INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006
Dubrovnik - Croatia, May 15 - 18, 2006.

CO-DESIGN OF INNOVATIVE PRODUCT & NETWORK OF FIRMS: CATALYSTS FOR CO-WORKING

M. Zolghadri and P. Girard

Keywords: product design, added-value network, co-design, network efficiency, co-working risks

1. Co-design paradigm

Concurrent Engineering and Simultaneous Engineering were emerged in 70's to reduce long time-to-market, improve quality and cut cost of new and innovative products (Ottosson). Academic experts and practitioners set up, since then, best ways to manage production processes and products design simultaneously.

Focusing on innovative products, one understands intuitively that, product design process is complex or not, depending on the product's *innovation degree*. To simplify, we can consider two innovation classes: radical or incremental. For an incremental innovation, product development objectives and process are "known" and company's partners (suppliers, sub-contractors,) do not participate to development at all or at most participate just by offering their specific components characteristics (dimensions, weight,…). On the contrary, for radical innovative products development, even if the development process is known globally, development activities or their results are not really known in advance meaning that the knowledge about the process, its results and its necessary actors are incomplete.

To push the context toward more realistic situations, we consider those radical innovative products development for which partners' collaboration is necessary. This is especially the case of SMEs that cannot assume by their own all aspects of innovation such as necessary technologies. These partners, considered as *critical*, are involved more or less in product design phases to fit the best to that innovative product. This means that they should collaborate.

Collaboration is at the heart of every common project and authors agree on that collaboration between partners may bring prosperity and business success. However, efficient collaboration between partners requires strategic, tactical and organisational *co-working* methods and protocols, clearly defined and accepted by all.

Here, we do not study co-working procedures but their framework by focusing our purpose on what is called *co-design* paradigm, which takes account of two activities: collaborative product design and network design/management simultaneously. The objective is to understand the way by which one activity influences the other. We think that the consideration of these problems is crucial for SMEs during innovation tasks. Every decision made regarding innovative product design will, more or less, influence the way the network of partners should be designed and managed/controlled. These links, logical and temporal, should be identified and studied in order to be able to measure somehow co-working risks. Successful industrial collaboration (Airbus for example) have already shown that co-working is performed by big companies and it brings them efficiency and satisfactory solutions to clients. However, co-working is risky for SMEs because its successes or failures could be of important consequences; big groups are less influenced by disturbances coming from their partners. Moreover,

the negotiation power of SMEs forms a hard constraint for them to participate to any network. It means that risks and success parameters have to be known and taken into account before any co-working decision, especially for SME's.
In short, we can summarize study's characteristics hereafter:

- Product: innovative,
- Product profitability's period: short due to coming concurrent products,
- Product design: collaborative,
- Firms: Small and Medium Enterprises,
- Study's focus: on a company which looks for innovation.

2. Brief survey of the literature

2.1 (Collaborative) Product design

Design process commonly defines activities characterizing evolution of product knowledge from customer's attendees to customer's satisfaction. This process is generally constrained by design objectives (customer requirements on product definition), by enterprise organization (Mintzberg) and are influenced by technologies or human and physical resources (Wang F., Wang G.). Many research works focus on design methods which model design process (*i.e.* designers' activities during different steps of the product life cycle). Different models used to represent engineering processes have been proposed in the scientific literature (Love). (Perrin) classifies those models in five categories: succession of hierarchical steps (Pahl), iteration of an elementary design cycle (Blessing), (Roozenburg), emergent phenomenon of self-organization (Brissaud), cognitive process (Hacker), communication and interactive mode (Buccarelli,) (Hatchuel). (Pahl, Ullman) propose to characterize the product development life cycle (activities composing the design process) at the highest level of abstraction by four steps: clarification of tasks, conceptual design, embodiment and detail design.

