Four-dimensional concurrent engineering - an extended theoretical framework integrating packaging

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Abstract
This paper takes on the challenge to integrate packaging in a concept of four-dimensional concurrent engineering (4DCE). The purpose is to explore a conceptual model and empirically evaluate the specific performance of packaging in interrelation with product and processes in the Supply Chain (SC). The objectives are to better understand the concepts of packaging logistics and logistics management in the SC. The conceptual model 4DCE is developed based on the three-dimensional concurrent engineering theories.

The tool Packaging Scorecard is applied to evaluate the concurrent performance of packaging throughout the SC. The packaging system involves many actors that are integrated into the 4DCE framework with focus on interaction of SC and logistics in relation to packaging and product, with the overall aim to operate as effectively and efficiently as possible. In order to explore the potential of the 4DCE framework, empirical verification and testing of the concept has been carried out. The process has been done through multiple in-depth, action-oriented case studies in three different industries on the Swedish market. The case studies covered holistic aspects on the packaging system.

The concept 4DCE contributes to packaging logistics theory by providing a framework for assessment incorporating complex and dynamic interactions between product, packaging, logistics and SC. Furthermore, the holistic packaging development concept is ensured by increasing knowledge of the packaging system and how it interacts with actors and performs to fulfil requirements along the SC. The 4DCE provides valuable data for packaging development processes in the cases, however there is a need for broader studies in different industries.

Keywords: packaging logistics performance, concurrent engineering, packaging scorecard, 4DCE, redesign

1. Introduction

In increasingly challenging and competitive environments, businesses can use logistics and supply chain management strategies in order to minimise costs and create effective supply network operations, to provide customer value (Hsuan et al, 2015). Further, the Supply Chains (SCs) are moving toward managerially coordinated initiatives to increase overall efficiency, continuous improvement and competitiveness (Bowersox et al., 1996). While increased competitiveness and efficiency have great potential for the companies, complexity as the number of interactions involved in co-ordination and collaboration increases (Bode & Wagner, 2015). In order to improve packaging logistics performance, this paper explores the potential of integrating packaging, with the concept of concurrent development of product, process and SC. This research takes on the challenge to integrate packaging in the concept of four-dimensional concurrent engineering. In this paper we propose and explore a conceptual model

that will be empirically evaluated. The specific performance of packaging in the SC is the result of an interwoven network of aspects, often unknown in the system, but valuable for all the actors involved the SC.

The objectives of this paper are - (1) to contribute to a deeper understanding of the concepts of packaging logistics and logistics management in the SC; (2) to develop and apply concurrent engineering with packaging integrated; and (3) to present a conceptual model for concurrent development. The paper will commence with a literature review to develop a conceptual model for concurrent development with a packaging logistics related perspective. Thereafter three case studies and concluding remarks with some directions for future research will be presented.

2. Literature review

The role of packaging has gained strategic importance as it covers both customer-value enhancement and cost efficiency aspects (Lochamy III, 1995; Saghir, 2004). The overall increase in trade of products has led to an immense demand for efficient packaging to perform, functionally and commercially at the right time (Blackwell, 2000) and in the right part of the SC. Another aspect is the sustainability role of packaging (Smorch, 2010; Welcome, 2009; Saghir, 2004; Prendergast and Pitt, 1996). Efficient performing packaging increases logistics efficiency (Chan et al., 2006; Paine, 1990). In the process of packaging development, it is common that each actor is only requiring specific instant performance (Chan et al., 2010). Consequently, it is difficult to monitor the overall performance of the packaging system. Small modifications in the packaging system could have a greater impact across the SC. However, such impacts are not always easy to detect, can cause inefficiencies and may create unnecessary waste and product damages and costs (Fugate et al., 2006). Packaging is an important component in the SC (Lockamy III, 1995) which facilitates efficiency for the companies directly involved in SC activities by increasing safety and protection for the product, as well as providing added value by passively selling the product (Dischter, 1957; Pilditch, 1961). Thus involves many considerations, and often brings with it conflicting or at least challenging demands and requirements. (Vernuccio et al., 2010; Twede 1992). Zacharia et al. (2004) have a view that from a process perspective in the development of new products, logistics processes have a strategic role to play. Chapman et al. (2003) concluded that, by increasing knowledge-sharing with logistics functions and/or providers in the SC, the achievement of greater efficiency, increased customer satisfaction and better strategic planning can lead to more flexibility and adaptation to market changes, rapid and flexible SC management processes enabling rapid innovation capabilities. Coles and Beharrell (1990) state that “with high distribution costs, increased profitability from product or packaging innovation can be wiped out immediately if new packaging units do not fit with existing distribution systems”. As a result, rethinking processes in distribution and logistics opens up an innovation potential for packaging by focusing on handling, delivery, hand-over and service to the customer/consumer. In line with this suggested rethinking, Fine (1998) presents the concept of three-dimensional concurrent engineering (3DCE), in which the product, process and SC are designed in parallel (Fine (1998), Fine et al. (2004), Ellram et al. (2007),Ellram and Stanley (2008)). Dominic et al (2000, pg. 98-102) and Bramklev (2007) suggests an integrated product and package development procedure model. They state that it is preferable to consider the function decomposition of product and package when specifying the product, whereby Dominic et al. focuses on the product strength versus packaging mechanical protection properties. Bramklev states that integrative aspects will be heavily dependent upon product area, whereby modeling

