and his community	System architect
Who recognizes the skill?	Alter	Design manager
What is its content?	Object	To develop a powertrain system satisfying key requirements
What does the professional?	Tasks	Requirements analysis and architectural design
What are his tools?	Tools	Systems engineering standard, models, software
What is the content of his specialized knowledge?	Knowledge, expertise	Architecture principles, technological knowledge that enables to link requirements and architectural elements
Who are his peers?	Community	Systems engineering community
With what other communities are the links?		Communities of specialists of embodiment design, software engineers...
In which organizational entity does his job position fit?	Division of labor	Design office, department, team...

Table 2. Activity-based definition of a skill network.

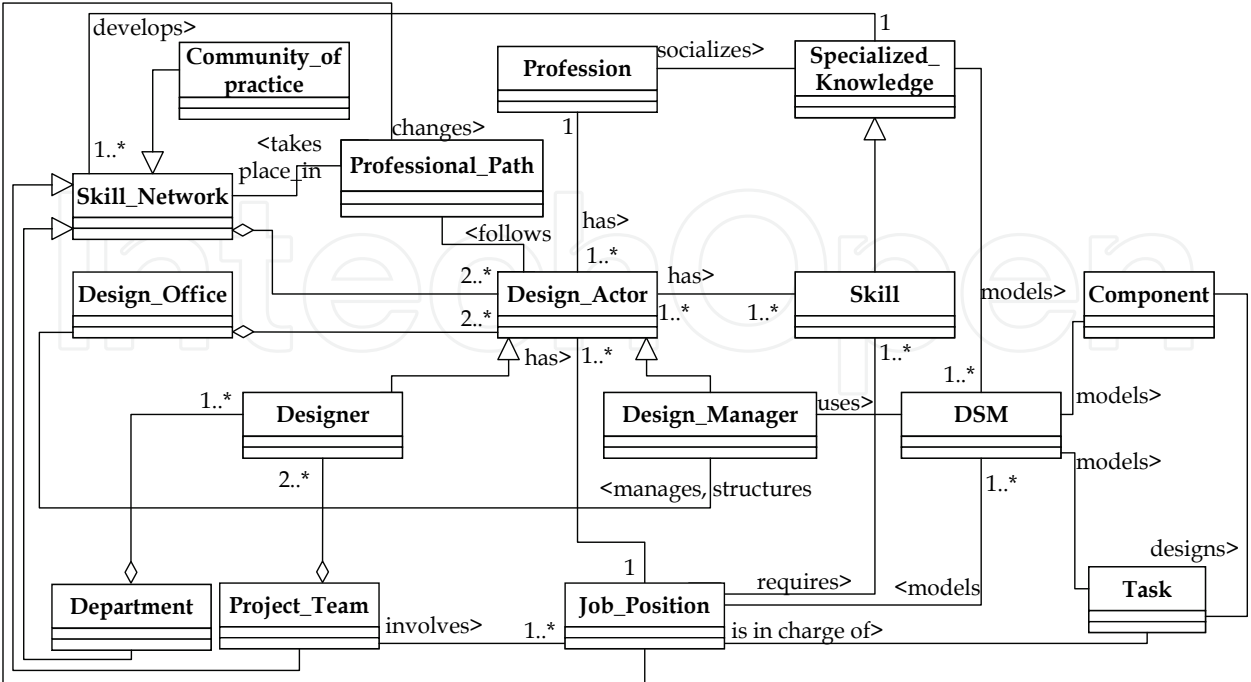


Fig. 1. Skill network conceptual framework.

3. Examples of skill networks

In 2003, the design office that was in charge of the chassis design was decomposed into functional departments. The design manager used two criteria to structure this organization:

1. the nature of the design task,
2. the nature of the designed object.

For instance, a first functional department was responsible for the architectural design (design task) of chassis (designed object). Another one was responsible for the integration and validation of chassis. Chassis were seen as a system composed of axles, suspensions, steering and brakes.

Therefore, functional departments were responsible for the architectural design of axles, of suspensions, power steering and brakes. Other departments were in charge of the integration and validation of these organs. The department related to the architectural design of axles was composed of the following job positions: axle system architect, modelling and simulation of mechanical systems, CAD (Computer Aided Design) definition (profession known as projector), specification of simulations and physical tests for risk mitigation, team leader. A project team was composed with designers who played these different roles. These job positions were found in other departments such as the architectural design of the suspension. Of course, some differences exist between functional departments, due to the difference between designed objects.

Only one skill network related to CATIA V5 was recognized through these two functional departments. Its purpose was to develop specialized knowledge related to the recognized profession (projector) who was in charge of the CAD definition. Several reasons may explain this fact. Firstly, design managers underestimated the need for boundless skill networks.

Secondly, they did not recognize the other job positions as professions. Thirdly, their knowledge was not judged important enough to justify that designers spent time to create and develop communitarian knowledge. The harmful consequence was that the experience feedback throughout the chassis projects was rather poor. Moreover, we diagnosed another delicate situation. Acoustics was specialized knowledge to help designers meet a key requirement related to the customers' comfort (reduction in noise and vibrations). An expertise in this domain requires at least a decade of experience. But the turnover that was imposed to engineers led to a dissemination of the skilled individuals. An effective community of practice, with leaders, experts, junior engineers, apprentices, should have been built and reinforced.