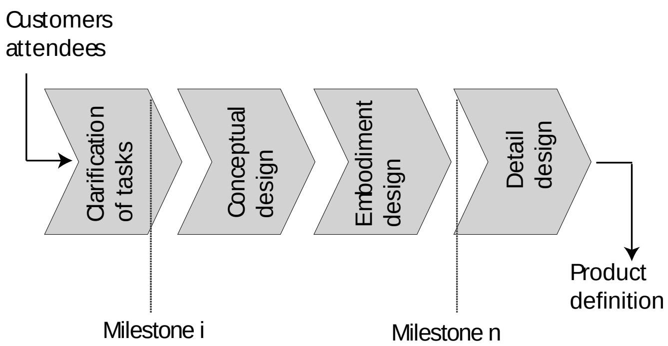

Figure 1. Product development life cycle

2.2 Network design and management

Various works have been done in the scope of network design (Beamon, Ballou, Cakravastia, Goetschalckx, Guillen, Gunasekaran). (Beamon) classifies these works into four modelling paradigms: deterministic analytical models, stochastic analytic models, economic models and simulation models. These works answer mainly geographical positioning of various partners of the network. Moreover, he defines several performance measures, qualitative such as customer satisfaction and flexibility or quantitative like cost. (Garg) looks for a tactical/strategic level process-product design. One of the key problems on which some scientists work is the case of supplier choice (Wang G., Geunes). Techniques such as Analytic Hierarchy Process, Mathematical programming are commonly used. Specially, Geunes provides an interesting survey of SC design works and underlines that this problematic could be studied from strategic, tactical and operational levels. Results he gathered come from industrial applications too, but the question of product design is not considered. (Gunasekaran) considers Buildto-order SC and defines this concept and provides an extensive literature review; innovative product collaborative design is not considered. (Hicks) studies this context and argues that there could be an efficiency niche for consideration of strategic trends in SC design for early product design. (Harrison) distinguishes the SC problems into two inter-connected areas: SC design and SC execution. Even in SC design questions to answer, the question of product design does not mentioned. Obviously, this state-of-the-art is not exhaustive; but it seems clearly that the product-network co-design problem is rarely considered.

3. Product & Network design, concepts and vocabulary

To study co-working here one should consider interactions between collaborative product design and its management, and collaborative network design and its management. Vonderembsea resumes design of supply chain as an issue of product design: "Supply chain design should be, in part, a function of the product characteristics and expectations of the final customer (Calantone, Reiner and Trcka)." These elements together form what is called *collaborative design environment* (Figure 2).

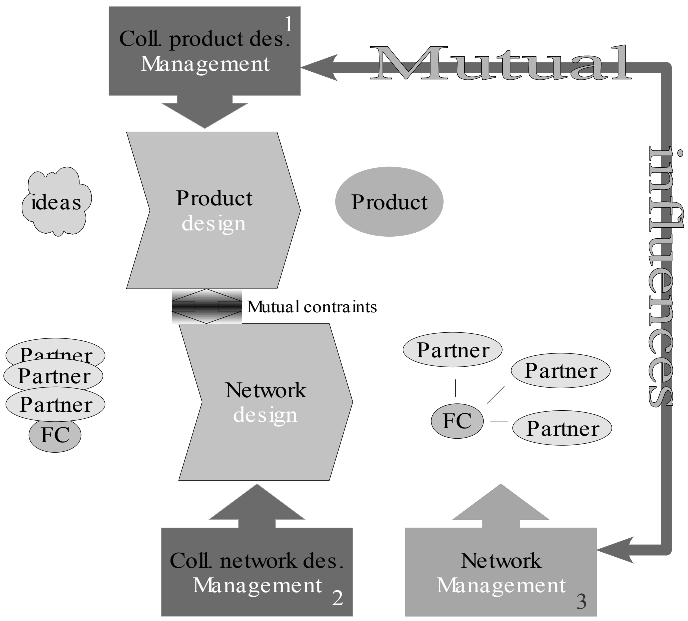

Figure 2. Collaboration design environment

3.1 Characteristics

Short time-to-market, high quality and relevancy are some of the attributes of any innovative product. However, the SMEs' innovation project is in danger if the design environment in one side and manufacturing environment on the other are not really ready and if operational or tactical shortcomings subsist in co-working protocols.