of product and package leads to technical, organizational, process and goal oriented implications. This means that when the product area is known, relevant measures for the integration of product, package, logistics and SC at operational level could be outlined. Based on Bramklev and Dominic et al 2003 it is suggested to integrate packaging as the forth dimensions in concurrent engineering. Figure 1 present an illustration of four-dimensional concurrent engineering (4DCE) combining an integrated approach on product, packaging, logistics and the SC.

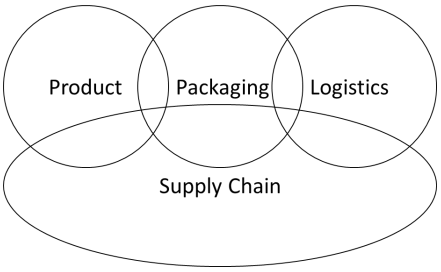


Figure 1 A conceptual illustration of four-dimensional concurrent engineering (4DCE)

3. Methods

The tool Packaging Scorecard (PSC) (Olsmats et al., 2003) was designed to identify the concurrent performance of packaging in a SC. The focus here is on conflicting yet crucial criteria for the actors involved in SCs. The aspiration level of packaging performance criteria i for actor j is denoted as $\gamma_i\tau_{ji}$ where γ_i is the weighted value for performance criteria i. The model was designed to systematically evaluate performance criteria and indicate performance on a holistic level as illustrated in Figure 2. The objective function of the model is thus:

$$A_1 = \sum_{i=1}^{n} \gamma_i \tau_{1i}, \quad A_2 = \sum_{i=1}^{n} \gamma_i \tau_{2i}, \quad A_3 = \sum_{i=1}^{n} \gamma_i \tau_{3i}, \quad \dots \quad A_N = \sum_{i=1}^{n} \gamma_i \tau_{Ni} \qquad (1)$$

In equation (1)

