Transdisciplinary Lifecycle Analysis of Systems
R. Curran et al. (Eds.)

doi:10.3233/978-1-61499-544-9-565

Engineering Collaboration in Mechatronic Product Development

Sergej BONDAR[a], Henry BOUWHUIS[b] and Josip STJEPANDIĆ[a,1]
[a] *PROSTEP AG, Germany*
[b] *Sensata Technologies Holding N.V., The Netherlands*

Abstract. Sensata Technologies Holding N.V., a global industrial technology company, is a leader in the development, manufacture and sale of sensors and controls. It produces a wide range of customized, innovative sensors and controls for mission critical applications such as thermal circuit breakers in aircraft, pressure sensors in automotive systems, and bimetal current and temperature control devices in electric motors. Business centers and manufacturing sites in twelve countries are involved in the engineering process for over 50 OEMs all over the world. Providing that the engineered data is delivered to the recipient in the right format, quality and time is crucial in the collaboration between Sensata and its customer. As the numbers of partners and CAD systems (which differ by releases) expand the complexity exponentially, a direct transfer and translation service resembles a big challenge for Sensata's IT. Not to mention that know-how protection is becoming increasingly important and is usually a part of the exchange process. Sensata has tackled the challenge by establishing a focal point of data exchange and translation (including a knowledge protection process), which can be controlled in an easy way to ensure that the compliance of Sensata is kept. The OpenDESC.com service, utilized by Sensata as the focal point of data exchange and translation, is capable of sending data to all Sensata partners, ensuring the desired translation and knowledge protection settings and standards are set to the newest releases. By this Sensata is independent from the standards and tools their partners use. Therefore a partner's transition to JT or other formats does not affect the engineering process at Sensata, which leads to large efficiency and quality gains and cost savings. This paper describes the requirements in the engineering collaboration of mechatronic product development and implemented solution.

Keywords. Engineering Collaboration, Mechatronic Product Development, CAD Data Exchange Service Center

Introduction

About 50 different sensors are installed in a normal middle class car, and every year this number increases. Sensors ensure a cleaner environment, driving safety, higher fuel efficiency, and efficient energy consumption (Figure 1) [1] [2]. Such expanding application fields generate huge growth potential for sensor industry worldwide. One of the global leading manufacturers of safety-critical sensors and controllers for the automotive industry, but also for other industries such as aerospace, shipbuilding, railway, domestic appliances, air-conditioning, photovoltaic or mobile communication is Sensata Technologies. The international company headquartered in Attleboro, MA

[1] Corresponding Author; E-mail: josip.stjepandic@opendesc.com.

(USA) generated sales of 2.4 billion dollar in the last fiscal year. With 17,000 employees, it is the global leader for high-level pressure sensors. Thanks to the growing demand for sensors and a series of strategic acquisitions, Sensata has grown dynamically over recent years. The product portfolio of the company covers 17,000 separate articles (Figure 2).

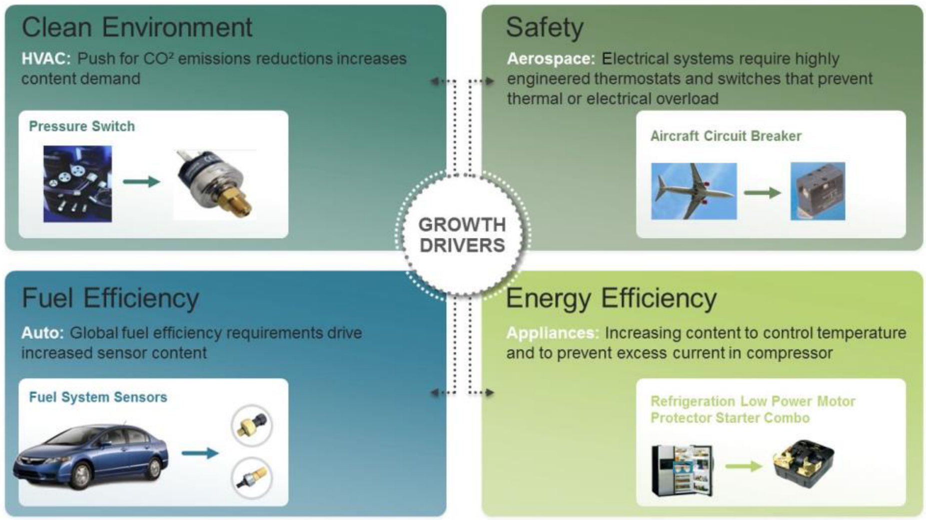

Figure 1. Growth drivers for the sensor industry.