Talking about network of firms, often one thinks of Supply Chains, SC. According to Beamon in (Beamon) a SC "is an integrated process wherein a number of business entities work together (*i.e.* suppliers, manufacturers, distributors and retailers) in an effort to: acquire raw materials, convert them into specified final products and deliver them to retailers".

Partners network in our work has a *variable* frontier or architecture. It is defined based on the following fact closely related to the decomposition of collaboration process between partners.

In our opinion, one may roughly distinguish two network design levels: *gross-coarse* design and *fine-coarse* design. Gross-coarse design concerns strategic design orientations or high-level decisions. It corresponds to contact establishment, business discussions, choice of partners, definition of partners' dependencies, definition of exchanges protocols, and so on. While fine-coarse design is focused on precise determination of stocks, retailers, best level of goods transportation, ... Our research concerns mainly gross-coarse design.

3.2 Innovative product and Network of partners from Focal Company's point view

The study focuses on a typical SME, named *Focal Company* FC, which looks for innovative products. FC's managers should choose their best partners within a set of potential firms and co-work with them during their common project. The network constitution is then launched based on FC's initiative.

FC may know well some of the potential suppliers of components and raw materials and technology sub-contractors or providers. A subset of these partners will form those critical partners, which should co-work with FC during product design phase from the beginning. Once, based on clients' requirements or market survey, the idea of collaborative design of an innovative product accepted, the development process will be launched. One can imagine intuitively those problems, not treated here, related to data sharing between partners.

During this collaborative situation, partners have to co-operate not only by exchanging products and data but also by making best and as fast as possible decisions together respecting their mutual constraints. Manufacturing of this innovative product represents the next step of the global project and its success depends obviously on strategic, tactical and operational management decisions made far in advance. Somehow these problems can be summarized by one question "How shall managers think of the most appropriate network of partners for future co-working while designers prepare an innovative product?"

4. Some concepts for characterising mutual constraints

4.1 Design decision-making principles

Two classical concepts of decision-making procedures, used specially in enterprise management analysis, are: temporal *Horizon* and *Period*. Horizon represents the global time interval over which decisions are made and remain fixed. As the controlled system remains open loop between the beginning and the end of this temporal horizon, a set of fine-tuning decisions should be made in between. These shorter time intervals are called period.

Analogous concepts may be defined for design process: *logical horizon* and *logical period*.

- Logical horizon. It defines the longest set of design activities that can be determined without any doubt at a given moment. For a car design process, body design is a global known activity even if inside, new detailed activities (not already executed) can be identified.
- Logical period. Global activities are then decomposed into lower level activities. A logical period corresponds to a sequence of design activities whose execution can be planned.

Inside a logical horizon where activities are known globally and after every logical period a synchronisation *milestone* is put and future activities are defined more precisely during *functional* and *technical* characteristics synchronisations.

Design process related to innovative product and to network can be split up roughly into:

- *Translucide (logical) zone*. Design activities are already known (or had become clearer). Managers and designers are able to plan future co-works.
- *Opaque (logical) zone*. Design activities are fuzzy; there are uncertain orientations. Designers and managers use their expertise to define more and more precisely what they have to do in this zone: new activities, new milestones, …

Three classes of design activities can be distinguished:

- *Known activities*. Their characteristics, considered from a functional point of view, are: inputs, outputs, mechanisms, technical and human resources, required know-how.
- *Possible activities*. They correspond to various design alternatives.
- *Unknown activities*. They are unknown at least for one of the following items related to a IDEF0-like model of an activity: activity by its own or its inputs, outputs, mechanisms, technical or human resources or know-how.

The evolution of activities is as follows: unknown → possible → known.

Finally, a design activity can be critical or not. A product (respectively network) design activity is critical if and only if its results can modify any network/networking (respectively product) orientation. These activities should be identified as soon as possible in order to make more efficient decisions.

The challenge of product designers and managers is to minimize the number of (unknown-) critical activities or to minimize the influence level of their results. These mains roles show various strategies to manage risks during co-design of product/network: *prevention* strategy (to reduce the number of critical activities), *mitigation* strategy (to reduce the influence of these activities) and finally *combined* strategy (to reduce number of critical activities and their influences).