A_N Actor N involved in the SC

γ Performance criteria weight

τ Performance score

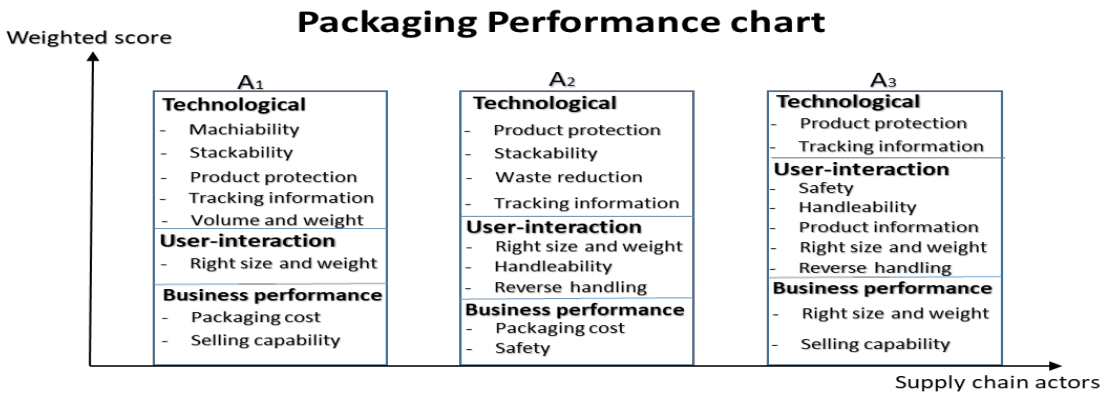


Figure 2. Bar charts indicating packaging performance based packaging criteria

The packaging system involves many actors both inside and outside the SC, and adequate performance at every stage is desired for the system. Figure 2 and equation 1 visualise how the packaging system is performing within the SC. It does this by registering requirements divided into Technological, User-interaction, and Business performance, and determine whether these requirements are fulfilled in the SC. The requirements are summed up as a whole to identify overall performance as it is presented in the Packaging Performance Chart illustrated in Figure 2. Consequently, the interaction between packaging, product, processes and the SC will all be considered and integrated in the creation of the 4DCE.

4. Four dimensional concurrent engineering (4DCE)

In order to increase the efficiency of the SC, alignment between the logistics processes, product and the packaging system is suggested and conceptualised in the 4DCE framework developed. The 4DCE framework has a focus on interaction of SC and logistics in relation to packaging and product, with the overall aim for the SC to operate as effectively and efficiently as possible. SC actors therefore need to work together, through deliberate co-ordination and through self-organisation, to satisfy customers' and consumers' requirements and needs. At the same time each actor is often primarily interested in making their own processes efficient, which means that they only make demands on the level of packaging they interact with. This also applies to packaging suppliers since they are often involved in only one or two levels of the packaging system. Consequently, when it comes to the packaging system, nobody has a holistic approach regarding the SC and nobody owns or controls the total packaging system or the logistics processes (Dominic, 2006); only a part of them. For the SC actors working with a focus on packaging issues, concurrent tasks will emerge and these are often solved instantly. The problem is that the solutions are rarely developed in the broader context of the overall SC. Hence, in order to achieve 4DCE, the approach needs to facilitate the interaction between actors focusing on improving the overall efficiency of the flow in the SC. Consequently, in order to emphasise the content and the processes the 4DCE starts with the evaluation of the packaging and packaging system downstream in the SC. In this evaluation Packaging Scorecard is used in gathering input on the packaging performance, and each actor's requirements and needs are assessed. The assessment results are then used in the interaction with other actors, the aim being to create increased efficiency through reflection, discussion and creation of packaging modifications, process improvements and/or SC set-up changes. By facilitating focused meetings with SC actors based on packaging assessments, improved performance in processes can thereby be incorporated. From this interactive process, outcomes emerge concerning modifications and reengineering as well as outcomes which testify to increased understanding and knowledge-sharing among the actors. Hence, the development of the SC is increased as participants become integrated within the SC.

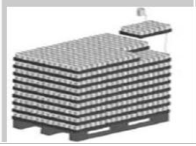
5. Case study

In order to explore the potential of the 4DCE framework, empirical verification and testing of the concept has been carried out. The verification and testing process is an important element in framework development according to Eisenhardt and Graebner (2007). The process has been done through multiple in-depth, action-oriented case studies. The case study methodology has been considered appropriate here based on the findings by Yin (2003). The case studies were carried out in three different industries acting on the Swedish market (the brewery industry, the vitamin-producing industry (non-pharmaceutical) and the fresh food industry). Each case study

