Proceedings of ICAD2013
The Seventh International Conference on Axiomatic Design
Worcester – June 27-28, 2013
ICAD-2013-29

AXIOMATIC DESIGN OF PRODUCTION SYSTEMS FOR OPERATIONAL EXCELLENCE

Gabriele Arcidiacono
g.arcidiacono@unimarconi.it
Dipartim. per le Tecnologie e i Processi di Innovazione
Università degli Studi Guglielmo Marconi
Via Plinio, 44 - 00193 Roma
ITALY

Christopher A. Brown
brown@wpi.edu
Department of Mechanical Engineering
Worcester Polytechnic Institute
Worcester, Massachusetts 01609
USA

ABSTRACT

Companies should design unique production systems according to each company's overall strategy. The production system is the set of methods that transform resources into finished goods and services. To be competitive and profitable, these resources should be appropriately managed. While what is appropriate depends on the company, every organization should be dynamic and adapt to changing market conditions. It is not sufficient to improvise, so it is necessary to structure companies considering all the variables and scenarios. This should guarantee that all the different contexts and situations have been accommodated in the best way. This paper focuses on Axiomatic Design of production systems.

Adding global operations optimization to a global manufacturing strategy can provide cost-reduction opportunities and process efficiency. In particular, the paper focuses on building and sustaining the organization and capabilities of the supply chain. At the same time, the paper compares different operational excellence models to balance efforts and advantages. Design for operational excellence means creating a strategic operating model.

Keywords: Axiomatic Design, production system design, decomposition, design for operational excellence

1 INTRODUCTION

Advancement can be difficult in a market, similar to that which is being experienced currently, that many find to be competitive and complex. Companies that wish to advance can restructure. To be successful, the restructuring can be designed using new solutions that are more scientific and, at the same time, more flexible. Today the "Blue Oceans" are even smaller, the variability in raw material and shipping costs are more unpredictable, and the markets are crazier and more subject to the difficulties of economic crises [Chan Kim and Mauborgne 2005]. Therefore, companies should design a production system, according to the particular company's strategy. It is might not be sufficient to improvise. It might be better to take into consideration all the relevant variables and scenarios and to radically restructure companies. One important objective of restructuring is to assure that all the different contexts and situations will be accommodated in the best way for an individual company.

In this paper Axiomatic Design (AD) is used as the tool to design production systems that reach this objective. Axiomatic Design provides a framework in which the design process can be managed [Brown, 2011]. In particular, it provides criteria for distinguishing bad designs from good ones [Suh, 1990]. The systematic bi-dimensional decomposition used in Axiomatic Design facilitates the inclusion of all the relevant variables and scenarios, as well as contexts and situations. The first dimension of the decomposition into functional, physical, and process domains provides a clear categorization of functional requirements (FRs), design parameters (DPs), and process variables (PVs). These represent the domain where the concepts "WHAT we want to achieve" and "HOW we want to achieve it" lie (see Figure 1).

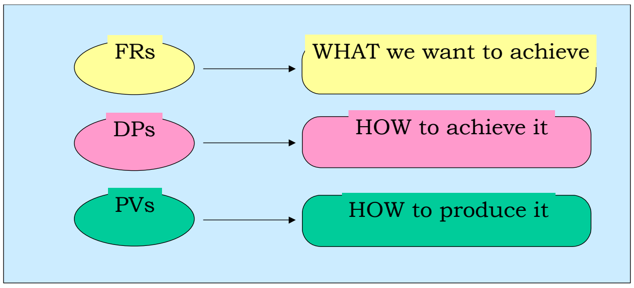

Figure 1. Meaning of the different variables related to the domains.

The second dimension of the decomposition is hierarchical within the domains. This analysis can be done according to equivalence relations, based on partitioning [Brualdi, 1999]. The objective is to achieve a collectively exhaustive and mutually exclusive collection of the functions [Rasiel, 1999; Brown 2011] to address the relevant business situations. Axiomatic Design supplies companies with a disciplined design process [Nordlund *et al.*, 1996]. In particular, the AD process drives the decomposition between domains and "qualitatively" defines the project structure. It provides the basis for the selection of the key physical variables (DPs) that characterize the design that satisfies the FRs. The selection of the DPs is tested against the axioms.

