Planning for Manufacturing – Managing Connective Designs and Asymmetric Designer Knowledge in Product Consortia

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Abstract This paper presents production management as a three dimensional concurrent engineering (CE) problem, where the third dimension, besides product and process, is the organisational structure. The need of the organisation theoretic dimension is inspected from a point of view of ideal organisational types and an extended concept of equifinality analysis taking the special considerations, like flexibility, of network organisations into consideration. Methodologically we stress the need to define the ideal organisational roles using measurable micro-level quantities. We exemplify the need to model the organisational dimension by presenting a program that constructs the set of possible networks and uses it to illustrate how approaches using global organisational measures or using no measures at all are both insufficient approaches.

1 INTRODUCTION

Knowledge has been recognised as one of the key forms of wealth of the new organisation. In the information era, organisation transforms into a specialised agency that needs to cumulate, manage, develop and protect its core competence. In economic science literature, theories of intellectual capital promulgate the need to make this knowledge explicit. This does not solve the management problem in network organisation because information asymmetry limits possibilities to generate global explicitly presented knowledge. In manufacturing industry the knowledge concerns intimately the practical ways of how product components are really produced and delivered. In the meanwhile the increasing global competition sets high requirements for the products, which need to be advanced and highly

integrated. How to overcome this paradox of simultaneous organisational dispersion and increase in the integration degree of products?

The main result of this paper is a novel reformulation of the concurrent engineering problem as a planning problem. While the classical requirement is one of making the manufacturing process and the product match, in our approach a match between organisational action and components of product structure is established in a level of finer granularity and enhanced semantics. In the networked organisation the process dimension becomes scattered and requires improved representation formalisms. The new formulation for the concurrent engineering problem calls for tools that support concurrent design of the product and the organisational network responsible for the production activities.

Project as a model of business behaviour is increasingly penetrating to new business domains. Therefore we believe that the results of the study can be generalised to many areas. One of the motivations for the research was that information flow diagrams, typically used as the formalism in the initial phase of the behaviour modelling are inadequate for network organisation. It was soon discovered that an enriched representation formalism that can refer to product and design scopes was needed.

The paper is organised in the following way. In section 2 we discuss the problems of asymmetry in network organisation. The following section, section 3, lays out the framework. Illustrative experimental case is presented in section 4. Section 5 contains the conclusions.

2 ASYMMETRIC KNOWLEDGE

Classical organisational structure categorisation distinguishes hierarchies and markets. Network organisations aim at combining the desirable features of the two classical ideal extremes. However, network organisations can not be considered as an intermediate form of the two, because it requires elements that are not as such encountered in the other forms. Trust of a different type is one of the distinctive features. Network organisations balance stability against flexibility, specialisation against generalisation, and centralisation against decentralisation (Alstyne 1997). Specialisation leads to information asymmetry, more restricted scope, economies of scale and cost efficiency, whereas generalisation leads to information symmetry, economies of scope, and efficiency of greater resource utilisation (Alstyne 97).

Asymmetric knowledge means that agents have different knowledge structures. Typically a component supplier as a customer to sub-component supplier knows less about the sub-component than the sub-component

supplier. Still the component must be an integral part of the whole. Let us model this situation by listing product component features that agents must know roughly (and call them desires) and product component features that agents must know in detail (and call them capabilities).

Different measures of organisational design (Doty et al. 1993, So and Durfee 1996) have been developed both at the macro-level and the micro-level. We define the following micro-level measures.

Table 1 Local measures of organisational entities.

Measures	Description
Span of desire (sod)	Agents are characterised by a set of goals. This measure describes the demand of the agent for final products and sub-component deliveries
Span of capability (soa)	Agents are also characterised by a set of goals they can reach by themselves
Ideal type	Agents can set a strategy concerning their policy of doing themselves the activities needed for producing the products and components, or getting them from the network environment. Value 0 means that the agent's desires and capabilities do not intersect, whereas value 100 means that they coincide.