Nowadays, powerful sensors are developed by using modern IT tools like CAD, PDM and validation tools. Many automotive suppliers develop their products with the CAD systems of the respective customer [3]. Sensor manufacturer Sensata saves the costly maintenance of a zoo of tens of different CAD systems, but translates 3D models and 2D drawings. Since then, there are hardly any complaints, although the automotive manufacturers are becoming even more demanding [4]. This paper describes the challenge, the solution and the practice of engineering collaboration in mechatronic product development related to Sensata with focus to data exchange in customer process. After the explanation of background and related work with relevant research fields, we will illustrate the application case of Sensata in this paper.

1. Background and Related Work

Mechatronic development process has been subject of research for many years. For a general classification, two types of mechatronic systems that illustrate the wide range of mechatronics can be distinguished: systems based on the spatial integration of mechanics and electronics, and multi-body systems with a controlled movement behavior [5].

The aim of the first type of system is a high number of mechanical and electrical function carriers on a small installation space. The essential capability of the system integration lies in miniaturization, the lower manufacturing cost and higher reliability. The assembly and connection technology with specific characteristics such as MID (Molded Interconnect Devices) is the prime focus. The special consequence of the development of such products is that the product concept is already determined by the production technology. This yields the necessity to develop the product and the production system virtually, concurrently and integrally using comprehensive validation procedures [6] [7].

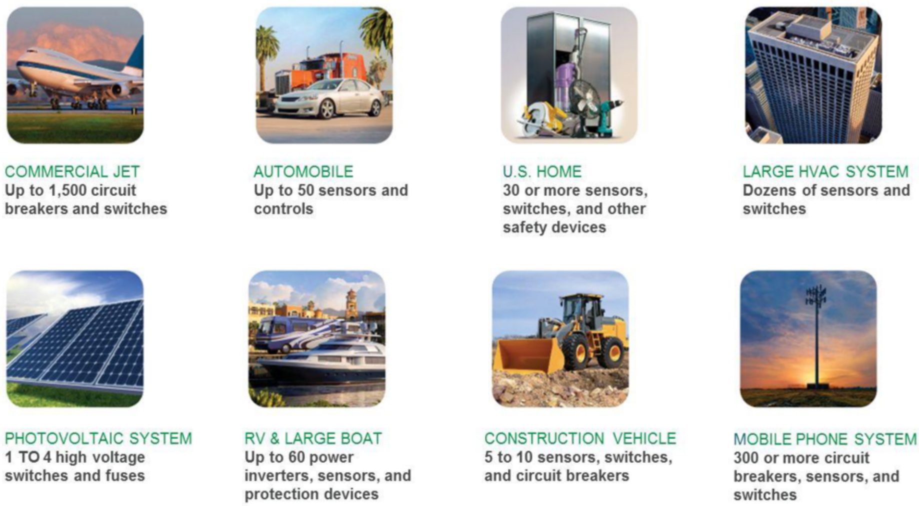

Figure 2. Sensata's product portfolio

The latter type of systems is about improving the movement behavior of multi-body systems. Therefore, sensors detect information about the environment, but also about the system itself. This information is subsequently processed and, with the aid of actuators, suitable reactions in order to improve the movement behavior are triggered in the respective context. Control systems engineering is the major task in the development of products of this type. The Guideline 2206 from VDI (Association of German Engineers) gives the practitioner a guide for the development of such systems [8].

The interoperability of the disciplines involved in the product development process is often not mastered yet. As before, the technical system is considered primarily from the point of view of the rather isolated specialist discipline and domain. At the latest, since contributions from different fields of study have been merged to the product as a whole, there are time-consuming and costly iterations. This results in a need to address methods, tools and procedures for model-driven and synchronized development [9] [10] [11].

