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Transdisciplinary product development

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Abstract

Research Question (RQ): How can transdisciplinary approach increase the product development process in future industry?
Purpose: The aim of the research is to develop a model of an effective product development in the automotive industry based on the transdisciplinary approach.
Method: We used a qualitative research approach in order to develop a theoretical framework of transdisciplinarity. The framework comprises the concurrent engineering and experts from different disciplines. The framework was represented by a mathematical model which based on stochastic dynamic programming.
Results: We developed a theoretical framework and a practical case of transdisciplinary product development in the automotive industry. We presented a mathematical model and information environment which supports such a model.
Organization: The findings of the research will provide higher productivity, lower operating costs, change in personnel structure, higher added value, lower sales costs, lower administration costs, reduction in growth of expenses, and lower costs of work equipment.
Society: The research impact on higher customer's satisfaction, increased flexibility of operations, better quality of information, improved control of sources, less waste materials and less pollution, improved planning process, more favourable consideration of employees , improved portfolio management, and better corporate presentation of company.
Originality: Transdisciplinary framework combines methods of concurrent engineering and interdisciplinary approach in a process of product development. The development of such a framework is a complete novelty and represents an original approach to product development, which will be particularly suitable for the smart factories of the future. Transdisciplinary framework was transformed into a mathematical model based on stochastic dynamic programming. Model is supported by the existing information warehouse and represents a potential for upgrade business intelligence.
Limitations / further research: Proposed model was implemented in automotive industry. In the future it could be implemented also in other industries as a part of smart factories.

Keywords: transdisciplinarity, concurrent engineering, decision-making, business intelligence, dynamic programming.

1 Introduction

The aim of the article is to present a new model of an efficient product development process in the automotive industry based on the transdisciplinary approach. In product development, companies generally use the approach of concurrent engineering which is mainly focused on engineering process only. The classical interdisciplinary approach to work under which experts from different research disciplines aim at a common project goal, has also become insufficient. The transdisciplinary approach is, however, a combination of (inter)disciplinary and undisciplinary approaches and based on the principle of concurrence allows a significantly better interaction between science, development entities and technologists on one hand, and other environment on the other hand.

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An important co-creative part of the model of transdisciplinary product development in the automotive industry consists of a modern information environment which is consistent with the company's strategic goals.

2 Transdisciplinarity

Interdisciplinarity is a type of collaboration in which specialists drawn from different research disciplines work together in pursuit of common goals. This type of collaboration boasts numerous benefits, however there are some restrictions. The key restriction is that the team members usually follow the project goal while they fail to deal with how this goal or the result affects other stakeholders in the process or the wider society. We are aware of cases of excellent development groups who nevertheless have difficulties acquiring financial resources, communicating, managing or marketing their development outcome. In our company, we try to avoid these difficulties as much as possible; therefore we are searching for new approaches conveying most effectively the development solutions to users or customers.

Unlike the interdisciplinarity, the transdisciplinarity is a less recognized category involving progress of concepts which cannot be comprehended in terms of any individual discipline and needs a simultaneous combination of knowledge related to several disciplines. Transdisciplinary approach is a combination of (inter)disciplinary and (un)disciplinary sphere allowing interaction between science or researchers and wider society. In addition to »hard« disciplinary knowledge, the approach also involves the so-called »soft« knowledge, information and know-how existing in a company (Nicolescu, 2008, pp. 10-20). Figure 1 symbolically shows disciplinarity, multidsciplinarity, interdisciplinarity and trans-disciplinarity.

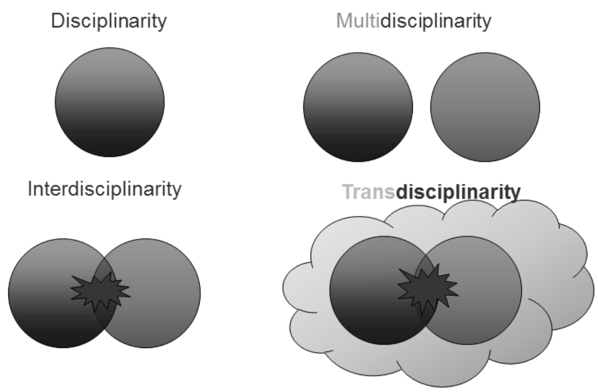

Figure 1. Disciplinarity, multidisciplinarity, interdisciplinarity and transdisciplinarity.