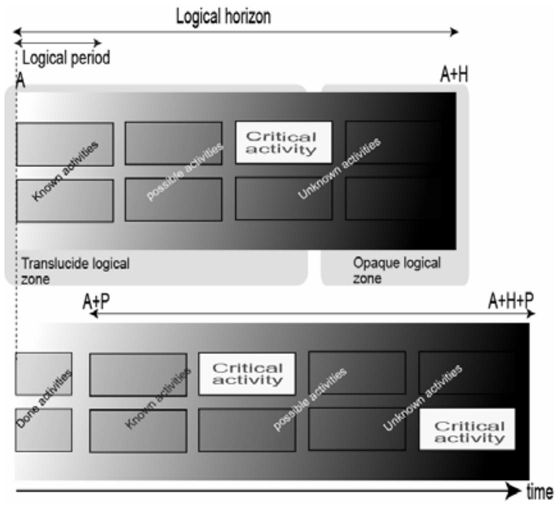

Figure 3. Concepts of design decision-makings

4.2 A model for co-design

Modelling product and network design processes and their mutual constraints are modelled in Figure.4. Identification of various kinds of activities (unknown, possible and known) may be done based on links that connecting results of activities with each other. During a logical period, a part of known product design activities is executed. Results of these activities can allow identification of new activities and specially generate new constraints for network gross or fine-coarse design activities. On the other hand, every network design activity can generate new activities to perform and new constraints on product design.

5. Constraints

Consideration of production management constraints during the product development phase and *vice versa* is an important issue for firms. Obviously, not all of the constraints can be considered. We note Z the set of "necessary strategic and tactical network constraints to take into account during innovative product design phase". More intuitive constraints coming from product development process toward network design activities are noted Δ (*cf.* Figure 4).

In next paragraphs, we will identify and structure Z and Δ sets globally.

We refer to a control entity, which allows taking account of various product-oriented and network-oriented parameters, as product-network design co-ordination space, **C** in short. **C** should be able to control and manage both activities of collaborative product design process and those of network design. From a functional point of view, **C** will work with network design space, which is in charge of network design co-ordination, and collaborative product design in a closed-loop structure. **C** uses:

- Business strategic objectives, feedbacks from both network and product design activities and Δ constraints to prepare product design framework, and

- Business strategic objectives, feedbacks from both network and product design activities and Z constraints to define network design framework.

These constraints are determined during feasibility and final design phases (*cf.* Figure 5) which form product design activities.

Feasibility phase defines various technological solutions and tries to combine all partial technological solutions into several global solutions or prototypes. During this phase, thinking about technological solutions should allow product design engineers to conduct network design managers toward a selection of potential partners. Data determined by feasibility engineers should be gathered in "network architecture specification books" which contain needed technology at least and known partners and known companies on the market supposed to be able to answer FC's needs when possible.

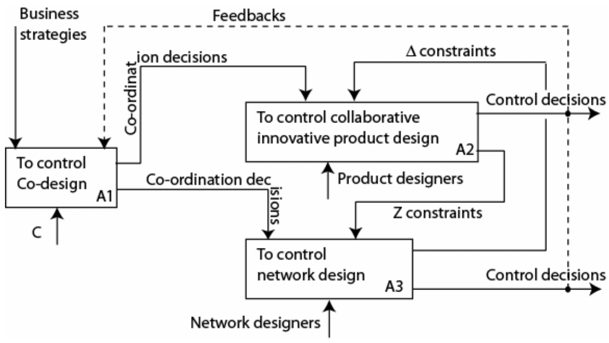

Figure 4. Functional model of co-design activities

The logical horizon of these network specification books equals the feasibility phase activities. However, after each logical period, a new version of specification book has to be transferred to network designers during milestones synchronisation. In other words, based on execution of known activities and the determination of possible activities, product designers have to identify as much as possible future critical activities.

Based on a network framework, network designers should begin to identify various scenarios of network architecture by focusing on critical activities.