The mechatronic products are still not reliable enough. This is reflected, for example, in the automotive industry by increasing goodwill costs and warranty costs. There is a substantial need for action regarding the prediction and securing the reliability of mechatronic systems, as well as monitoring, inspection, testing and diagnostic procedures [12].

Mechatronic system design requires a high degree of integration; therefore the complex mechatronic system is often divided into simpler subsystems or components, and meanwhile, the complex design project calls for the coordination of resources and persons in order to be successful [13]. Collaboration is a measure for enhanced agility [14]. As the result, the collaboration among different individuals and disciplines during the mechatronic system design process plays a key role to ensure that the results of their efforts are successful, especially to get an integrated system [15] [16] [17].

Basically, there are two types of collaboration levels. The first one focuses on the collaboration of individuals, in other words, the interaction between designers, which can be called low-level collaboration (micro level). The second one, called high-level collaboration, emphasizes the collaboration among different disciplines or domains (macro level) [18] [19].

The low-level collaboration, which takes place among the individuals, is highly important for mechatronic system design. A design project is often decomposed into tasks or subtasks, and each task or subtask is assigned to individuals. The project management is based on the organization of available resources to accomplish these tasks or subtasks. In the project management, the collaboration is significant because it is possible that one task must be started when several tasks have been done and any individual in the project should be able to determine the status of the project [20] [21]. Traditionally, the low-level collaboration is often realized thanks to informal communication supported by face-to-face meeting or communication equipment (mail, telephone, tele-conference).

Compared with the low-level collaboration, the high-level collaboration emphasizes the multi-discipline/domain collaboration [22]. The high-level collaboration not only focuses on the assembling specific-discipline design, but pays special attention to the design interfaces among them as well. It can help us to achieve a sound integration of the components, and meanwhile, it brings us a synergetic integration. In case of Sensata, all aforementioned design models are relevant above in the high-level and low-level collaboration.

The aforementioned design models provide available approaches for mechatronic system design. Three criteria can be used for the classification of collaboration: concurrent design, macro level collaboration, and micro level collaboration [18] [23].

(1) Concurrent design of the expert knowledge is very important to shorten the period of the design process as markets are rapidly changing and lead to shorten product development lifecycle; the sequential design model is the only one that cannot provide a concurrent design [1] [6].

(2) Macro level collaboration; Exchange of domain-specific design data and simulation results supports the multi-physic simulation during the mechatronic system design process. Actuators (electronics and mechanics), embedded control systems (electronics and software) and sensors (mechanics, optics and software) are considered as the links between the different expert components, so there are links between the expert components in every design model discussed above, but not explicit in V-model and VDI 2206 [8].

(3) Micro level collaboration; Specific management of the collaboration between the expert knowledge allows engineers to manage the design data systematically and to obtain more integrated mechatronic products. The hierarchical design model is considered to "partially" realize the specific management of collaboration between the experts because all design parameters and requirement parameters affecting multiple disciplines have been presented in the mechatronic coupling level of hierarchical design models [18] [24].

In case of Sensata, concurrent design is mostly important in the customer process. Macro level and micro level collaboration are relevant for internal processes.

2. Use Case

The product portfolio of Sensata covers 17,000 separate items, of which about 1.3 billion units are shipped to the customers every year. Recently, Sensata set standards in terms of innovation with the development of a pressure sensor, which is used in the cylinder heads of internal combustion engines to optimize the compression of the mixture. In this way the CO^2 emissions can be significantly reduced. Sensata has a presence in 15 countries worldwide with development and production facilities. The business center in Almelo (The Netherlands) is responsible for the design and development of pressure sensors for automotive and commercial vehicle sectors (Figure 3).

The sensors for the automotive industry are usually developed by customer order for a particular model or a model series. Due to the various spatial installation situations, there are numerous design variants. To develop all these variants quickly, is an important competitive advantage of a supplier [14] [25]. A key challenge for the product developers on the supplier's side is the demanding documentation obligation towards their clients, because their sensors are used for safety-critical applications and must not fail. Therefore, such a supplier is forced to exchange his product documentation frequently with his customer in an appropriate way [26]. Large automotive manufacturers evaluate this ability of their suppliers in the purchasing process [27] [28].