Axiomatic Design also provides the basis for generating the systems architecture for complex machines and systems: Axiomatic Design Systems Architecture (ADSA). The process of matching variables in one domain (e.g., FRs) with other variables in another domain (e.g., DPs) is called mapping: to go from WHAT to HOW [Cochran *et al.,* 2000].Compared to TRIZ [Altshuller, 1988], which is adept at suggesting physical solutions to design problems, Axiomatic Design has the advantage of illuminating and avoiding potential problems in the conceptual stages of design [Kim and Cochran, 2000].

2 PRODUCTION SYSTEM DESIGN: THEORY

A system produces an output by acting on and transforming its inputs. The output is influenced by noise factors, which are generated from interactions. AD provides for control of interactions and noise factors.

The production system is the set of methods used in industry and the related processes that transform resources into finished goods and services. The resources are generally labor, capital, and land, but generally are called also the "six M's": men, machines, methods, materials, money, and mother-nature.

Why should you project your own production system according to company strategy? To be competitive and to generate profits, these resources should be appropriately managed [Kalpakjian, 1995]. What is appropriate depends on the situation. Every organization should be dynamic and adapt to changing market conditions. In addition the capital investment should be linked to focus on areas in alignment with the strategy.

The most common method used to develop company strategy is a Balanced Scorecard or BSC [Kaplan and Norton, 2001], which uses an excellent performance measurement dashboard to give managers and executives a more "balanced" view of organizational performance. It is based on four perspectives:

1. Economic-Financial perspective
2. Customer-Market perspective
3. Processes perspective
4. Learning & Innovation perspective

The courses of action selected by the company should be structured so that they can be overseen from these four perspectives. This oversight would verify their efficiency in the chosen market segment. It would also establish the role by which companies are ordinarily classified. This classification is based on:

1. Product
2. Product plus (the best product compared to the competition, e.g., extra comfort in an airline)
3. Price
4. Customization

The first step is to choose the placement in the market, i.e., the first of the four categories mentioned above, and to project the subsequent business model. At the same time, it is also necessary to design an appropriate production system to optimize the processes. The objective of this design is to improve process efficiency and to introduce new products/services or new technologies.

The Production System basically consists of four general types:

1. The project (one-shot) system-for a one-off product, such as a made-to-order ship, or a prototype.
2. The batch system–variable lot sizes, depending on the kind of process/product.
3. The continuous system (assembly line) - common in mass production.
4. Any mix of the above systems.

The production system is characterized by physical flows of materials and by flow of information in the process, depending on the previous typology of the system.

3 PRODUCTION SYSTEM DESIGN AND AXIOMATIC DESIGN: DESIGN FOR OPERATIONAL EXCELLENCE

This paper focuses on production system design, using AD in order to decompose what we want to achieve (functional requirements) and how to achieve it (design parameters). Adding a global operations optimization to a global manufacturing strategy can provide cost-reduction opportunities and make processes more efficient. In particular, focusing on building and sustaining organization and capabilities of the supply chain, it is useful to compare different operational excellence models in order to balance efforts and advantages. Design for operational excellence means creating a strategic operating model.

The top managers (called also Chief or C-Levels) have to be focused on assessing and developing a customized global production system. CEOs of some major companies that have developed customized, global production systems have been studied in order to define the business macro aims (FRs), within the functional domain. Typical BSC perspectives are used to suggest a theme for the decomposition (see Figure 3 and Figure 4):

FR1= Establish shareholders' value (Economic-Financial perspective)
FR2= Provide competitiveness in the Market (Customer-Market perspective)
FR3= Improve process efficiency (Processes perspective)
FR4= Provide innovations (Learning & Innovation perspective)

To satisfy these FRs, the following DPs have been suggested by the CEOs:

DP1= Sector selection and the placement of the company (Economic-Financial perspective)
DP2= Business Model Design (Customer-Market perspective)
DP3= Production System Design (Processes perspective)
DP4= New products/services or new technologies Innovation System (Learning & Innovation perspective)

The highest level Design Matrix (DM_X) is shown in Figure 2. The interactions have been determined by the CEOs.

