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Evolving Product Information in aligning Product Development Decisions across Disciplines

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Abstract

Today's product development is fragmented across various disciplines all with their own fields of expertise. Maintaining overview in consequences and implications of decisions is difficult, since many stakeholders are involved. To optimise the product development, many methods are developed based on optimising the process of information exchange, which is required in analysing consequences and implications of potential decisions. This information exchange is often by means of communication between stakeholders. This paper describes an approach that is not based on the process, but on the product information itself, since the final product system is key in product development. The suitability of employing the Actor-Artifact network in aligning decisions across different disciplines by focusing on the evolving product information is investigated.

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1. Introduction

Once upon a time, products were developed by one person. A blacksmith, for example, made the iron products for all the inhabitants of his village. He (implicitly) made designs for the products, made sure that he purchased the required raw materials, provided the required tools and equipment and he produced and sold his products. The sequence of the activities was not dictated, and the processes could well be concurrent. Most of his products matched perfectly with the requirements of his customer. Storage of the produced goods was not necessary due to his make-to-order strategy.

Dictated by population growth and individualisation, leading to mass-customisation, more and larger businesses have been established, designing and developing more products as well as a higher variety of products. Due to the inherent embroilments of this type of product development, many experts are currently involved in the underlying processes and a division of tasks and expertise is needed. Consequently, the strength of 'common experience' is

increasingly difficult to exploit in product development. Whereas in the past the entire product development was performed and assessed by one craftsman, nowadays adequate product development is the responsibility of many different departments, each contributing to specific aspects (e.g. marketing, design, production, quality) of all different product development cycles in the company (figure 1). The (strategic)

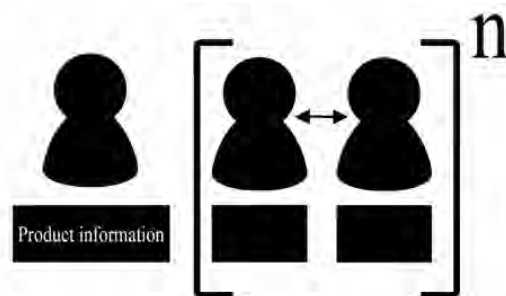


Fig. 1. Blacksmith versus today's product development

allocation of tasks, including the co-ordination and supervision thereof is part of the organisational structure. Although task specialisation allows for optimised (local) performance, the division of responsibility over different fields of expertise causes problems. After all, leaving behind the blacksmith as the ultimate integrator of information, processes, decisions, actions and evaluation, companies have to explicitly address the coherence, interdependencies and polytelic of all aspects that play a role in product development. This is all the more true, as the vast number of stakeholders that is involved in any development cycle represent different perspectives, interest, backgrounds and even time scales. Moreover, the high diversity of products and projects whose development cycles simultaneously compete for scarce resources as concerns time and other assets not only cause operational, but also tactical and strategic challenges. By this complex design and development environment, the implications of decisions are not always clear while the impact of a decision for the total cost, the environmental impact or the quality of the product system (including e.g. product definition, manufacturing process, supply chain information, marketing strategy), may be high. This publication describes the problem in more detail. It gives some examples of solution directions and finally describes an approach that can be enabled for aligning decisions across different disciplines in a product development trajectory.

2. Fragmented product development

A product development trajectory can be defined as a sequence of decisions [1]. These decisions often lead to a feasible product definition in combination with e.g. a production plan, marketing strategy and supply chain definition. In order to develop products effectively and efficiently, the consequences and especially the implications of the consequences need to be taken into account to avoid unnecessary iterations, and thus extra resources, in later stadia of the development trajectory. Information about different options is required in order to examine the potential consequences and implications of a decision. The solution space for each decision is influenced by the preceding decisions, as many decisions are mutually dependent. The output of one decision is often input for following decisions. For instance, the decision about the type of material influences the solution space for the decision about the dimensions of the product. This is an example of a decision that influences a decision in the same discipline. However, the decision can also influence the solution space of decisions that are made in other disciplines. Determining the dimensions of a product for example, influences the solution space concerning manufacturing processes.