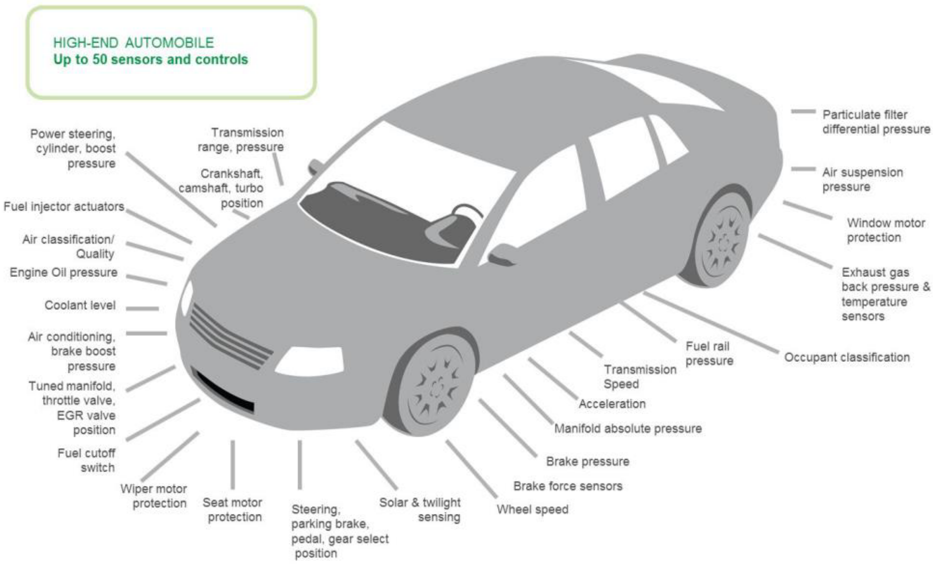

Figure 3. Different sensors in an automobile.

3. Stringent Documentation Obligation

The requirements of the automotive manufacturers and their large system suppliers have become more stringent in recent years in terms of product documentation.

Formerly, suppliers were allowed to deliver their CAD data in neutral formats such as STEP. Today, most of the original equipment manufacturers (OEM) require not only the 3D models in native formats for approval, but further want to have geometric associative 2D drawings that are generated according to their guidelines [29] [30]. Subsequently, the translation of CAD data into different customer required formats can hardly be fully automated.

Sensors are mechatronic products in which the mechanical components play an important role for reliability. At Sensata, these are always designed with the 3D CAD system SolidWorks that is installed at around 100 workplaces worldwide and can be used simultaneously as a floating license. To speed up the coordination with the clients, product developers may deliver their product geometry in neutral formats during the design phase. However, at the latest for the approval, the CAD data has to be translated to the appropriate target format of CATIA V5, NX or PTC Creo.

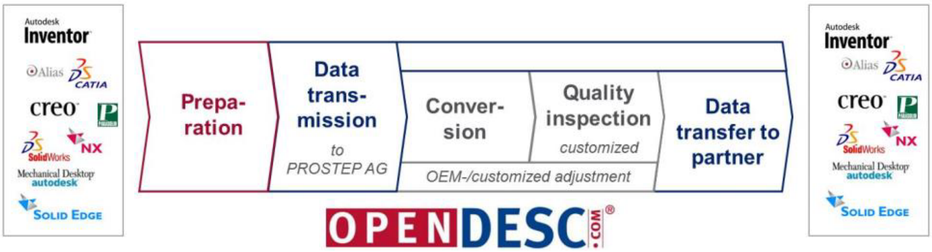

Figure 4. CAD exchange and translation in www.opendesc.com.

While the developers in the headquarter translate their CAD data in-house, European business centers always took advantage of an external service provider for the CAD translation. Nevertheless, they had to take care about the upload of the data to the client systems and portals by themselves before, which required human resources with the appropriate know-how. In order to reduce the corresponding costs, four years ago Sensata decided to replace their former partner and use the translation and exchange service OpenDESC.com instead (Figure 4). There are not many alternative service providers globally who offer both services from a single source. The service provider must know the target systems of the OEMs, their configurations and start models and what CAD data the customers need. Even if Sensata gets a new customer, the service provider must be able to provide his service after the transition phase [31]. Further requirements such as the intellectual property protection can be taken into account here [32].