has served as a distinct experiment, providing rich data for further quantitative and qualitative analysis or as Dubois et al. (2002, pg.555) state, a relationship between ”everyday language and concepts”. We have used three case studies as discrete experiments which together with our theoretical foundation have converged into the theoretical contribution of 4DCE. Based on the time frame for the case studies, snowball sampling (Goodman, 1961) was modified and applied to select the case studies and data providers. The initial data providers were packaging and logistics managers who introduced informants involved in solving strategic and operational tasks in the SC. The participant organisations provided multiple data sources for the studies. The data for the PSC assessment has been collected by in-person visits through a series of unstructured and semi-structured interviews lasting approximately an hour each. In the case presented in this paper, the informants (packaging and development manager, SC and sourcing manager, transport and operation manager, technical manager, and sales and marketing manager) in the SC were interviewed. Each interview was recorded, transcribed and finally documented in a written report. The key informants of the participant companies were asked to verify that case data were accurate and possible uncertainties were subsequently clarified by telephone. The interviews were thematically analysed in accordance with the PSC criteria described in Figure 2 and an assessment of the packaging system performance was conducted by the researchers. A report and presentation material were created as input to the subsequent meeting with SC actors. In all cases the meetings were held as workshops, where participants were given information about the PSC assessment results beforehand. The workshops then focused on identifying and prioritising improvement potential in the SC from a packaging and product perspective. The workshops were documented by one of the participating researchers and analysed afterwards based on content, process and outcome. In the next section the case studies are presented.

The case study from the fresh food industry in which the holistic packaging development concept has been used (see Table 1) is first presented here. Insights from the other two case studies are briefly introduced and then highlighted at the end of the section. Findings were similar in all three cases insofar that improved SC performance based on 4DCE has been obtained. In addition, improved integration among the SC actors has been achieved. This is largely because this is the first time the SC actors have come together with a common focus.

Table 1. Case study packaging systems studied from 3 industries

Supply chain	Primary packaging	Secondary packaging	Packaging system	Performance value
Fresh foods				2.63
Vitamins				2.83
Beverages				2.33

The primary package from the fresh food case was a plastic trough with lid, sealed with a label which provided information both for logistics activities and about the product. Secondary packaging was a reusable tray and tertiary packaging consisted of plastic pallets. The performance value is the current performance of the packaging system measured applying PSC.

The retail SC for the fresh food product was a network consisting of a sequence of different stages: packaging suppliers, product fillers, distribution centers, warehouses, convenience stores, supermarkets and megastores (see Figure 3). A reusable system for plastic pallets was implemented. The product filling actor adapted multiple sourcing strategies in order to avoid disruptions in the product-filling process and to guarantee a continuous flow. The actors involved were connected by physical transport systems between two actors. The materials for the packaging systems were supplied by various sub-actors. There were reverse logistics systems to reuse or recover secondary and tertiary packages. The diagram in Figure 3 present a snapshort of the current consolidated flow of how packaging is filled and assembled at the product-filling actor's, re-packed by the distributor, and disassembled at the customer. The related actors are presented in rectangular boxes.

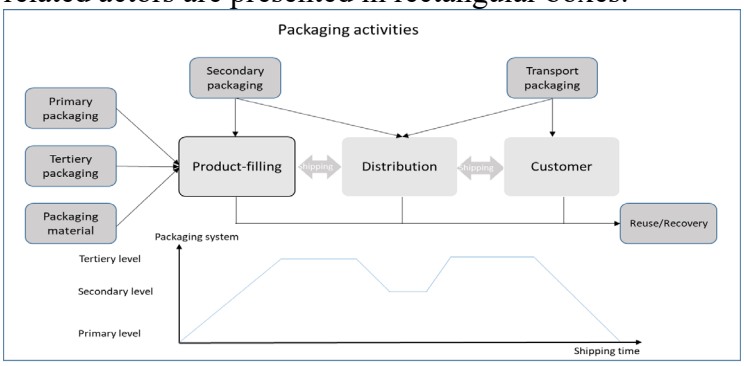


Figure 3 Packaging system is mounted and interactions with the SC

Figure 4 presents the results of packaging system for fresh food by consolidating the performance for each actor in the SC.

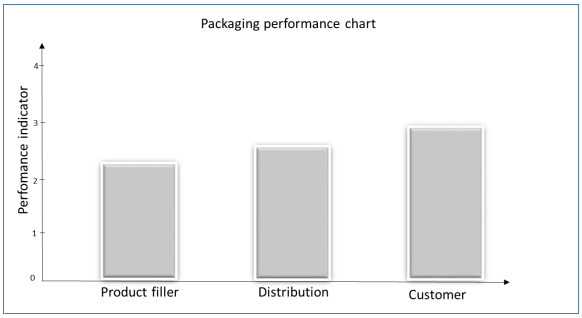


Figure 4. Aggregate results for the fresh food case study

The bar charts in Figure 5 show the normalised criteria sorted in descending order for all the criteria which were weighted by the three main actors. The packaging performance scores indicate a value for each criterion on a SC level.