3 Concurrent Engineering

Concurrent engineering is a systematic approach to integrated product development that emphasizes the response to customer expectations. It embodies team values of cooperation, trust and sharing in such a manner that decision is making by consensus, involving all perspectives in parallel, from the beginning of the product life cycle (Ashley, 1995, pp. 74-77).

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Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including, manufacturing and support. This approach is intended to cause the developers from the very outset to consider all elements of the product life cycle, from conception to disposal, including cost, schedule, quality and user requirements (Pennell, Winner, 1989, pp. 27-30).

In order to define development activities within the industry, we can summarize that concurrent engineering is a simultaneous performance of sequential development task. Concurrent engineering is a philosophy, a concept, a way of thinking, a way of organizing work whose basic characteristics are as follows (Mihelič, 2012, pp. 16-20):

- Concurrent/parallel performance of activities;
- Multidisciplinary team approach, common goal of all participants;
- Project organisation;
- Early sharing of information.

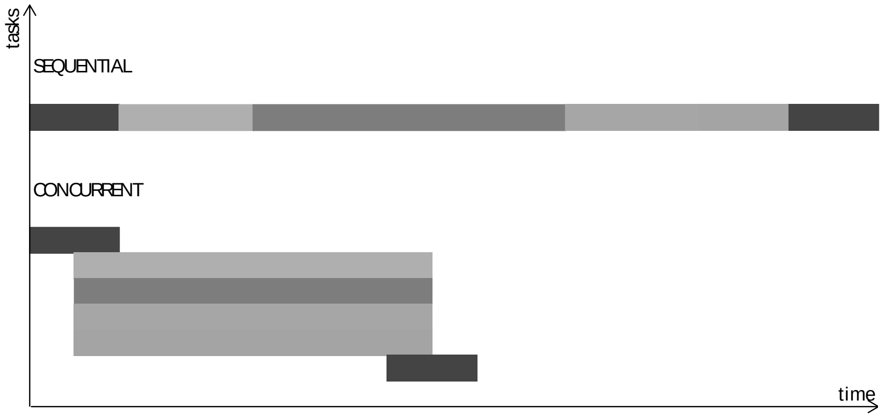

Figure 2. Concept of concurrent engineering. Adapted from "Concurrent Engineering", by P. Mihelič, 2012, FINI, p. 21.

Concurrent engineering is a thorough, comprehensive and sustainable approach to product development taking into consideration the lifetime use of product already at the stage of its design. It is directed to the user; it reduces time to market and is based on application of advanced development methods and a strong joint information and communication platform. Figure 2 symbolically shows the concept of concurrent engineering.

4 Business intelligence in corporate management

In today's fast changing environment, corporations with higher awareness of their operations and environmental involvement are privileged. They gain competitive advantage after having used this awareness to make good decisions. Systems of business intelligence (BI) enable them to develop knowledge by means of data gathering and provide for the shortest time interval possible between the data and the information or in other words for an almost immediate response (Makovec, 2014, pp. 248-255).

Decision-making process takes place continuously. Decisions are made about strategies, action plans, budget and corrective actions in case the factual situation for different reasons deviates from the desired results. Today, processes are complex and relying on intuition is no longer enough. We need information about process flow here and now. However, to get a perfect picture, information needs to be completed with information from the environment.

Since Henry Ford's famous statement in 1909 that customers could have any colour the Ford Model T as long as it was black, a lot has changed in the automotive industry. Today, almost every manufactured car is unique. Customers are offered various engine, exterior, interior and colour options. This diversity, however, is reflected in a demand for a quick response in the supply chain and a need for excellent planning. On the other hand, the price pressure requires lean operations and minimum stocks. In terms of information, all this implies a lot of data which need to be monitored and controlled. A well-known management principle says that what we are not able measure, cannot be managed. The same holds true saying that we are not able to manage what is not supervised. Some studies shows, that only about 20% of the collected data is used by about 20% of decision-makers. Why so little?! The first reason is that data are difficult to access, and the second is that it takes too much time to create new extracts, reports and summaries for decision makers (Makovec, 2013, pp. 221-228).