4. Translation of Drawings

Using the OpenDESC.com pipeline, the translation of 3D models can be largely automated. For such purpose, specific workflow methods are pre-defined. However, the fitting of the data to the OEM-specific standards requires a mostly manual intervention of translation experts who, for example, need to set the appropriate starting model or to customize the profile for the quality check, depending on the particular recipient. They also take care about the visual inspection of the data to be translated, which sometimes contain errors already in the original system and therefore must be corrected prior to the translation [33].

When translating the CAD models, the associativity between 3D geometry and the derivative 2D drawings is lost. Since the OEMs increasingly require associative drawings in native formats for documentation purposes, these relations must be subsequently restored. For such purpose, appropriate templates were developed for the different target systems that make it possible to partially automate the process of correlating model and drawing. However, some manual work is always required due to the complexity of drawings.

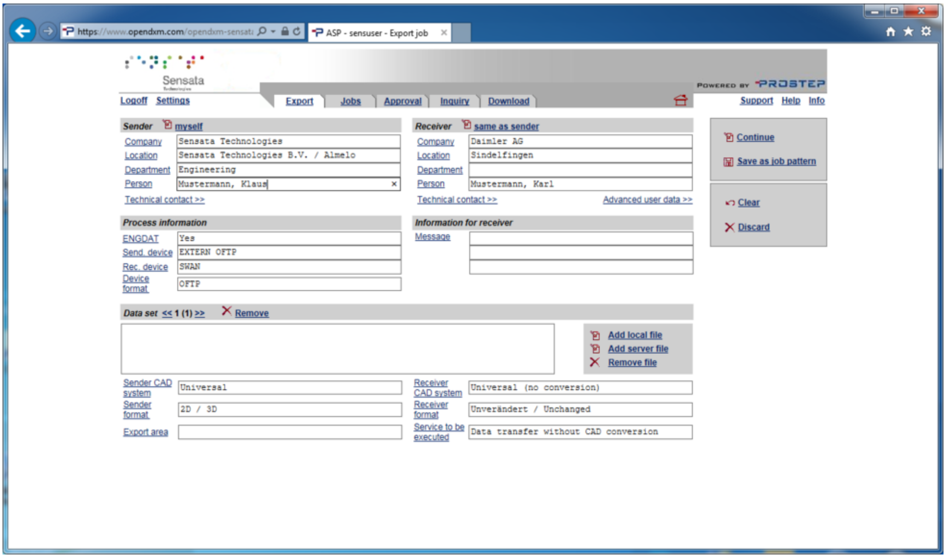

Figure 5. User interface of OpenDESC.com.

The users do not send their files directly to OpenDESC.com but put them in a special transfer directory together with the information about the intended recipients.. That is where the key user responsible for data translation collects the files and uploads them via an encrypted connection to OpenDESC.com, on which the data is translated. For quality control, Sensata gets the translated drawings and models as 2D and 3D PDF documents. At the same time, the translated files are provided on the platform ready for dispatch in the CAD format of the respective OEM, so that after approval they can be automatically sent to the receiver or made available to download (Figure 5). Usually, such a translation order does not take longer than two days.

5. Experiences and Achievements

OpenDESC.com keeps track of the data exchange and informs the sender whether the data has been properly delivered. When the transmission to the OEM is finished or the experts for data exchange have received an end-to-end response in the transmission via OFTP, they send a time stamped copy of the transmitted data to the corresponding Sensata employee, who stores the data into the PDM system Agile. This allows the sensor manufacturer to proof the kind of version and the sending time to the client at any time, regardless of the service collaboration with OpenDESC.com.

Since sensors are not particularly large, the volume of data to be translated is about a few megabytes. The number of translation jobs actually increased continuously thanks to the company's growth and the growing number of development projects in recent years. Currently, about 100 new sensors are annually translated to the formats of the customers at the sites in the Netherlands, Belgium and France, who actively use OpenDESC.com. It is expected that the number of translation jobs will increase with the integration of additional locations and acquisition of new customers in the next few years (Figure 6).