At the macro-level *sod* and *soa* are used to state the worst case sizes of span of desire and span of control. In the experiment the macro-level measures are used when generating experimental random cases that are within the limits of these global measures.

The typology by Miles and Snow (1978) identifying four ideal types of organisation: the *prospector*, the *analyser*, the *defender*, and the *reactor*, has empirical backing (Doty et al. 1999). Wood (2000) identifies eight organisational types that fall into three categories: *shapers* are capable of changing significantly the aspects of their environment, *adapters* reflect the environment, and *reactors* are generally resistant to change. Of these shaper clearly has both knowledge and control over facts of the environment. The theory does not however support modelling the knowledge structures and aid in pinpointing any specific control mechanisms. Common to these categorisations is that they are based on the emphasis placed on the external domain as opposed to the internal domain. Actual definitions of these types are too lengthy to be presented in this paper, but we redefine them in terms of a set of measures of the knowledge structures.

In our constructive approach we redefine two of the original types of Miles and Snow in a way that allows us to study the internal and external world of agents and the interaction of these worlds in network formation:

- Defensive organisation is focused on its capability scope and lets it direct the external scope. This is a resource-based strategy. The ideal type value is close to 100.
- Prospective organisation is focused on its external environment and does not let its internal capability scope limit it. This is a market-based strategy. The ideal type value is close to 0.

The main part of the environmental structure, that organisations share, is in the product domain. It might be that the structure is abstracted in order for it to be understandable by the set of organisations forming the organisational structure. Specialisation leads to asymmetry and asymmetry together with the reciprocity requirement leads to the criteria that the system at some level and in some time horizon is to be expected to have a balance of dependence.

At the strategic level, organisations express their desires and capabilities in terms of facts concerning the environment. Combined desires of a set of organisations form the goal-state of the potential consortium formed by the organisations. Assume an initial state differing from the goal-state, and action schemas describing ways to bridge the gap. Ways of doing this, plans, are located at an intermediate layer in between the strategic layer and the operative layer.

Equifinality means that a system can reach the same final state from different initial conditions and by a variety of paths. In economics literature this usually means that different organisational structures have the same organisational effectiveness. The model presented here allows a more general interpretation of equifinality, because the planning problem representation of the strategic decision making task allows a more explicit setting of the goals. This forms an integral framework for studying both efficiency and flexibility of organisational designs.

3 THE FRAMEWORK

Planning is seen as an intermediate level of co-ordination between the strategic level and the operative level (E. Durfee 93). The structure of our CE- framework conforms to this basic division of levels. So and Durfee (1996) mention subsequent research where organisational structures were experimented and the results supported the contingency theories. Problems with this research included the fact that the research was embedded in complex task-environments, with agents whose abilities and behaviours were difficult to clearly characterise, and with performance measures that were not clearly articulated (So and Durfee 1996).

Figure 1 The framework

Prospector and defender organisational types are characterised in terms of the measures *sod* and *soa*, which can be calculated as the number of desires and number of capabilities an agent has. The type of the organisation defines the strategy for deciding what abilities to develop within the organisation. If the strategy is that of a defender, the tendency is to develop capabilities that produce things that are among the set of goals needed by the organisation itself. In figure (Figure 1) agent1 is a defender because it maintains capability to manufacture components marked by goals g1 and g2 and depends on others for g3. Agent2 is pure prospector because it relies on other on all its desires. There is a reciprocal need for collaboration between agent1 and agent2 because they exchange services (g3 and g4). Consortium is a network where the members jointly can reach all the goals they mutually desire. Changes in desires and abilities change the intersection (Figure 1) of these two sets, size of which is interpreted as indicator of the ideal type of the organisation. Because changes also effect the desire-capability arrows and their direction, we try to avoid, as a policy here, drawing means-ends hierarchies, because they are scenario dependent.