BI is defined as a capability to understand mutual relations in a way to be able to conduct activities towards attainment of objectives (Luhn, 1958, pp. 314-319). BI can also be seen as a concept and methods for improvement of corporate decision-making process by using a support system based on data. Today, definitions of BI are currently being amended and modified in accordance with development of BI tools. One of the latest definitions (Jaklič, 2013, pp. 1-5) says that BI is a corporation's ability to reason, plan, forecast, solve problems, think abstractly, comprehend, innovate and learn in a way to increase organisational knowledge, provide information for decision-making processes, enable effective and efficient activities and help determine and meet the business objectives.

BI can also be seen as a transfer of data into information and delivery of information to the right people at the right time. Nevertheless, we should consider BI is not a mere methodology but a set of processes, technologies and tools.

Reasons for application of BI in companies are varied:

- The information obtained contribute to better decision-making;
- The information is faster, therefore we can make decisions on time;
- Data integration from different sources including data from transaction systems, different data bases, files of various formats and web data.

5 Business value of Information Technology in the environment of transdisciplinary product development

In a competitive corporate environment, effective corporate management comprehends their information environment as a strategic tool for creation of new business models and competitive advantages in the market. Company's business strategy is becoming increasingly connected with development strategy of the information environment and the latter mainly focuses on development of their strategic capacities to support the implementation of company's strategic objectives (Smith et al., 2007, pp. 51-60). New business models (Kovačič in Bosilj-Vukšič, 2005, pp. 15-56) intended to increase the added value determine the operations, relationships and progress of implementation of individual business actions. Moreover, they provide answers to key questions related to corporate sustainability and therefore determine the strategic reference lines, process model, and organization, structure of knowledge and conduct of business rules, roles and responsibilities and spatial dimensions of the company's operations.

Searching for levers enabling the information technology to impact directly or indirectly the growth and progress of the company is one of the current and first-rate joint missions of the business management and the IT manager. The future of the company and the business value of the IT depend to a large extent on efficiency of this strategic reflection and cooperation. Progress and deployment of modern approaches and tools in the area of product development in automotive industry (ERP – Enterprise Resource Planning, PLM – Product Lifecycle Management, SCM – Supply Chain Management, CRM – Customer Relationship Management, ECM – Enterprise Content Management, BI – Business Intelligence, SOA – Service Oriented Architecture) enable the company (providing the IT development strategy is in compliance with the company strategy) to operate more effectively and more sustainably and to increase their competitiveness. Therefore, the real power and sustainability of the IT's business value lies mostly in (Cerovšek, 2012, pp. A27-A35):

- Moderate use of information technology (compliance of IT objectives with the company's objectives);
- Business process management (extended view on renewal and informatization of processes and operations);
- Involvement and progress of informed and motivated employees.

In the process of transdiciplinary product development the information technology upgrades its technological value with business value which is becoming an essential element in orientation of its function. It provides (Groznik et al., 2005, pp. 213-222) measurable (tangible) and non-measurable (intangible) benefits for the company. The latter ones are getting more and more importance, yet they are often neglected (see Table 1).

Strategic management of information environment has through the management of process of product development an important impact on the company's effectiveness and efficiency. The word is about management of modern information technology according to the principles of business environment and on the correct understanding and application of approaches related to management of business processes.

Table 1. Measurable and non-measurable benefits for the company.

Measurable benefits	Non-measurable benefits
• Higher productivity.	• Higher customer's satisfaction.
• Lower operating costs.	• Increased flexibility of operations.
• Change in personnel structure.	• Better quality of information.
• Higher added value.	• Improved control of sources.
• Lower sales costs.	• Improved planning process.
• Lower administration costs.	• More favourable consideration of employees.
• Reduction in growth of expenses.	• Improved portfolio management.
• Lower costs of work equipment.	• Better corporate presentation of company.