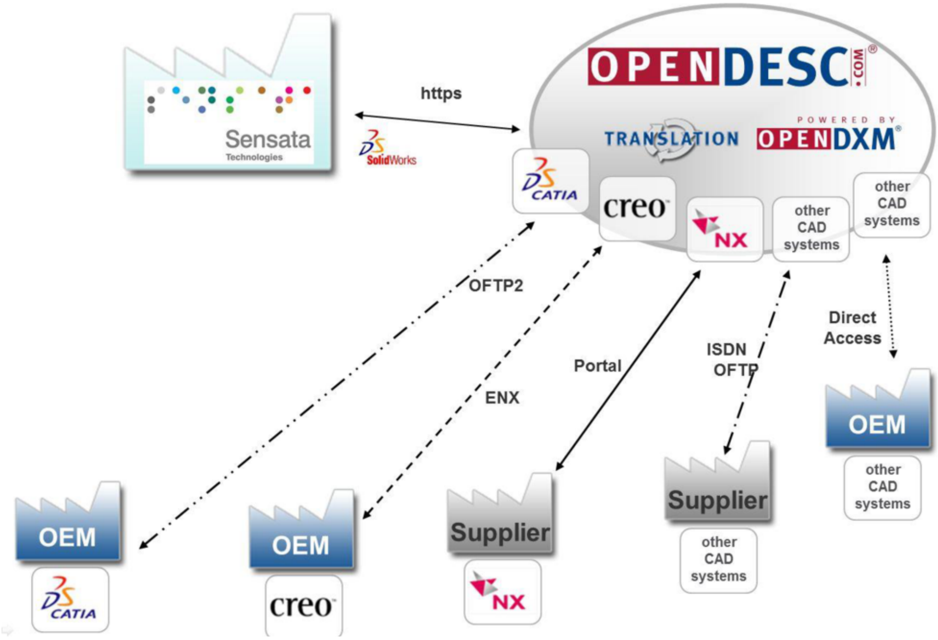

Figure 6. CAD translation via www.OpenDESC.com

A key advantage of the translation and exchange service is the full transfer of responsibility to the service provider [34]. As a result, no erroneous data or data that do not meet the formal requirements of the OEM, are sent to the client. By using OpenDESC.com, the quality of outgoing data was improved significantly. Thus, Sensata hardly gets back any data rejected from the customers. Improving data quality is to ascribe to the good knowledge of OEM requirements on the one hand, and to the thorough data quality check by appropriate check tools prior to translation on the other hand [30]. If the original data does not meet the quality requirements, the job is simply aborted and restarted after the data has been corrected.

How much money Sensata saves due to outsourcing, can not be quantified precisely due to the entirely changed workflows. In order to translate and exchange the data by themselves, the company would need at least one license for each CAD system and an operator who can use it. In addition, trained personnel would be required to keep the IT environment up to date. In the sum, that are fix costs of several hundred thousand Euro which exceed the annual service costs. Big advantage of outsourcing is the resilience against not predicable changes in IT environment, when customers update their CAD and PDM equipment. The follow-up is quite sophisticated for a single company, even if you know what to do. Thus, it is not only cost effective but also more reliable, to subcontract the data translation and data transfer to an external provider.

6. Conclusions and Outlook

Manufacturers of typical supply parts such as sensors are forced to adapt their business processes to a plethora of customers with different process requirements. Engineering collaboration in mechatronics can be subdivided in different levels. For this, different approaches are available, not only to meet the requirements of the customers, but also to achieve the operational excellence [35]. In a dynamic collaborative environment like the global automotive industry, the working conditions are subject to continuous change. Suppliers who work together with different OEMs and tier-1 suppliers have to constantly cope with new requirements relating to exchange partners, data formats, system environments to be supported, quality and security requirements, etc. If they take data communication with their customers into their own hands, this means that they have to constantly adapt their data translation and exchange processes to the ever-changing requirements. To prevent the explosion of fix costs for setup and maintenance of such communication infrastructure, collaboration with a competent service provider could be an interesting alternative as it not only cuts costs but also facilitates making the exchange processes uniform and, thus, ensures a higher level of flexibility, reliability and traceability.