At the tactical level, special solvers can be built to solve the planning problem, which consists of three elements, namely the initial state, the goal-state and a set of operations schemata. Operations schemata describe

production activities and their external service interfaces including the preconditions and effects. In the recent years advances in the planning algorithms and increases in the computation power have made it possible to solve large enough planning problems to make the approach practically feasible to real world problems of moderate sizes.

In a network environment characterised by asymmetric desires and capabilities, states presented in product terms and activities defined in behavioural terms call in addition for modelling of the organisational structures, in order for the model to represent the components that are used as elements in formation of the manufacturing process. These elements can be used for constructing the scenarios (Wood 2000) of strategic business planning, as well as the information infrastructure that is capable of supporting all such relevant scenarios.

Process-paradigm is good for many things but its deconstruction is necessary for the flexible network organisation. Activities are situational and it is necessary to model preconditions of activities in terms of enriched domain model structures and varying scopes. Also parallelism needs to be based on clearly defined rules for mutual interaction and interference. Using process-paradigm it is not well understood what effects temporal squeezing has. Process diagrams can be used as normative models of the plans generated at the tactical layer.

The use of systematic reference to facts of domain state, i.e. the product facts (denoted by the g-starting variable names in Figure 1.), makes it possible indirectly to integrate the strategic planning and operative systems. This is possible because the tactical layer can act as an intermediary.

4 AN EXPERIMENT

An experiment was conducted by generating random case environments and counting cumulative occurrences of prospectors and defenders in the scenarios of those environments. Agent count was fixed to 7. Ideal type of the agents was taken from uniform distribution [Min,Max]. Figure 2 presents 3 data-sets with 80 cases each. The values in the data sets for [Min,Max] were [0,40], [0,100] and [60,100]. Desires were allocated randomly to agents so that their number has taken from a uniform distribution [0, sod]. Then capabilities were allocated randomly so that their number is from [0, soa] and they are selected from among the desires, if a random number at selection time belongs to the interval [0,ITA], where ITA is the ideal type of the agent.

Figure 2 Prospector-Defender ratios in 3 data sets with characteristic ideal type each having 80 cases (show on diagram). Counts cumulated over all scenarios within each case.

For each case there can be many scenarios, each corresponding to an operational alternative consortium, but often the case presents none. A program in C-language was written for the scenario generation. A Prolog-program was written to form the consortia and analyse their organisational constitution.

The experiment indicates that the macro-level measures are not good indicators of the situations. There is a large average-variation within the data sets and the regression lines do not differ that much. The explicit micro-level models of the specific knowledge structures are needed. Further research is needed, but the preliminary results indicate that strategic non-mainstream positioning and analysis of the explicit structures are worthwhile efforts for the agents. Strategy selection should take into consideration the relative overall structure of the desires and capabilities - if $soa > sod$ be a prospector and if $sod > soa$ be a defender. The actual structure of the desires and capabilities model effects the number of scenarios in a case and the participating potential of single agent strongly. From the individual agent's perspective besides the abundance of networking possibilities, the membership in those and the lack of solutions that exclude the agents are of interest.

The foreseen advantages of the planning approach presented in the paper for the manufacturing industry include better activity based life cycle

planning, capability based product consortium formation, and deeper insight into inter-organisational co-ordination requirements.

5 CONCLUSIONS

The primary contribution of this paper is a framework for 3-dimensional concurrent engineering. The third dimension besides product and process is the organisation. Organisational dimension makes it possible to combine strategic planning and manufacturing planning. Grounding of the goals and actions to the state has the effect that congruence of goals, interferences of actions, and semantics of the both are better managed. Also the goals become easier to update and action representations become generic, because abstracted action schemas are used.

The role of the organisational dimension in the framework is exemplified using an experimental case study of ideal organisation types and network organisation version of equifinality. The experiment shows that the type of things provided by such a framework are required when reengineering the networked manufacturing business.

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