6 Transdisciplinary model of product development

6.1 Conceptual framework of product development

Product development in the automotive industry is based on three main parts: design and development, production, and management. Design and development of a new product is based on the principles of concurrent engineering. This process consists of two phases:

A. Phase of new product design, and
B. Phase of product development.

The phase of new product design is coordinated by key account managers from the commercial division. Activities are organised according to the team work, where experts from different areas are involved:

- Design of a product; definition of design, virtual analysis.
- Design of a production process; definition of technology.
- Logistics; draft planning of logistics in plant(s), logistics between plants, and transportation to the customers.
- Purchasing; draft planning of materials, of equipment, tools, machines, and buildings.
- Quality; Failure Mode and Effects Analysis (FMEA).
- Economics; pricing.

In the phase of new product design team members contribute knowledge and expertise from different areas or disciplines, like: mechanical and electro engineering, materials, logistics quality management and economics. Besides knowledge from so-called "hard" sciences also knowledge from the "soft" disciplines is necessary, like communications skills, psychology and global understanding of the trends and market. The result of that part is an offer for the customer. There is an important milestone of the whole process, where a decision about the further development should be made. Decision making is a complex process, which is based on existing knowledge and relevant information. However, the decision making is very often supported by emotional intelligence and intuitive decision making (Erenda, 2013, pp. 48-54).

The phase of product development is coordinated by project managers from the project office. Activities are organised according to the project work, where experts from different areas are involved:

- Development of a product; analysis, testing, prototyping, standardization.
- Development of a production process; design of machines and tools.
- Logistics; detailed planning of logistics in plant(s), between plants, transportation to the customers.
- Purchasing; detailed planning of materials, equipment, tools, machines, and buildings.
- Quality; detailed planning using methods like FMEA, Advanced product quality planning (APQP), sorting, straightening or setting in order to flow or Streamlining, Shining, Standardize, and Sustain (5S), and Statistical Process Control (SPC).
- Industrialization: constructions, installations, equipment.