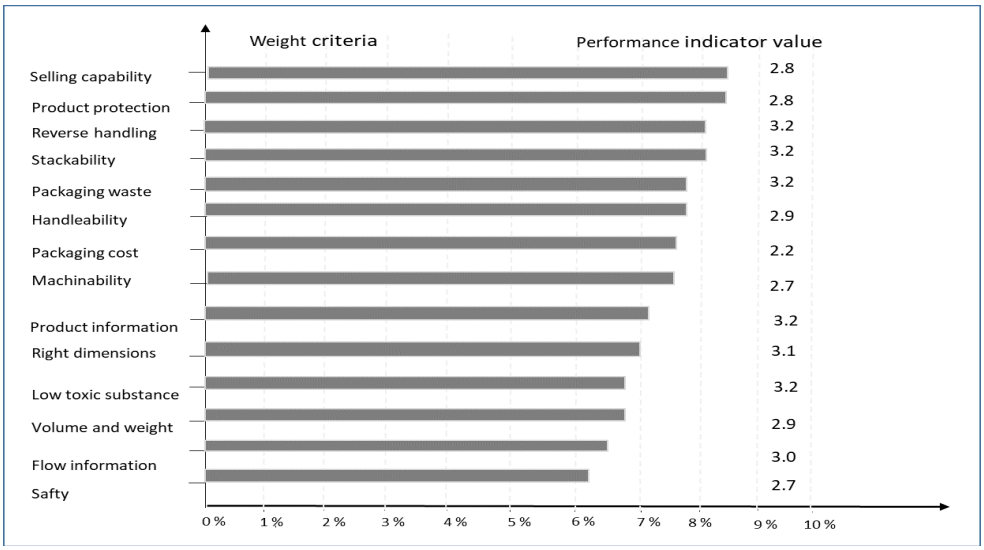


Figure 5. Aggregate values for fresh food case study, sorted by most important criteria and on a weighted level

Figure 5 shows that selling capability, product protection, reverse packaging management and stackability were considered important criteria. The performance indicator values for selling capability and product protection were slightly low compared to the targeted value of 3.0. The reason for this underperformance was that primary packaging was not fully adapted to the number of products being sold and was not completely suited to secondary packaging. Moreover, pallets caused problems when they were manually handled, while reverse packaging management (3.2) and stackability (3.2) over performed slightly. Stackability, packaging waste, handling and packaging cost criteria were met satisfactory.

As illustrated in the previous section, when the concept of holistic packaging development is applied the PSC tool provides specific packaging data from the different SC actors and the processes involved. This data was used as a starting point for the concurrent development of product, package and logistics processes. The analysis was carried out in a workshop where the participants were the primary packaging supplier, product filler, brand owner and retailer specifically involved in the study. The purpose of the workshop was to systematically understand the performance of packaging systems in the SC, and to establish stronger links among the actors interacting within the SC. The idea was to rethink not only packaging but its interaction with processes and structures in the downstream SC. During the workshop several issues and problems were elaborated on, and suggestions for redesigned packaging solutions and logistics processes were made. Each participant expressed a long-term view towards increasing efficiency along the SC. However, it was also found that the main driver for these actors to participate in this workshop was cost reduction achieved by reducing handling, material waste and product damage.

The analysis carried out by the participants indicated that there was a problem at the distribution centre with the packaging system packed with mixed products that required extra time for resorting. To solve this problem, it was suggested that secondary packages be clearly labelled with labels of different colours in order to make the distribution actor's task easier. Figure 6 illustrates how packages containing different products were placed. The colour-coded labels were pasted onto the trays and this helped in the process of re-sorting the trays. Each colour on the labels illustrates how the packages were placed on the pallet before and after colour labels were attached. This small adjustment led to reduced re-packing time at the distribution actor by half an hour per load carrier.