FRs\DPs	**DP1** Sector/ Placement	**DP2** Business Model	**DP3** Production System	**DP4** Innovation System
FR1 Add value	X	.	.	0
FR2 Competetiveness	X	X	.	0
FR3 Improve efficiency	x	X	X	0
FR4 Innovate	x	X	x	X

Figure 2. Design matrix DM_X.

The DM_X demonstrates that the project is decoupled, considering A_{12}, A_{13}, A_{23} (whose correlation value has been indicated with a dot, ".") and negligible with respect to the others values "x" as well as "X". In other words, it is possible to consider a dot as being equal to"0". Axiom 1 can also be satisfied by a decoupled design, taking into account the order in which the DPs must be adjusted (the proper sequence). It is worth noting that, for a full triangular matrix, there is only one order in which the DPs can be adjusted to satisfy the FRs without iterating. In practice, when designing from scratch, it is best to find an uncoupled design. If this is impossible, a decoupled design is acceptable. Under some circumstances, however, it might be necessary to deal with designs that are coupled. Even in these cases, it is important to realize that Axiom 1 can still provide guidance. Beyond the three main categories of coupling, further sub-types of coupling with variable levels of severity exist (e.g., full coupling is worse than sparse coupling, and stiff coupling is worse than robust coupling) [Arcidiacono *et al.,* 2001]. In this way, the proper sequence has been identified as required by the first axiom of Axiomatic Design [Suh, 1998]. First, select the sector, then the business model, followed by the production system, and, lastly, the innovation system.

Through the decomposition process, it is possible to study the details in the functional and physical domains (FRs in Figure 3 and DPs in Figure 4) through zig-zagging (Figure 6). Using mapping and zig-zagging, the design can be summarized in two structures that are hierarchically arranged in levels of increasing detail and correlated by the design matrices.

The expected output of this exercise is a production system that leads the company to maximum competitiveness, considering the constraints of available resources and available capital. Competitiveness in the market requires a calculation of the capacity of the system. Too much capacity could burden a company with high costs. Too little capacity, and opportunities could be lost, especially if a market is developing rapidly.

Mechanisms such as hiring-&-firing workers, scheduling overtime and cutting back on work hours, changing the rate of production, adding and shutting down machines, etc., are singular important leverages to be included in a global company strategy. Some of the effectiveness of "adjustment" of the capacity of a company would be an important design tool.

The capacity of the system for managing the flows in order to achieve the expected FRs depends, for example, on the quality of the goods and services, durability, functionality, and on-time delivery by the company and by the suppliers. The flexibility of the production volume, which is required to meet changes in market demand, depends on the technology to be used and on the process design. These include the choice of equipment, layout, space, and procedures. In this scenario, the process efficiency has to be improved with the appropriate production system design. The focus should be on the strengths for value-added activities, simultaneously designing a business model that can capture the voice of the customer and increase customer satisfaction.

FR1= Establish shareholders' value (Economic-Financial)
- FR11= Increase revenues
- FR12= Improve EBIT margin
- FR13= Maximize Return on Invested Capital
- FR14= Maximize free Cash Flow
- FR15= Generate profitable business growth
- FR16= Optimize financial structure

FR2= Provide competitiveness (Customer-Market)
- FR21= Increase Customer Satisfaction
  - FR211= Ensure ROI and Value for the Customer
  - FR212= Deliver products on time (TTM, quantity and quality)
  - FR213= Maintain Product Quality Consistency
  - FR214= Provide effective Customer Service
- FR22= Grow in the core business
- FR23= Optimize geographic diversification