As described in the introduction, product development nowadays is fragmented into many different disciplines with their own fields of expertise. The stakeholders are involved in the process at different moments in time. This makes it difficult to oversee all of the consequences of decisions. Alignment and integration of results of each process from different departments has to be found. In an attempt to obtain the information that is required for investigating the

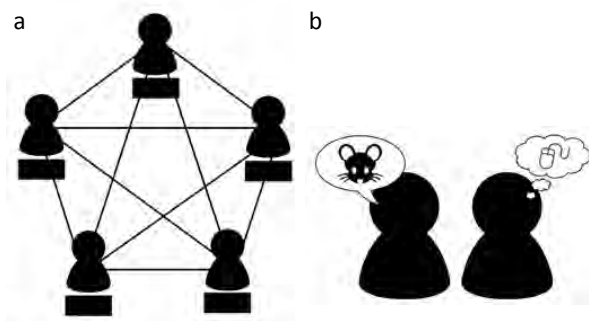


Fig. 2. (a) Communication between disciplines (b) Misinterpretation

implications of a decision, communication with stakeholders within the field of expertise as well as stakeholders from other disciplines is essential for most product engineers.

2.1. Process-oriented approaches

A variety of methods is developed to optimise the product development process. Approaches that can be used in an attempt to optimise the product development trajectory are for example the methodologies developed by Pahl and Beitz, Andreasen, Roth, Ullman, Ullrich and Eppinger etcetera [2]. Each of these well-known design and development approaches already pay attention to other important disciplines involved in the subsequent phases of the development trajectory, superseding the over-the-wall engineering problems often found in practise. Approaches explicitly focusing on the integration of different disciplines are nowadays commonly referred to as Concurrent Engineering in which relevant domains are attuned. In the 1980s, organisations began to develop and implement methods to simultaneously design products and processes and involving both product designers and process engineers [3] in order to introduce new products more efficiently and effectively. Examples of concurrent engineering allied approaches are Lean Production Methods, Design for Manufacturing (DFM) and collaborative strategies. Fine [4] introduced an adaption of concurrent engineering; three-dimensional concurrent engineering (3DCE), which can be defined as simultaneously designing a supply chain as well as the related products and processes.

These approaches are based on optimising the development process by serving as a reminder for involving stakeholders (from other disciplines) on the right moment in the development trajectory or by giving guidance in the communication between stakeholders. Processes described in the different existing methods are transmitters of information between stakeholders in order to efficiently exchange (product) information between different fields of expertise or stakeholders. Consequently relevant, but often unstructured and undocumented information is transferred by many unordered communication lines between stakeholders (figure 2a). This information about the evolving product and its corresponding process is scattered amongst all involved stakeholders, making it well-nigh impossible to obtain a

coherent overview and status of a product or process under development.

An additional problem with such communication is that the used information can easily be misinterpreted, especially when communication partners stem from different backgrounds and have their own expertise language. This is often the case with different disciplines within an organisation as well as between different organisations. A question in one domain can be answered completely irrelevant by another domain (figure 2b). Moreover, in order to maintain control over the relations, the difference between the required information and the employed information is often large. In its mildest form, this phenomena does not contribute to an efficient and effective product development process, but often even severely hampers the process, causing unnecessary halts or loops and costly corrective procedures.

The blacksmith described in the introduction was able to manage and align both his processes and the information. In most approaches, developed in an attempt to adequately integrate the different disciplines in the development trajectory, information and processes are integrated to such an extent that they cannot be decoupled. As the focus in practice often is on the processes that transmit the information between disciplines (often communication), the balance between information and processes is instable.

3. Solution direction

The aim is to find a solution for aligning decisions about the product system made by different stakeholders involved in the product development process. An important prerequisite is to prevent (the alignment of) procedures becoming the dominant factor. In such approaches communication unwittingly gets prevailed over the evolvement of the underlying product information. A more balanced approach will provide benefits for the final product system and an efficient and effective development process since less resources are needed for unnecessary iterations in later stages of the process.