A second example of skill networks identification can be given. Within the design office that is in charge of the design of powertrain and chassis, we can cite the following job positions: requirements analysis leader, system architect (responsible for system architectural design), design project manager. These job positions are linked to systems engineering processes (ISO 15288). Within the functional department that is responsible for the powertrain system design, the design actors form a recognized skill network. Its purpose is to develop world class knowledge in powertrain engineering: specification, architecture, modelling and technical synthesis (acoustics, chemistry...), integration and validation of powertrain. Career paths (syn. professional paths) within this skill network are possible across these job positions.

Within this design office, the profession of project manager has been also officially recognized. A specific department, called engineering management, has been formed in order to use and to develop specialized knowledge related to project management at the system level. Different names have been attributed to these job positions, e.g. product-process pilot. He/she coordinates the design of sub-systems. According to the system decomposition level, different job positions have been identified. Project leaders intervene at the sub-system level. Team leaders operate at the level of the components. Project leaders and team leaders are assigned to functional departments. Together they form a community of practice. Last but not least, professional paths exist between those job positions.

4. Skill network mapping

How to put Skill_DSM into practice? A skill network is supported by something which is shared by several design actors. It may be a designed object (engine, gearbox, chassis...), a design task (requirements analysis, architecture, validation...), a disciplinary field (chemistry, acoustics, reliability, project management...), a shared-cost tool (CAD, test benches...)... Expressed differently, all design activity entities (designed object, design task, disciplinary field, tool...) can be used as skill network identification criteria. The design manager can use one or the other. A single well-defined criterion does not exist. If he/she adopts a bottom-up approach, then he/she will consider first the profession. If he/she adopts a top-down approach, then he/she will consider first the designed objects, the design tasks or the tools.

If one returns to the example of the design office responsible for chassis development, one can see that its design manager has followed the following steps to structure it:

- the chassis was divided into several functional modules (product breakdown structure). Thus the design manager adopted an object-based approach (top-down approach),
- the design tasks were defined following Systems engineering standard (ISO 15288),
- the job positions were both defined following Systems engineering and automotive professional standards,
- each functional department was defined by mapping a module to a set of tasks, so a set of job positions.

This organizational design facilitated “dialogue” (Lester & Piore, 2004) between different designers sharing a same object, i.e. a given functional module. However, this design world (skill network) was separate from the validation world that was responsible for physical tests and chassis design evaluation. The main criterion that explained this separation was related to cost-shared tools. It has a major drawback. Designers were acting in a virtual world. They make little connections with the physical world. A community of practice was created (but it was not a boundless community) and professional paths were facilitated between these two worlds to mitigate this drawback. “Engineering liaisons” (Bonjour & Micaëlli, 2010) roles or job positions were clearly defined in some design departments, for instance, specification of simulations and physical tests for risk mitigation (see the example 1 above).

5. Skill network reengineering

Once skill network identification criteria are adopted, it is then possible to create what we call a Skill_DSM. We propose a method for identifying knowledge clusters which are relevant to build new departments, teams or communities of practice.

This method is structured into the following steps:

- list the design tasks,
- estimate the cognitive proximity between tasks by estimating the knowledge or the methods shared by designers. The proximity is estimated on a scale [0, 10],
- build the corresponding numerical DSM matrix,
- apply a clustering algorithm to highlight clustered tasks,
- interpret and check the consistency of each cluster as an interesting skill network.

Data are obtained through interviews with design managers, project managers and experts. The managers are more oriented towards the identification of departments. The experts are more interested in identifying communities of practices.

We applied the previous method to depict the skill networks related to the functional architecture of hybrid powertrains. Fig.2 shows a real size Skill_DSM. For privacy reasons, the picture of this DSM was blurred (empty cells are equal to 0).

Several interpretations of this DSM can be made.

Firstly, one can be focused on its static aspects. Each module depicts a closed skill network the design manager can recognize as a functional department or a team. For example, the fifth cluster represents the functional department responsible for a key requirement of powertrains: reductions in polluting emissions in compliance with Euro VI regulation. Expertises, routines and specialized knowledge belonging to this skill network contribute to a current automaker’s design core competence (Bonjour & Micaëlli, 2010). This skill network is based on specialized knowledge related to design (functional design, fuel specification...),

to chemistry (fuel chemistry, combustion, catalysis...), to purchases and outsourcing (partnerships with exhaust pipe suppliers...)... The presented DSM also points out potential job positions related to engineering liaisons between this cluster and the cluster 2 (another potential skill network).

Secondly, one can extract some evolutionary phenomena from this matrix. It shows professional paths within a given skill network or between skill networks. These paths lead to three different types of knowledge:

- a narrow and deep expertise belonging to a specific cluster (syn. skill network),
- an expertise in engineering liaison,
- an expertise in integrative knowledge.

Integrative knowledge is a knowledge that is common to almost all the other knowledge in a given cluster. A novice can manage few specialized knowledge whereas an expert can navigate between different knowledge related to the same cluster.