FR3= Improve process efficiency (Processes)
- FR31= Create "Continuous Improvement"
  - FR311= Lead and sustain processes efficient
  - FR312= Reduce or eliminate the Non Value Added activities
  - FR313= Restore basic conditions & standardize best practice
  - FR314= Reduce NVA by reviewing the Value Chain
- FR32= Cut the costs ("hard" cost savings)
  - FR 321= Reduce labor costs
  - FR 322= Reduce material costs
  - FR 323= Reduce products/activities portfolio
- FR33= Avoid the costs ("soft" cost avoidance)
  - FR 331= Avoid a labor's hours increase
  - FR 332= Avoid a raw materials/supplier's price increase
  - FR 333= Avoid a new material purchase in the intr. of a new product

FR4= Provide innovations (Learning & Innovation)
- FR41= Build a strong corporate culture
- FR42= Become innovators and customer-driven
- FR43= Increase number of New Products/Services Development
- FR44= Develop new competitive business models for the Mkt

Figure 3. Functional domain.

The first issue is that most production systems are not designed today. The second issue is that few production systems are customized. Ultimately, the goal of this paper is to design a customized production system to improve process efficiency in order to optimize overall processes. Simultaneously, it must consider both macro-economic and market prospective as well as the company prospective, which can also vary quickly.

Generally, any manufacturing system has four types of operations: processing, inspection, transportation/motion, and inventory. Few operations are value-added activities. For instance, inspection, transportation/motion, and inventory are non-value adding, even if sometimes necessary. Optimizing operations means reducing and eliminating the wastes inherent to integrating the entire system, rather than treating them one at a time. This is the difference between the application of some basic tool (basic Lean) and taking a global approach. When extended to an entire company, Lean [Womack and Jones, 2003] is integrated to the entire supply chain. It is also called the Toyota Production System [Ohno, 1988].

Cochran [1994] uses AD to illustrate the differences between two different production systems (mass and lean production). More specifically, AD is an important element for defining how the production system goals are accomplished from a system design perspective. In this paper, using recent methodological developments, the aim is to extend Cochran's comparison by considering different models of operational excellence, enterprise cost reduction, and cost avoidance. In this way it is possible to create continuous improvement and obtain hard/soft cost savings.

DP1= Sector selection and the placement of the Company (Economic-Financial)

DP11= focusing on market segments where product portfolio has significant competitive advantage (emerging economies; 35% of total revenues coming from aftersales activities; price increase strategy)
DP12= positioning product and services at market value (Price) and reviewing organization & structure on a regular basis (Cost)
DP13= thorough analysis prior to engage in any capital investment activity and subsequently stringent project management.
DP14= Three main levers DSO, DPO and Inventory
-DSO: contract negotiations, credit collections and disputes resolution
-DPO: extended payments to supplier base
-Inventory: minimize inventory levels and maximize inventory turns
DP15= Pipeline management, Quotation budgeting & follow up, Project execution management, Overall flow governance
DP16= correct mix between debt and equity with regularity and certainty of income (minimum cost of capital, minimum risk, maximum return, commensurate to legal requirements)

Figure 4a. Physical domain.

DP2= Business Model Design (Customer-Market)

DP21= Capturing the customer delighters
DP211= Applying Kano model
DP212= Leading Lead Time
DP213= Using appropriate Survey
DP214= Listening VOC
DP22= Increasing Market share focusing the Company efforts
DP23= Creating new extendible opportunities across different countries

DP3= Production System Design (Processes)

DP31= Operational Excellence Model
DP311= Lean Six Sigma
DP312= Basic Lean
DP313= World Class Manufacturing (WCM)
DP314= Toyota Production System (TPS)
DP32= Enterprise Cost Reduction
DP321= Downsizing
DP322= Optimizing BOM
DP323= Redesigning assets and Company Strategy
DP33= Cost Avoidance
DP331= Increasing job rotation and people flexibility
DP332= Selecting alternative raw materials/suppliers with the same quality
DP333= Standardizing codes and reducing the relative number

DP4= New products/services or new technologies Innovation System (Learning & Innovation)

DP41= Communicating and sharing the Vision and the responsibilities of the Company
DP42= Deploying the VOC into VOP (through QFD)
DP43= Using Product Design and Development
DP44= Using Design for X (through TRIZ, Robust Design)

Figure 4b. Physical domain.