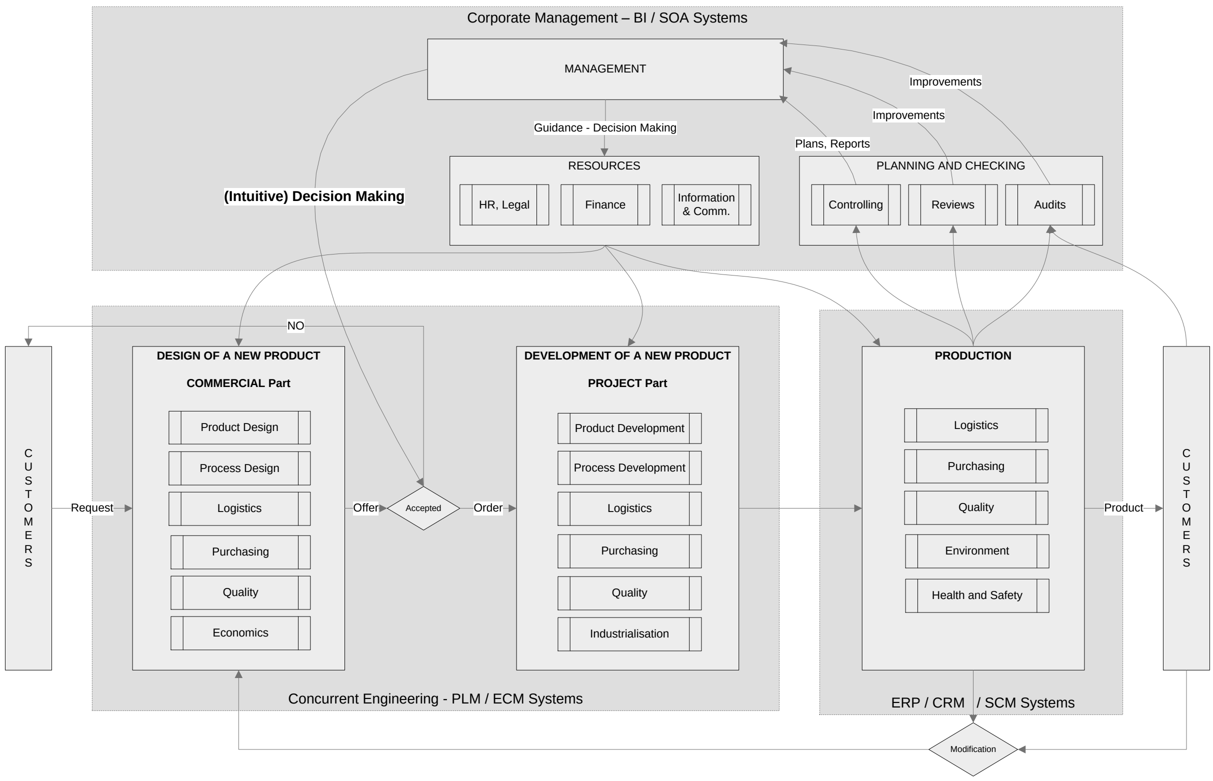

Figure 3. Presentation of the conceptual framework of transdisciplinary model.

In the phase of product development project members contribute knowledge and expertise from different disciplines. Project team must follow the project goals, so we can talk about the interdisciplinary approach. However, the project manager should be aware about the broader, strategic goals of the company, about the changes in the environment and be able to react to different risks. That is why we can also talk about the interdisciplinary approach. One of the most important pre-condition for the successful project is an appropriate level of communication in the project team, and communication of project manager with the top management and with other project managers in the company. Project manager as the representative of the middle-level management is very often confronted with the optimisation of the resources and with the process of decision making. Sometimes he/she has enough information for relevant decision, but it happens very often that he/she must make a decision with insufficient information in a fuzzy environment (Savšek, 2015, pp. 13-20). Decision making at the top-level as well as at the middle-level management is much more relevant and less frustrating, if these is available appropriate information technology and IT solutions. Figure 3 presents the conceptual framework (Erenda et al., 2014, pp. 1937-1946).

6.2 Optimization and decision making

Optimization is a mathematical technique for determining the most suitable or least disadvantageous choice out of a set of alternatives. Typically the set of alternatives is restricted by several constraints. Optimization is also modern term for operations research.

Decision making is a process undertaken by an individual or organization. The intent of this process is to improve the future position of the individual or organization in terms of one or more criteria. Decision making is one of the stochastic operation research tools that can be used to assist management in making decisions under certainty, risk or uncertainty. In the operations research problems the objective is to find the optimal (may or min) values of the decision variables, that is, those variables that can change or be controlled within the problem structure (Nemhauser, 1989, 573-623).

6.3 Stochastic Dynamic Programming

Dynamic programing is an approach to problem solving and a decomposition technique that can be effectively applied to mathematically describable problems having a sequence of interrelated decision. It determines the optimum solution F to an N-variable problem by decomposing it into N stages with each stage comprising a single variable sub-problem at stage n. Value $f_n(S_n)$ represents accumulated optimal returns and can be written as recursive equation (Ravindran et al, 1987, pp. 437-440):

$$f_n(S_n) = opt_{d_n, d_{n-1}, \ldots, d_1} \{ r_n(d_n, S_n) \; \Theta \; r_{n-1}(d_{n-1}, S_{n-1}) \; \Theta \; \ldots \; \Theta \; r_1(d_1, S_1) \}$$

where

S_n = input state n = stage number
d_n = decision r_n = return function

In this general formulation Θ represents any operand dictated within the context of the problem at hand, in addition, might change from one stage to the next. For example, Θ might represent addition, subtraction, division, or multiplication (+, −, ÷, ×, respectively).

Multistage systems can be divided into two large classes: deterministic systems and stochastic systems. In deterministic systems it is assumed that all the variables are known or can be determined exactly. Real world problems, like socio-economic, which contain random variables with variance large enough that an unacceptable error is produced by replacing them with their expected values should be described by stochastic systems (Ravindran et al, 1987, pp. 477-479):

$$f_n(S_n) = opt_{d_n, d_{n-1}, \ldots, d_1} \{ r_n(d_n, S_n, K_n) \, \Theta \, r_{n-1}(d_{n-1}, S_{n-1}, K_{n-1}) \, \Theta \ldots \Theta \, r_1(d_1, S_1, K_1) \}$$

where K_n is random variable.