As described in section 2, many methods that are developed to design products and corresponding processes more efficient and effective are based on optimising the exchange of undocumented or fragmented information at the

right time in the development trajectory, in many cases communication between different fields of expertise, in an attempt to examine the consequences and implications of potential decisions. A shift in focus is needed from optimising the process of product development (communication) towards optimising the product system itself in order to overcome over the wall engineering and misinterpretation of information. Process and information have to be decoupled to ensure that it is possible to base product decisions on the common result of the development trajectory: the product system. The solution direction described in this publication is based on coordinating the decisions made by the different stakeholders of multiple disciplines by means of evolving product information. Providing the stakeholders with the adequate set of information instead of developing processes to exchange that information would be beneficial. Depending on the information, the required process can be selected. Focusing on the result or output instead of on the process by using evolving product information will minimise the need for communication. Relevant product information can be 'pulled out' when needed instead of being provided as one package at a predetermined moment, avoiding a lot of communication effort [5]. A visualisation of the solution direction is presented in figure 3.

In order to focus on the product system itself, it has to be sure that all disciplines work on the same, unambiguous product system which evolves over time during the development trajectory. A dynamic information management system is needed which can be used by different stakeholders. This information management system has to contain information related to the different disciplines e.g. dimension and materials of the product parts, information about the corresponding manufacturing processes and information about related suppliers and customers which is required in examining the consequences of an adjustment of a variable (a potential decision). The dependencies between information are very useful in this process. Consequences of decisions for different aspects like the environmental impact, cost and quality can be analysed by distilling the required information from the information management system and by selecting a mechanism that can calculate the impact. The impact of a decision for the final product system as well as the implications for other stakeholders and disciplines can be examined prior to actually making the decision.

4. Actor-Artifact network

4.1 Background of the Actor-Artifact network

As described in section 3, a dynamic information management system in combination with relevant mechanisms are needed, recognizing the various views on information while simultaneously fostering the integration of information resources already in use. In relation to the research project 'packaging chains in lasting balance', a modelling technique and a corresponding dynamic information management system in combination with calculation methods are developed in order to integrate an

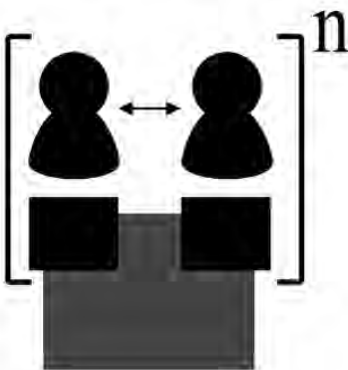


Fig. 3. Communication based on evolving product information

aspect like sustainability in the development of content-packaging development trajectories [6, 7, 8, 9].

The approach is developed taking as starting point the product definition including information about the accomplishment thereof. The framework seems to be suitable in the alignment of decisions across disciplines since it is possible to make all product and process information available for all stakeholders involved. In the following sections, a short description of the framework is given and the usefulness of the framework and the software tool for aligning decisions across disciplines by means of evolving product information is described.

4.2 Description of the actor-artefact network tool

The framework is a result of integrating multiple product development cycles (product cycles and packaging cycles). Since the approach has to be applicable for different types of organisations in the life cycles (from the manufacturer of materials to the company that recycles the waste) and thus many different types of products (roll of steel, cans, soup), a very flexible approach is required being able to take different parts of the life cycle into account making use of different zoom levels. In order to develop a tool that can handle the required differences in strategies, products and perspectives, the framework of the tool needs to be flexible and no hierarchy is permitted [8].

The actor-artefact network is a modelling technique in order to depict the life cycle of products (and packaging) by using the available information while simultaneously taking into account the (un)certainty of that information. By taking into account this (un)certainty, the tool is suitable in every stage of the product development trajectory, making it possible to estimate consequences of decisions in early stages of the development trajectory. The life cycle exists of e.g. information about stakeholders (so-called actors), their products or services (so-called artefacts) and (manufacturing) processes. In the actor-artefact network, actors, products and processes are represented by elements (nodes). The elements are connected to each other by different types of both directed and undirected relations (edges) (figure 4). This network can store different information formats and can be employed in analysing consequences of potential decisions by comparing at least two situations. Consequences for different aspects (cost, environmental impact, quality) can be analysed by selecting relevant mechanisms, often calculation methods (example in figure 4) which are valuable in investigating the

impact of a decision. Additionally, consequences and implications for other stakeholders and processes in the network can be examined. These stakeholders could be internal (departments) and external actors (suppliers, customers).