The design matrix (DM_{3X}) in Figure 5 shows the results of this comparison. DM_{3X} is decoupled and satisfies Axiom 1. It could be argued that the FRs 'cut cost' and 'avoid cost' are inherently coupled. If so, then this decomposition would violate the decomposition directive to be mutually exclusive. However, in this case 'cut cost' refers to reducing existing costs, and 'avoid costs' refers to avoiding new costs; so the two are independent and satisfy Axiom 1.

FRs\DPs	**DP31** Operational Excellence Model	**DP32** Enterprise Cost Reduction	**DP33** Cost Avoidance
FR31 Continuous Improvement	X	0	0
FR32 Cut Cost	X	X	0
FR33 Avoid Cost	X	X	X

Figure 5. Design matrix DM_{3X}.

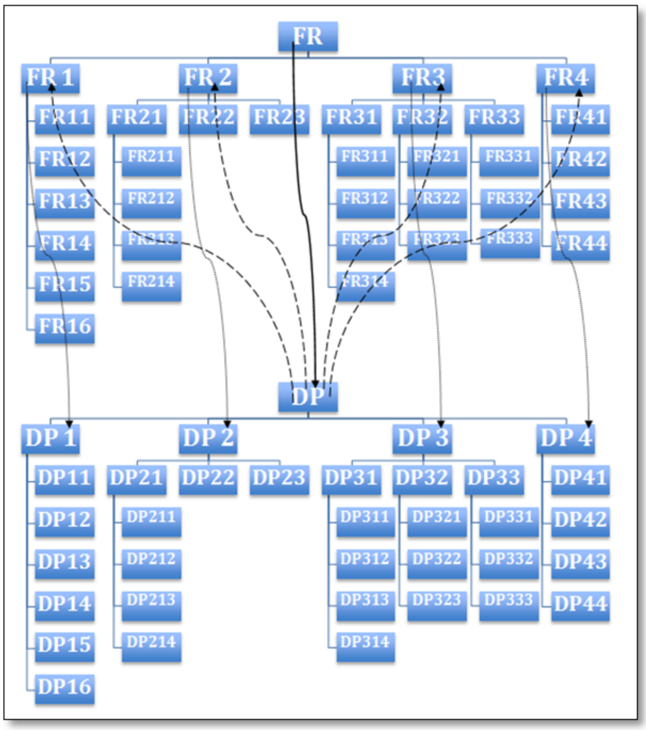

Figure 6. Hierarchical tree: decomposition and zig-zagging.

Decomposing F31 and DP31, 'continuous improvement' and 'operational excellence' results in the following elements (see Figure 3 and Figure 4):

FR311= Lead and sustain processes efficiency
FR312= Reduce or eliminate the Non Value Added (NVA) activities
FR313= Restore basic conditions and standardize best practice
FR314= Reduce NVA by reviewing the Value Chain (more global than just NVA as in 312)

and

DP311= Lean Six Sigma (LSS)
DP312= Basic Lean
DP313= World Class Manufacturing (WCM) [Kinni, 1996]
DP314= Toyota Production System (TPS)

whose design matrix (DM_{31X}) is:

	DP311 LSS	DP312 Basic Lean	DP313 WCM	DP314 TPS
FR311 Process Efficiency	X	0	0	0
FR312 Reduce NVA	X	X	X	X
FR313 Best Practice	x	0	X	X
FR314 Review Value Chain	X	0	0	X

Figure 7. Design matrix DM_{31X}.

In this case, the design matrix is coupled, indicating that Axiom 1 is not fulfilled. Therefore, different solutions need to be sought, or a proper sequence for adjustment of the DPs is required for decoupling. Following this last choice, "reordering" [Suh, 1998] between FR/DP_{312} and FR/DP_{314} has been applied. The design matrix DM_{31X} after "Reordering" is:

	DP311 LSS	DP314 TPS	DP313 WCM	DP313 Basic Lean
FR311 Process Efficiency	X	0	0	0
FR314 Review Value Chain	X	X	0	0
FR313 Best Practice	x	X	X	0
FR312 Reduce NVA	X	X	X	X

Figure 8. Design matrix DM_{31X} after reordering.