An important issue for the definition of these specifications books is to be able to represent as soon as possible various dependencies between partners and their know-how modelling by:

- Tasks dependencies graph: It models logical precedence constraints between tasks to perform in both design activities by various partners.
- Competency dependencies graph: It defines dependencies between core competencies of partners.

The iterative process between product design and network design during the feasibility phase can be represented by a helix cycle (*cf.* Figure 5).

It must be underlined that the construction of network dynamic scenarios is not possible during the feasibility phase due to numerous unknown data regarding partners that must be considered.

The result of this phase is one or several prototypes. In co-design paradigm, these prototypes have to correspond to two things: technical solutions assembly and network constitution (at least for critical partners).

Final design phase. Data exchanges performed between product and network designers during the feasibility phase correspond to closed-loop connections between feasibility and gross-coarse network design activities. At the end of this loop, the network architecture should be stabilized as much as possible. The relationships between product designers and network managers remain the same during the final design phase of the product. However, product designers should determine definitive network architecture specifications books according to all design decisions made by FC and its critical partners, iteration by iteration.

Final design decisions concern information that globally defines technical data of the innovative product too (formed by quantifiable properties of products such as geometry, kinematics, mechanical and so on). These design decisions have a logical horizon that equals the complete design activities. Again, after each logical period, product designers have to prepare a new version of network specifications book. These books lead network managers toward the definitive partners network.
The target of network designers here is to build not only architecture alternatives but also to gather as much dynamic macro-data as possible in order to be able to define management parameters. These parameters correspond to framework of products and data exchanges with appropriate attributes. Products exchanges framework between partners contains elements such as delivery delays, lot-sizing data, cost and quality. While data exchanges framework corresponds to data-sharing characteristics such as forecasts availability and load and capacity.
Once the network architecture finalized, network designers should simulate various network scenarios according to discussions with partners. Somehow, they have to use performance indicators to assess the networking during industrialisation phase. Scenarios' analysis provided to product designers by network designers may be taken into account by product designers in order to finalize the design of the innovative product. This analysis should be done from static and dynamic points of view.
In short, the network specifications books formalize mainly Δ constraints while Z constraints are represented by network intelligence corresponding to analysis of static (or logical) and dynamic simulation of scenarios.

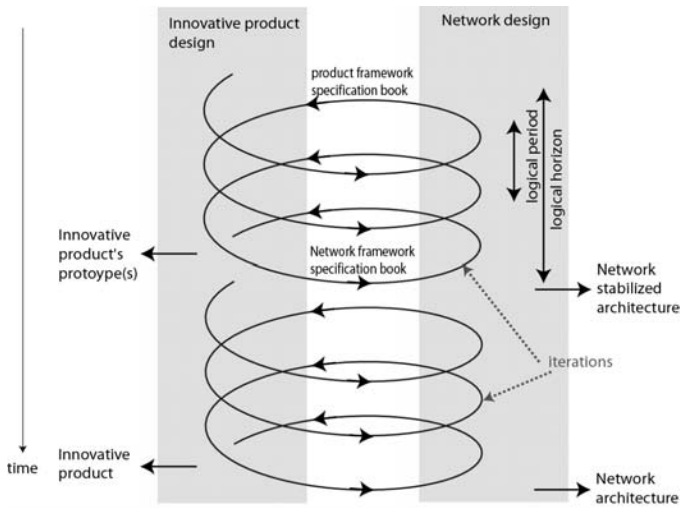

Figure 5. Co-design life cycle

6. Conclusions and focus of future works

Network-product co-design provides another efficiency roadmap to managers. Real engagement of material, technology and service providers should be managed as soon as possible. FC's partners have to be identified and their functionality must be synchronized largely in advance. In this article, the very first elements of dependency between these two major activities are shown and modelled. Constraints linking product and network design activities are described and the way by which these constraints are transferred from one activity to another are formalised through specifications books and network intelligence. Authors look for defining reference models of functional and technical dependencies between network-product design activities. These models will allow defining techniques a methodology to analyse co-operation modes between partners. Moreover, by introducing a structured approach, it will be possible to control the whole co-working project of the FC as soon as the first collaboration decisions are made.