5. Using the Actor-Artifact Network

The actor artefact network enables building a scenario around the often incomplete, uncertain and scarce information sources that are available in development trajectories. Both structured and unstructured information sources that already play a crucial part in this daily practice can form the starting point for the network, ranging from first drafts for a new production line to complete bills of material from ERP or PLM systems in use. By selecting mechanisms on beforehand, the required information, or most influential parameters, can be specified.

In building up the network, the ontology of that network, defined as often occurred structures, keeps track of the various elements and relations. As such, the ontology is an important starting point when information is not readily available. While the specific information about a new packaging material or a new supplier might be unknown, the few details that are known – a principle material group or product catalogue – can be used to find similar structures in the ontology. These structures can then serve as a general template that outlines a certain part of the product or life cycle.

Furthermore, the ontology serves as a legend that allows the user to understand and ‘read’ the structure of the network. It allows to put focus on a certain part of the network in filtering on certain types of actors or artefacts, while in the background the entire network is still available. In a similar manner, the ontology gives access to so-called mechanisms that enable calculations based on the available information. If, for instance, the locations of two actors are known, the various transport options and the total distance can be determined by using mechanisms. If a material is known, properties such as the density can be determined. As such, these sets of mechanisms allow first rough estimates that aid in assessing the consequences of alterations, but can be build up to allow more advanced algorithms if the information becomes available.

The relevance of mechanisms does not only lie in the results they generate. As important is the fact that mechanisms also take into account the probability of the

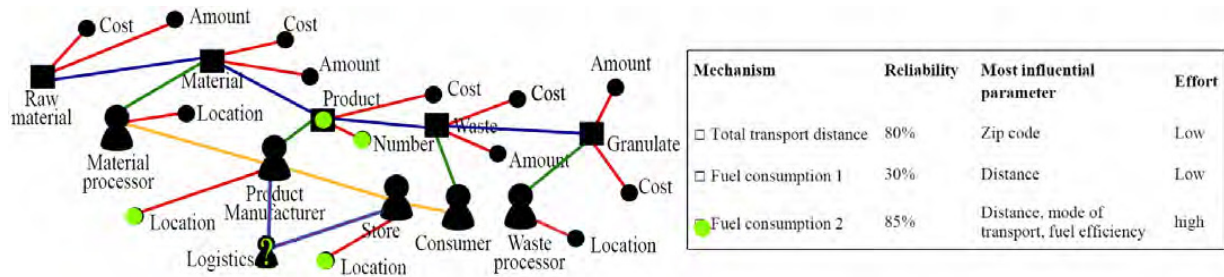


Fig. 4. Example of an actor-artefact network based on a specific perspective. Mechanisms can be selected to calculate for example fuel consumption

outcome, while assessing the uncertainty of the variables used as well as the accompanying bandwidth of the outcome. Therefore, the use of the mechanisms can also be instrumental in determining the most relevant and influential variables. The mechanisms can aid in determining the most influential parts of a network or, in combination with ontology-based templates, hint at important information that is currently lacking. More importantly, it offers basic techniques to deal with the non-deterministic nature of the early phases of development trajectories and aid in overcome the indefiniteness of used information in those phases.

5.1. From theory to practice

The actor-artefact software tool contains functions to guide the users in using the modelling technique as depicted in section 4. A starting point (case) and one or more perspectives are required to start building a basic life cycle. In order to achieve this, information is taken from the case and reworked into the network. Such information can relate to, for example, different product parts, already selected suppliers, requirements from customers; the information is always interpreted in the context of the perspective(s) provided.