The design matrix in Figure 8 is decoupled and therefore satisfies the Independence Axiom. The proper sequence of adjustment that satisfies the FRs without iteration is indicated.

The question is: how does a company become the best in manufacturing? Currently, the quick answer is to become a Lean company (with advanced Lean tools and with a global deployment of TPS), or, better, a Lean Six Sigma company, as indicated by previous results. Lean Six Sigma, which is better than Toyota Production System and World Class Manufacturing, represents a new model of operational excellence. It operates inside the production system; in other words, it is the driver of the production system.

Based on DM_{31X}, in fact, it is evident that LSS suits, and to some degree satisfies, all the FRs. As a consequence, LSS becomes the most powerful tool. At the same time, LSS is also more complex. And, if LSS is not well structured and "customized", it is more convenient for companies to follow a gradual "proper sequence". In any case LSS must be well defined in order to reach excellence.

For those who wish to create a path of continuous improvement starting from scratch, introduction to the Lean approach basically requires a "waste walk", identifying the eight types of waste, in order to eliminate them. In this way, NVA activities are eliminated. Subsequently, following what our study of DM_{31X} has demonstrated, the application of World Class Manufacturing permits restoration of basic conditions and standardizes the best practices. At a later stage, the introduction of Toyota Production System concepts to the whole company permits the increase of value and reduces the flow of different operative and transformation phases. This introduction of TPS allows for faster response to the client's requests and, at the same time, increases competitiveness.

Finally, creating the right culture for change can bolster the company to hold out against conditions of high criticality, where results are achievable only with a radical change of mindset. Such conditions could be similar to the current global recession. Lean Six Sigma shows the most complete and structured method for industrial process engineering and optimization, for both manufacturing and service.

Lean Six Sigma aims to relentlessly identify and eliminate waste in order to maximize the speed and flexibility of business processes and thereby to deliver what is needed when it is needed and with the quantity required by the customer. The waste is the use of resources (time, material, labor, etc.) for doing something that customers are not willing to pay for.

Waste does not add value to the product or service provided [Arcidiacono *et al.,* 2012].

Each of the five phases in which Lean Six Sigma is structured (DMAIC) sets few milestones that indicate the "walk to do", i.e. the roadmap to be followed. The way that these milestones are defined, the ability of the people involved to understand the contextand supply the proper effort required to achieve the goal are issues that could influence the final results. Correct use (the right one for the right information) of the tools, the rigor of the method, the step-by-step approach, and strict time management on projects, are surely the basis for success [Arcidiacono, 2006]. Among different management techniques, Lean Six Sigma is the one that gives a scientific approach. It does this through the use of proper tools, both statistical and other, and a strict method that develops in five steps, DMAIC. LSS starts from the recognition of criticalities and ends with their resolution. It does this in a way that respects the above needs. In particular, Lean Six Sigma is the most effective and efficient business strategy for optimizing existing processes. It can enforce a business vision that can consolidate a company's market leadership.

At the beginning, it is necessary to understand the system design fully, as well as to grasp the "as is" picture of the plant, the industry, and the manufacturing sector. To reach this goal requires knowledge and leadership. The knowledge is in terms of operations, system design, methodology and strategy.

If the C-Level Managers don't acquire the right information, or the right data, and if they don't know the processes in depth, which would be sufficient for a customized production system design, then they cannot drive the company successfully.

4 CONCLUDING REMARKS

Processes that use a system design that is able to deploy the company strategy through singular operations and relative interactions [Arcidiacono *et al.,* 2012] are required for management.

The differences between diverse operational excellence models approaches from a design point of view can be understood using AD.