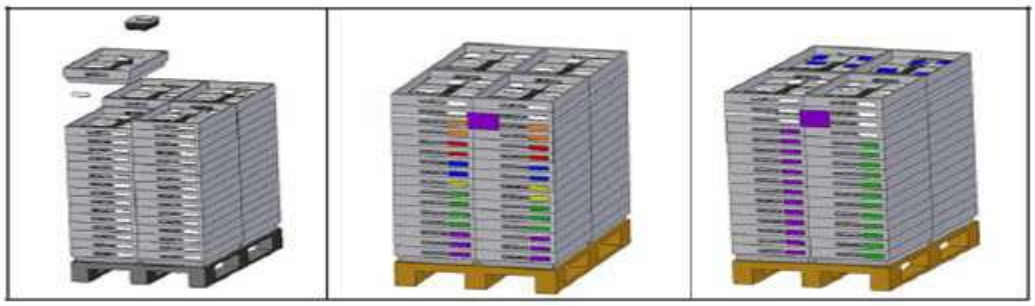


Figure 6. The trays labelled white (figure on left) show the unsorted fresh food packages arriving at thedistribution centre. Coloured labels (middle figure) made it easier to sort and re-pack the system (figure on the right)

By implementing colour-coded labels the performance indicator values were raised by an average of 15 per cent. Figure 7 presents the details before and after the concept of 4DCE was used. This small change in the system contributed to a major change in the downstream SC.

Current performance indicators

Criteria	Performance indicator value
Information flow	2.7
Minimum of toxic substance	3.0
Handling	2.5
Machinability	2.0
Packaging cost	2.0
Selling capability	2.5
Reverse packaging management	3.0

Predicted performance indicators after adjustments

Criteria	Performance indicator value
Information flow	3.0
Minimum of toxic substance	3.1
Handling	3.0
Machinability	2.7
Packaging cost	2.3
Selling capability	2.7
Reverse packaging management	3.1

Figure 7. Performance before and after holistic packaging development stages

The case study for vitamin and brewery packages gave similar results with an average improvement of 12 %. By requiring design modification on the primary packaging the space utilisation and usability for vitamin packages were improved. For the third case study the product damages during transport were reduced after the modifications, and hence SC performance was improved by an average of 15%.

6. Discussion

The study covered both holistic aspects and detailed studies of the packaging system. The 4DCE starts with an evaluation of the packaging system in each logistic process in order to obtain and assess each actor's requirements and needs. These intermediate evaluations provided data to rethink the packaging design, and seemed to be an appropriate step towards a more holistic product and packaging development process. Our results are in line with previous results by Olsmats & Dominic (2000), indicating that the PSC can be a useful tool for analysing how a packaging system can contribute to increased efficiency in the SC. A workshop was conducted to elicit input from the actors in the SC. The representatives from the majority of SC actors (e.g. customers and product filling) discussed various business issues which are then transformed into requirement specifications communicated to the other actors (e.g. distribution and packaging supply actors). Until this separation of tasks happens it is difficult to talk about integrated SCs. For the 4DCE integrative activities are essential as they are the core of development if SC performance is to be accomplished, based on packaging and its related processes. Emergent outcomes concerning modifications and innovations are the results of this interactive process, as well as increased understanding and knowledge-sharing among the actors.

7. Conclusions

In this paper an approach for 4DCE has been presented. The concept utilises the PSC and is a further development of the concept of three-dimensional concurrent engineering, integrating also the packaging dimension. The 4DCE contributes to packaging logistics theory by providing a framework for assessment incorporating complex and dynamic interactions between product, packaging, logistics and SC. The case studies indicate that this approach requires a holistic view on the SC and relevant actors need to actively participate in workshops to improve overall efficiency. As presented in previous research (Bramklev, 2007; Klevås and Saghir, 2004) it is often found that small changes in a packaging system can lead to major changes for the entire SC, thereby impacting SC efficiency. Furthermore, the holistic packaging development concept is ensured by increasing knowledge of the packaging system and how it interacts with its actors and performs to fulfil requirements along the SC.
This research has certain limitations, e.g. applicability in different business sectors, which can be addressed in future studies. Even though the case studies indicate that the 4DCE provides valuable data for packaging development processes, there is a need for broader studies in different industries: indeed, further research should strive to extend the analysis of the concept. Moreover, it might be interesting to develop studies which consider applying new technologies such as rapid prototyping to present at the workshops involving SC actors in order to generate innovative packaging concepts in a product, process and SC context.

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