Those different interpretations of the Skill_DSM show how this model proposes a very rich semantics.

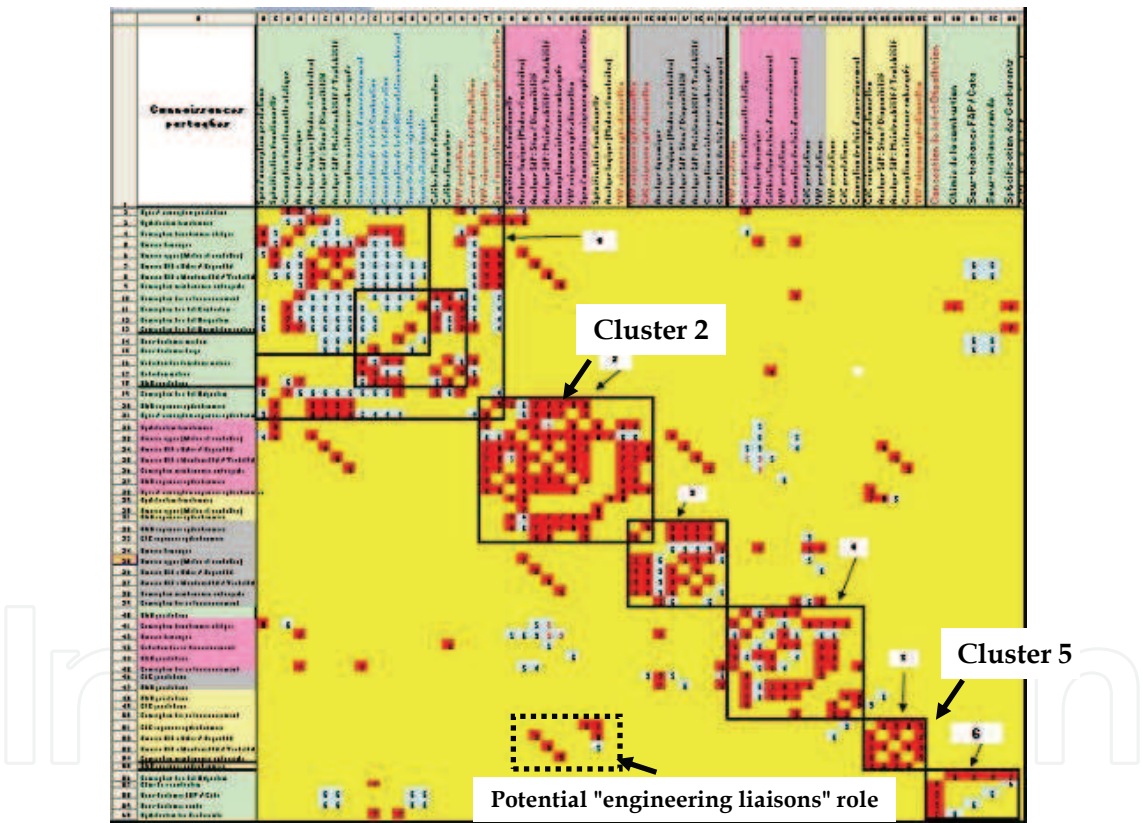


Fig. 2. Example of a Skill_DSM.

6. Perspectives

We have proposed a bottom-up approach to help design managers to identify potential key skill networks by using Skill_DSM. However, a top-down approach could be envisaged. It consists in analysing firms' design core competence and determining which skill networks could enhance skills, abilities or routines that largely contribute to core competence. This

approach should be developed to provide design managers a global skill network management approach. It is based on identification, structuring and evaluation tools.

This chapter has outlined the way of identifying potential skill networks. Its aim has not been to evaluate their contribution to core competencies. This lack is paradoxical because DSMs are primarily managerial tools and not only optimization-based representations. The main question is not: how to optimize such clustering algorithms to cluster such DSMs? But rather: What services do these tools offer to the concrete design managers' "activity" (Engeström, 1987)? Managerial issues that are related to this key question concern design dialogues (two characteristics which are contradictory and must be considered at the same time): Can they use Skill_DSM to balance the division of labour and the coordination between skill networks, the operative performance of the design project and the skills or competences development, the "exploitation" of existing skill networks and the "exploration" to create new boundless communities (March, 2008)? Can design managers use DSMs to integrate benchmarking and best practices? Can they use them to stabilize professional paths or to facilitate the evolution of professions?

Thus numerous extensions of skill DSMs are necessary to improve their integration in concrete design offices.

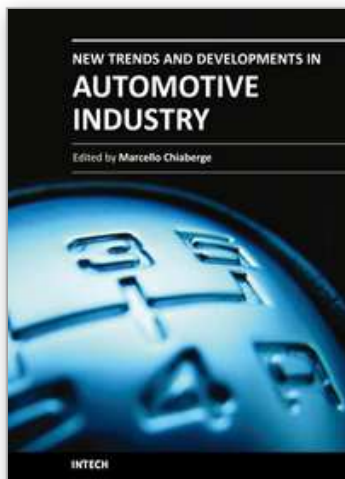
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