Three key elements of AD, adaptable to various manufacturing environments and extendible across industries, are:

1. Decomposition in design domains
2. Zig-zagging to create the design hierarchy
3. Independence Axiom

The decomposition includes functional and physical domains and provides the methodology for designing a customized operational excellence model (industry, manufacturing sector, or plant specific). The decomposition facilitates the selection of new DPs (system designs) to meet new FRs. The zig-zagging process establishes a hierarchy of DPs at a higher level, determining the decomposition of FRs at lower levels through the FRs-DPs leaves. The Independence Axiom drives the designer to select one and only one DP to satisfy an FR. Designing and improving operations is different from designing and improving the production system by means of the journey to operational excellence. This is the goal of Lean Six Sigma, understanding the purpose of each operation (inputs, outputs and relative iterations). Continuous improvement, which has been used for years, forces a company to specify concretely the quality of services and products in a daily action plan [Phadke, 1989]. Productivity increase, the growth of customer fidelity, and investment effectiveness are tools that improve competitiveness. Lean Six Sigma strengthens company leadership by setting a pace for steady development. The developmentis based on a given service and product level measurement and systematic analysis, on internal processes, continuous improvement, performance indicators, constant monitoring, market demand, and on internal competencies to meet the voice of the customer.

5 REFERENCES

[1] Altshuller G.S., *Creativity as an Exact Science: The Theory of Inventive Problem Solving*, New York: Gordon and Breach, 1988.

[2] Arcidiacono G., Campatelli G., Lipson H., "A Measure for Design Coupling", IMechE, *Proceedings of the International Conference on Engineering Design ICED 01,* Glasgow, 2001.

[3] Arcidiacono G., "Keys to success for Six Sigma", *Proceedings of ICAD06, The Fourth International Conference on Axiomatic Design,* Firenze, 2006.

[4] Arcidiacono G., Calabrese C., Yang K., *Leading processes to lead companies: Lean Six Sigma Handbook,* Springer, 2012. ISBN 978-88-470-2492-2

[5] Brown C.A., "Decomposition and Prioritization in Engineering Design", *The Sixth International Conference on Axiomatic Design*, *ICAD2011* Daejeon, Mar. 30-31, 2011.

[6] Brualdi R.A., *Introductory Combinatorics*, Third Edition, New Jersey: Prentice Hall, Upper Saddle River, 1999.

[7] Chan Kim W., Mauborgne R., *Blue Ocean Strategy*, Boston: Harvard Business School Press, 2005. ISBN 1-59139-619-0

[8] Cochran D.S., "The Design and Control of Manufacturing Systems", *Doctoral Thesis*, Auburn University, 1994.

[9] Cochran D.S., Eversheim W., Kubin G. and Sesterhenn M.L., "The application of axiomatic design and lean management principles in the scope of production system segmentation", *International Journal of Production Research*, 38:6, 1377-1396, 2000.

[10] Kalpakjian S., *Manufacturing Engineering and Technology,* Addison Wesley Publishing Company, 1995.

[11] Kaplan R.S. and Norton D.P., *The Strategy-Focused Organization: How Balanced Scorecard Companies Thrive in the New Business Environment,* Boston: Harvard Business School Press, 2001.

[12] Kim Y.S., Cochran D.S., "Reviewing TRIZ from the perspective of Axiomatic Design", *Journal of Engineering Design*, Vol. 11, No. 1, pp. 79-94, 2000.

[13] Kinni T.B., *Guide to World Class Manufacturing Plants*, Wiley, 1996. ISBN 978-0-471-16002-1

[14] Nordlund M., Tate D., Suh N.P., "Growth of Axiomatic Design through Industrial Practice", *3rd CIRP Workshop*

on Design and the Implementation of Intelligent Manufacturing Systems, Tokyo, pp. 77-84, June 19-21, 1996.

[15] Ohno T., *Toyota Production System: Beyond Large-Scale Production*, Cambridge, MA: Productivity Press, 1988. ISBN 0915299143

[16] Phadke S., *Quality Engineering using Robust Design,* Prentice-Hall International Editions, 1989.

[17] Rasiel E.M., *The McKinsey Way*, McGraw-Hill, New York, 1999.

[18] Suh N.P., *The Principles of Design*, Oxford University Press, 1990. ISBN 0-19-504345-6

[19] Suh N.P., *Axiomatic Design: Advances and Applications,* Oxford University Press, 1998.

[20] Womack J.P. and Jones D.T., *Lean Thinking*, HarperBusiness, 2003. ISBN 0-7432-4927-5