Obviously, information from earlier projects is available in the database, therefore it can easily be reused as a kind of template to speed up the construction of the network. Not only the actual information content can be used, also the ontologies in the database can provide the structure to quickly outline the backbone of the network. Therefore, such reuse of ontologies, allows for the employment of scenarios in the network. Once a basic life cycle is modelled, scenarios become available as templates for decision making in other projects. Such scenarios can address e.g. investigations on the differences in e.g. cost or environmental impact, material selection and usage or the product geometry. As scenarios can depend on a specific perspective, they become excellent means to represent the interests of a stakeholder and allow for the meaningful comparison of fields of expertise involved. The aspects addressed in the scenarios are dependent on different factors like the user's field of expertise, the strategy of the organisation, rules and regulations, the customer requirements and the type of product under consideration. Examples of mechanisms, based on the aspects, are different cost analysis methods and methods for analysing the environmental impact: calculations that can examine the energy use, carbon footprint calculations, LCA's using for instance the ReCiPe method,

calculation of waste streams, etcetera.

6. Design decisions in relation to the Actor-Artifact Network

Traditionally, decision making is treated as a set of process-based activities in development cycles. However, with the availability of the actor-artefact network, attention can change to the information that underlies decisions, and decisions become means to advance the evolvement of the information content. In other words, the aim is to illustrate the shift from parallelisation of processes towards the integration of information as a means to foster integrated product development and aligning decisions across disciplines. Information about these disciplines is obtained from interviews and workflow analysis with multiple respondents involved in different disciplines in the development trajectories. The corresponding development scenarios serve as input for future use, where the actor artefact network is embedded in the working environment. Table 1 shows a simplified excerpt from such a scenario. In this case, the transition from glass towards PET as principle packaging material for a sauce bottle is assessed. It illustrates the important decisions made in this case and highlights the required functionalities of the information contained in the actor-artefact network from three domains: product, process and supply chain. The decisions that can be made in the design and development processes and the evaluation of possible consequences and implications of these decisions are used in elaborating the (future) usage of the actor-artefact network and important focus points for further development of the framework and software tool.

The neutrality and objectivity of the inherent structure of the actor artefact network prevents the enforcement of any presupposed, domain-specific meaning. Simultaneously, it allows for a flexible representation of information that is tailored to the user and the development domain. Meaningful access to the information can be enabled by using the dominant perspectives within such domains as steppingstone for the representation. For instance, as a product designer is responsible for the formulation of the function fulfilment and the configuration of the product, the corresponding perspective could revolve around the product definition. Within the production domain, that same information will need a different representation in which the configuration of the processes and corresponding key measures form the foci.

Table 1. An excerpt of the case study Glass-PET with (simplified) short-term consequences of design decisions from different fields of expertise

Domain	Design decisions	Consequences
Product development	Specifications of PET that provides for the required functionalities of the package while pursuing significant reduction in weight.	New material request Adjusting processes and supply chain configuration
Process engineering	Filling line specifications that can handle the packaging specifications, the expected volumes and food safety standards.	Adjustment of machine configurations or replacement of (a part of) the current filling line with new PET specific components. Adjustments in material specifications that adheres to requirements set by current filling lines.
Supply chain management	The selection of appropriate PET suppliers within the boundaries set by auditing procedures and long-term contracts.	Procurement of new suppliers Adjustment in material specifications that adheres to the currently available suppliers.

Switching between these different perspectives or views allows a versatile assessment of the consequences of design decisions and aid in finding the optimal solution. For instance, from a product perspective it might seem appropriate to apply weight reduction of the principle packaging material or even switch to lighter alternative materials in order to limit the usage of scarce resources. However, that same material reduction in the current production domain has a significant impact on the speed of the current filling lines, potentially nullifying the sought after reduction of impact. In focusing on such causal relations within different domains, the actor-artefact network can foster alignment of decisions, based on the evolution of relevant product and process information instead of a parallelisation of processes. Whereas the latter inevitably puts focusses on the different responsibilities and roles within a development trajectory, integration of the information stemming from those processes highlights the mutual dependencies. Consequently, the evolution of that information can instigate concurrency when needed.

7. Concluding remarks and future work

Whereas in the past one craftsman was responsible for the product development, nowadays a variety of stakeholders are involved, all having different fields of expertise. The product development process consists of a sequence of decisions and the output of a decision is often input for the decision that follows. Due to fragmentation of the development process, consequences of decisions cannot be adequately addressed.