7 Discussion

Business environment surrounding the automotive industry is extremely dynamic. Many times, some unpredicted circumstances might occur and data might be incomplete or even false. In such critical situations, all available know-how and information need to be used in a very short time and people have to be able to communicate properly within the company, as well as with external stakeholders, e.g. customers, suppliers, partners and wider society. In such a situation, all disciplinary knowledge and set goals have to be overcome. In such a case we talk about a new, the so called transdisciplinary approach. Transdisciplinary model represents a significant leap in thinking while developing products in automotive industry. The traditional engineering knowledge based on interdisciplinary concept is supplemented with new »soft« know-how allowing a faster penetration of technical solutions to the end customer.

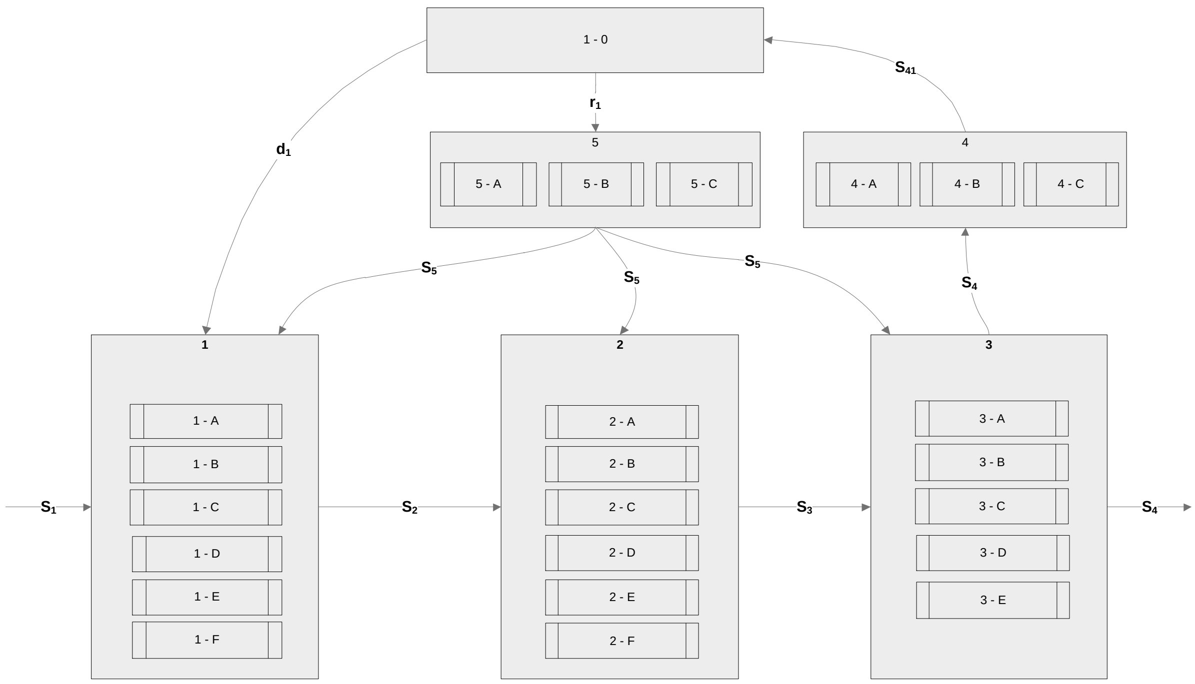

Figure 4. Representation of the conceptual framework by the mathematical model.

We transformed the proposed conceptual framework of product development into a mathematical model based on stochastic dynamic programming. By that we converted a typical socio-economic problem into a format that enables further modelling and simulation.

Depending on the specified optimization function we can search for local and global optimum according to the requested criteria. We can optimize the structure of project teams concerning the interdisciplinary participation of experts in the projects. We can also monitor the achievement of the global objectives of the company, which is the core idea of the transdisciplinary approach. The proposed mathematical model can be easily programmed by the existing software tools. Input data can be adopted from existing databases. Output from the expert system can be successfully used as part of BI in the company. Figure 4 represents the proposed mathematical model.