Whether outsourcing is worthwhile depends on various, hardly predicable factors with changing imapct such as the number of exchange partners involved, the volume of data, requirements regarding data quality, etc. The example provided by Sensata, however, makes it clear that the ROI for such an investment can be calculated relatively well. Based on contractual provisions with the service provider, the probably most important argument is the high customer satisfaction index which can justify such a decision.

As further consolidation and unification of CAD and PDM market can't be expected, suppliers must handle this constellation with heterogeneous target nodes in supply network again. The future development belongs the further automation of the whole communication process and provision of standard communication software products OEM-to-supplier communication based on recent standards (STEP AP242 and JT) to avoid the expensive point-to-point connection [4].

References

[1] B.T. Fijalkowski, *Automotive Mechatronics: Operational and Practical Issues*, Springer-Verlag, Heidelberg, 2011.

[2] K. Reif, *Automotive Mechatronics: Automotive Networking, Driving Stability, Systems, Electronics*, Springer Fachmedien, Wiesbaden, 2015.

[3] M. Borsato, M. Peruzzini, Collaborative Engineering, in: J. Stjepandić et al. (eds.): *Concurrent Engineering in the 21st Century: Foundations, Developments and Challenges*, Springer International Publishing Cham, 2015, pp. 165–196.

[4] A. Katzenbach, Automotive, in: J. Stjepandić et al. (eds.): *Concurrent Engineering in the 21st Century: Foundations, Developments and Challenges*, Springer International Publishing Cham, 2015, pp. 607–638.

[5] M. Jouaneh, *Fundamentals of mechatronics*, Cengage Learning, Stamford, 2013.

[6] S.I. Weiss, *Product and Systems Development: A Value Approach*, John Wiley & Sons, Hoboken, 2013.

[7] A. A. Alvarez Cabrera, K. Woestenenk, T. Tomiyama, An architecture model to support cooperative design for mechatronic products: A control design case, *Mechatronics*, Vol. 21, pp. 534–547, 2011.

[8] N.N., VDI-Richtlinie 2206, Entwicklungsmethodik für mechatronische Systeme, 2004.

[9] Y. Ni, J.F. Broenink, A co-modelling method for solving incompatibilities during co-design of mechatronic devices, *Advanced Engineering Informatics*, Vol. 28, pp. 232–240, 2014.