In an attempt to take stock of the situation and fathom the consequences of the (potential) decisions, information from other disciplines is obtained by means of communication during the development trajectory. A problem in communication between different disciplines is that information can be misinterpreted easily, since every stakeholder has its own context. Moreover, the flow of information between stakeholders is not efficient. There is a great difference between the communication that is employed and the information that is required which is caused by the attempt to maintain control over the different relations involved in a product development trajectory. A variety of methods are developed to optimise the process of product development. However, more important than the process itself is the result of such product development processes, the definition of (a part of) the product system. In order to align the decisions across various disciplines, the output of decisions within and between disciplines, and the input of a following decision, need to be coordinated. For aligning the decisions in different disciplines, information about the evolving product system is essential. A flexible information management system which can be used by all stakeholders involved in the development trajectory is required.

The Actor-Artifact network is a modelling technique in combination with a flexible information management system and is developed taking into account flexibility, the possibility to adhere to different viewpoints and dealing with uncertain or missing information. These characteristics are also relevant in aligning design decisions across disciplines by means of product and process information. An effective implementation

of the actor-artefact network will largely be dependent on linking the various databases of the disciplines and the information backbone. The actor-artefact software tool, which needs to be adapted to the different perspectives, serves as an interface between the different information domains.

The key ingredients for establishing views are already available, however the effective use of these views by different stakeholders involved in a development trajectory needs to be validated. While the principle information structure suits any situation due to the abstract modelling language, a successful implementation significantly depends on the modularity of the solution and the flexibility in fitting in the currently used/ dominant software systems while maintaining a neutral information backbone. Within the transition from proof of principle towards industry implementation the flexibility is of paramount importance. In this, it is essential that the influence of (pre)defined workflows and process sequences is minimised. By pursuing this, effective translations from rigid information structures stemming from e.g. PLM software or ERP systems to a neutral information structure can be ensured.

The current status of the case studies show promising results in extending the approach from an aspect like sustainability in a packaging development trajectory towards a more generic approach that allows for the alignment of development decisions across multiple fields of expertise, based on the integration of (evolving) product and process information.

Acknowledgements

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References

- [1] Krishnan, V., Ulrich, K.T., Product development decisions: a review of the literature. *Management Science* 47 2001; 1:1-21.
- [2] Tomiyama, T., Gu, P., Jin, Y., Lutters, D., Kind, Ch., Kimura, F., Design methodologies: industrial and educational applications. *CIRP annals Manufacturing Technology* 58 2009 2:543-565.
- [3] Yassine, A., Braha, D., Complex concurrent engineering and the design structure matrix method. *Concurrent engineering: research and applications* 11 2003, 3: 165-176.
- [4] Fine, C.H., *Clockspeed: winning industry control in the age of temporary advantage*. 1998, Perseus Books, Reading
- [5] Lutters E. *Manufacturing integration based on information management*. PhD. Thesis. University of Twente (NL); 2001.
- [6] Lange, J., Oude Luttikhuis, E.J., Klooster, R., Lutters, E., Towards integrating sustainability in the development of product/packaging combinations. *Proceedings of the 23th CIRP Design Conference*, Abramovici, M. and Stark, R. (ed.), 11-13 March 2013, Bochum (D), p. 855-864
- [7] Oude Luttikhuis, E.J., de Lange, J., ten Klooster, R., Lutters, E., Using actor networks in decision making during content-packaging development. *Proceedings of the 24th CIRP Design Conference*, Moroni, G., Tolio T.A.M. (ed), 14-16 April 2014, Milano
- [8] de Lange, J., Oude Luttikhuis, E.J., Lutters, E., Networked design decisions in balanced life cycles. *Proceedings of the 24th CIRP Design Conference*, Moroni, G., Tolio T.A.M. (ed), 14-16 April 2014, Milano
- [9] Lutters, E., Dankers, W., Oude Luttikhuis, E.J., de Lange, J., Network based requirement specification. *CIRP Annals Manufacturing Technology* 63, 2014, 1:133-136.