8 Conclusion

Product development in traditional production companies usually belongs to development departments which are due to their specificity often isolated from other processes in the company. In automotive industry, the product development usually starts with customer's demand to develop a certain car component. This demand involves geometric and functional requirements, estimated volumes and expected price. Time of offer preparation including all aspects of product and process development as well as overall costs is extremely short and there is usually no possibility to review. This is the reason why the product development cannot lie within exclusive competence of development departments and all stakeholders contributing to a successful realisation of the offer have to get involved in the early stage of development projects, i.e. commercial, product design and development, process design and development, purchasing, production, logistics, information and communications technology, environmental section and last but not least human resources and finance. The process of product realisation gathers experts from different areas or professional disciplines sharing a common goal which is why we talk about interdisciplinary teams. Product development in automotive industry is performed on the basis of concurrent engineering determined as a simultaneous planning and deployment of all processes and information which are necessary for product manufacturing, its sales, distribution and after-sales.

The innovativeness of the presented model lies in the upgrading of the concurrent engineering with »soft« and non-disciplinary contents, such as intuitive decision making. The model could be easily upgraded to involve product optimisation in terms of its functionality, technological applicability and price adequacy, as well as business intelligence, enterprise contents management, and communication channels module. The new model of efficient development represents a basis not only for automotive but also for other industries with the purpose of implementing a new development concept in their processes customizing their infrastructure and organization. The use of transdisciplinary model in the product development will not only reach the limits but will also exceed them.

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POVZETEK

Raziskovalno vprašanje (RQ): Kako lahko transdisciplinarni pristop izboljša proces razvoja proizvoda in industriji prihodnosti?
Namen:Namen raziskave je razviti model za učinkovit razvoj proizvoda in avtomobilski industriji temelječ na transdisciplinarnem pristopu.
Metoda: Uporabili smo kvalitativni raziskovalni pristop, da bi razvili teoretični okvir transdisciplinarnosti. Okvir je kombinacija sočasnega inženiringa in vključevanja strokovnjakov iz različnih raziskovalnih disciplin. Na podlagi tega smo razvili matematični model, ki temelji na dinamičnem programiranju.
Rezultati: Oblikovali smo teoretični model in zgradili praktičen primer transdisciplinarnega razvoja proizvodov v avtomobilski industriji. Prikazali smo povezavo sodobnega informacijskega okolja za tak model.
Organizacija: Ugotovitve raziskave bodo lahko zagotovile višjo produktivnost, nižje stroške poslovanja, spremembe v strukturi kadrov, višjo dodano vrednost, nižje stroške prodaje, nižje stroške uprave, zmanjšanje rasti stroškov in nižje stroške delovne opreme.
Družba: Raziskava bo vplivala na višje zadovoljstvo strank, povečala se bo fleksibilnost poslovanja, izboljšala se bo kakovost informacij in nadzor nad viri, razvijali se bodo izdelki z manj odpadki in manjšim onesnaževanjem, izboljšal se bo proces načrtovanja, izboljšali se bodo delovni pogoji zaposlenih, izboljšano bo upravljanje portfelja in korporativno komuniciranje podjetja.
Originalnost: Transdisciplinarni okvir združuje metode sočasnega inženiringa in interdisciplinarni pristop v procesu razvoja izdelkov. Razvoj tovrstnega okvira je popolna novost in predstavlja izviren pristop k razvoju proizvodov, ki bo še posebej primeren za pametne tovarne prihodnosti. Transdiciplinaren okvir je prenesen v matematični model na podlagi stohastičnega dinamičnega programiranja in je podprt z obstoječim informacijskim skladiščem in predstavlja potencial za nadgradnjo poslovne inteligence.
Omejitve / Bodoče raziskave: Predlagani model je bil realiziran na primeru tovarne v avtomobilski industriji. V prihodnosti se bo ta model še nadgradil in izvedel tudi v drugih industrijah kot del koncepta pametnih tovarn.
Ključne besede: transdisciplinarnost, sočasni inženiring, odločanje, poslovna inteligenca, dinamično programiranje.