References

Ballou, R.H. (2001). Unresolved issues in supply chain network design. Inform. systems frontiers 3-4, 417–426.
Beamon, B.M. (1998). Supply chain design and analysis: models and methods. Int.J.Prod.Eco. 55, 281–294.
Blessing, L.T.M. (1994). A process-based approach to computer supported engineering design. PhD thesis. University of Twente.
Brissaud, D.,O. Garro (1998). Conception distribue, mergence dans Conception de produits mcaniques. Hermes.
Buccarelli, L.L. (1988). An ethnographic perspective on engineering design. Design Studies 9(3), 1753–1786.
Cakravastia, A., I.S. Tohab and N. Nakamura (2002). A two-stage model for the design of supply chain networks. International Journal of Production Economics 80, 231-248.
Calantone, R., Dröge,C. and Vickery,S. (2002) Investigating the manufacturing–marketing interface in new product development: does context affect the strength of relationships? J.Op.Management, 20(3), 273-287
Garg, A. (1999). An application of designing products and processes for supply chain management. IIE Transactions 31, 417–429.
Geunes, J. and P.M. Pardalos (2003). Network optimization in supply chain management and financial engineering: An annotated bibliography. NETWORKS 42(2), 66-84.
Goetschalckx, M., C.J. Vidal and K. Dogan (2002). Modeling and design of global logistics systems: A review of integrated strategic and tactical models and design algorithms. Eur. J. Operational Research 143, 118.
Guillen, G., F.D. Mele, M.J. Bagajewicz, A. Espuna and L. Puigjaner (2005). Multiobjective supply chain design under uncertainty. Chemical Engineering Science 60, 1535-1553.
Gunasekaran, A. and E.W.T. Ngaib (2005). Buildto-order supply chain management: a literature review and framework for development. J. Operations Management 23, 423-451.
Hacker, W. (1997). Improving engineering design contributions of cognitive ergonomics. Ergonomics 40, 1088–1096.
Hailstone, R. (2001). Integration strategies : the state of convergence. IDC.
Harrison, T.P. (2001). Global supply chain design. Information Systems Frontiers 3:4, 413416.
Hatchuel, A. (1994). Apprentissages collectifs et activits de conception. Revue Franaise de Gestion 3, 109–119.
Hicks, C., T. McGovern and C.F. Earl (2000). Supply chain management: A strategic issue in engineer to order manufacturing. Int. J. Production Economics 65, 179–190.
Love, T. (2000). Philosophy of design: a metatheoretical structure for design theory. Design studies.
Mintzberg, H. (1989). Le management : voyage au centre des organisations. Les Editions d'Organisation.
Ottosson, S. (2004), Dynamic product development – DPD. Technovation, vol. 24, n3, p. 207-217, March 2004.
Pahl, G. and W. Beitz (1996). Engineering Design, a systematic approach. Springer Verlag.
Perrin, J. (1999). Pilotage et valuation des processus de conception. Harmattan.
Reiner, G. and Trcka,M. (2004) Customized supply chain design: Problems and alternatives for a production company in the food industry. A simulation based analysis. Int. J. Production Economics 89 (2004) 217–229
Roozenburg, N.F. and J. Eeckels (1995). Product Design: Fundamentals and Methods. John Wiley & Sons.
Ullman, D.G. (1992). The mechanical design process. McGraw-Hill.
Vonderembsea M.A, UppalbM., Huangc H.H and Dismukes J.P. (2005) Designing supply chains: Towards theory development. Int. J. Production Economics, 100, Issue 2 , April 2006, Pages 223-238
Wang, F., J.J. Mills and V. Devarajan (2002). A conceptual approach managing design resource. Computers in Industry 47, 169–183.
Wang, G., S.H. Huang and J.P. Dismukes (2005). Manufacturing supply chain design and evaluation. Int. J. Advance Manufacturing Technology 25, 93–100.

Dr. Zolghardi Marc
Université de Bordeaux 1, LAPS/GRAI
Cours de la Liberation, 351, Talence, France
Email: Marc.Zolghadri@laps.u-bordeaux1.fr