[10] H. Komoto, T. Tomiyama, A framework for computer-aided conceptual design and its application to system architecting of mechatronics products, *Computer-Aided Design*, Vol. 44, pp. 931–946, 2012.
[11] J.M. Torry-Smith, N.H. Mortensen, S. Achiche, A proposal for a classification of product-related dependencies in development of mechatronic products, *Res Eng Des*, Vol. 25, pp. 53–74, 2014.
[12] S. Sierla, I. Tumer, N. Papakonstantinou, K. Koskinen, D. Jensen, Early integration of safety to the mechatronic system design process by the functional failure identification and propagation framework, *Mechatronics*, Vol. 22, pp. 137–151, 2012.
[13] S. Alguezaui, R. Filieri, A knowledge-based view of the extending enterprise for enhancing a collaborative innovation advantage, *Int. J. Agile Systems and Management*, Vol. 7, No. 2, pp.116–131, 2014.
[14] A. McLay, Re-reengineering the dream: agility as competitive adaptability, *Int. J. Agile Systems and Management,* Vol. 7, No. 2, 2014, pp. 101–115.
[15] G. Barbieri, C. Fantuzzi, R. Borsari, A model-based design methodology for the development of mechatronic systems, *Mechatronics*, Vol. 24, pp. 833–843, 2014.
[16] A. Lanzotti, F. Renno, M. Russo, R. Russo, M. Terzo, Design and development of an automotive magnetorheological semi-active differential, *Mechatronics*, Vol. 24, pp. 426–435, 2014.
[17] M. Törngren, A. Qamar, M. Biehl, F. Loiret, J. El-khoury, Integrating viewpoints in the development of mechatronic products, *Mechatronics*, Vol. 24, pp. 745–762, 2014.
[18] C. Zheng, J. Le Duigou, M. Bricogne, B. Eynard, *Survey of Design Process Models for Mechatronic Systems Engineering*, 10e Congres International de Genie Industriel CIGI2013, June 12-13, 2013.
[19] C. Zheng, M. Bricogne, J. Le Duigou, B. Eynard, Survey on mechatronic engineering: A focus on design methods, *Advanced Engineering Informatics*, Vol. 28, pp. 241–257, 2014.
[20] C. Acosta, V. J. Leon, C. Conrad, C. O. Malave, *Global Engineering. Design, Decision Making, and Communication*, CRC Press, Boca Raton, 2010.
[21] A. Villa, *Managing Cooperation in Supply Network Structures and Small or Medium-sized Enterprises Main Criteria and Tools for Managers*, Springer-Verlag, London, 2011.
[22] R.C. Beckett, Functional system maps as boundary objects in complex system development, *Int. J. Agile Systems and Management*, Vol. 8, No. 1, pp. 53–69, 2015.
[23] C. Emmer, A. Fröhlich, V. Jäkel, J. Stjepandić, Standardized Approach to ECAD/MCAD Collaboration, In J. Cha et al. (eds.), *Moving Integrated Product Development to Service Clouds in Global Economy. Proceedings of the 21st ISPE Inc. International Conference on Concurrent Engineering*, IOS Press, Amsterdam, pp. 587-596, 2014.
[24] A. Biahmou, A. Fröhlich, J. Stjepandić, Improving interoperability in mechatronic product development. In: Thoben KD et al. (eds.) *Collaborative Value Creation throughout the whole Lifecycle. Proceedings of PLM10 international conference*, Inderscience, Geneve, pp. 510-521, 2010.
[25] M. Stevenson, The role of services in flexible supply chains: an exploratory study, *Int. J. Agile Systems and Management*, Vol. 6, No. 4, pp. 307–323, 2013.
[26] N.N., *VDA Empfehlung 4961/3, Abstimmung der Datenlogistik in SE-Projekten*, VDA, Frankfurt, 2012.
[27] D.W. Cho, Y.H. Lee, S. H. Ahn, M. K. Hwang, A framework for measuring the performance of service supply chain management, *Computers & Industrial Engineering*, Vol. 62, pp. 801–818, 2012.
[28] H. Carvalho, S.G. Azevedo, V. Cruz-Machado, An innovative agile and resilient index for the automotive supply chain, *Int. J. Agile Systems and Management*, Vol. 6, No. 3, pp 258–278, 2013.
[29] S. Bondar, L. Potjewijd, J. Stjepandić, Globalized OEM and Tier-1 Processes at SKF. In J. Stjepandić et al. (eds.), *Concurrent Engineering Approaches for Sustainable Product Development in a Multi-Disciplinary Environment,* Springer-Verlag, London, 2013, pp. 789-800.
[30] S. Bondar, C. Ruppert, J. Stjepandić, Ensuring data quality beyond change management in virtual enterprise, *Int. J. Agile Systems and Management*, Vol. 7, Nos 3/4, pp. 204–223, 2014.
[31] S. Bondar, J.C. Hsu, J. Stjepandić, Network-Centric Operations during Transition in Global Enterprise, *Int. J. Agile Systems and Management*, Vol. 8, No. 3, 2015, in press.
[32] J. Stjepandić, H. Liese, A.C. Trappey, Intellectual Property Protection, in: J. Stjepandić et al. (eds.): *Concurrent Engineering in the 21st Century: Foundations, Developments and Challenges*, Springer International Publishing Cham, 2015, pp. 607–638.
[33] T. Fischer, H.P. Martin, M. Endres, J. Stjepandić, O. Trinkhaus, *Anwendungsorientierte Optimierung des neutralen CAD-Datenaustausches mit Schwerpunkt Genauigkeit und Toleranz,* VDA, Frankfurt, 2000.
[34] F.J. Contractor, V. Kumar, S. K. Kundu, T. Pedersen, *Global outsourcing and offshoring: an integrated approach to theory and corporate strategy*, Cambridge University Press, Cambridge, 2011.
[35] E. Hofmann, P. Beck, E. Füger, *The Supply Chain Differentiation Guide. A Roadmap to Operational Excellence*, Springer-Verlag Berlin Heidelberg, 2012.