Proceedings of ICAD2006
4th International Conference on Axiomatic Design
Firenze – June 13-16, 2006
ICAD-2006-07

A FRAMEWORK FOR LEAN LOGISTICS BASED ON AXIOMATIC DESIGN

Mahmoud Houshmand
Hoshmand@sharif.edu
Associated professor, Dept. of Industrial Engineering, Sharif University of Technology, Tehran, Iran

Mohammad Daneshvar Kakhki
daneshva@yahoo.com
M.S. in Industrial Engineering, IT Power Consultants

ABSTRACT

Well designed and implemented supply chain is a critical success factor in global markets. Therefore organizations try to improve their supply chain processes and eliminate any type of waste (such as time, quality and …) within business processes. Elimination of wastes could be attained trough lean logistics and begins with diagnosis. In the next step, organization should define several projects to cure the roots of the problems which are recognized in diagnosis. Lean activities face failure most of the time since they are not well designed and planned. Definition of projects is the most important part of lean activities. Using hierarchical structure of design based on axiom one, an uncoupled plan can be designed. An appropriate practical structure and schedule is the outcome of mentioned approach. Considering axiom two, the outcome will contain low information content which reduces the failure probability. Considering value engineering techniques in decomposing design structure, reduces information content of defined projects. In this paper, authors present a framework for lean logistics based on axiomatic design. Along comes an industrial survey. The mentioned structure is utilized to design lean logistics activities for a sedan car manufacturer in Iran.

Keywords: Axiomatic Design, lean logistics, Supply chain management, value engineering

1 INTRODUCTION

The objective purpose of this paper is to explain how Axiomatic Design (AD) can be applied to rethinking of logistics system and scheduling KAIZEN projects..

Many approaches are available and widely used to represent and design logistics flow and processes. The axiomatic approach developed by Suh has not received much attention because it is thought preliminary as a product design tool (Cotoia et al., 2001). Axiomatic design can be used as a tool for the design of non engineering design objects, such as technology strategies, business plans and organizations (Suh, 1990; Engelhardt et al., 2000). In this paper we are to present a practical application of axiomatic design for reengineering the flow and processes of inbound and outbound logistics in IranKHODRO Co., manufacturer of sedan cars in Iran. We think that axiomatic design can be used in rethinking of logistics flow and processes based on following reasons:

- First, as the market and customer needs changes, the organization have to change their processes (Hammer et al., 1993). The emergence of new products and services obliges manufacturer to improve their logistics flow and processes and adopt it to new environmental conditions. Many criteria may change while the designed flow and processes is being applied to the company. Problems can be compounded when the statement of the customer needs changes during the design effort. Companies consider it infeasible to restart the design process from the scratch, new functional requirements and constraints are incorporated into the existing design. Moreover one design team may not be aware of changes to another group's requirements. Therefore it is extremely important to have tools and methods to trace the impact of design decisions on both local and system-wide levels (Hintersteiner, 2000). Companies need tools to assist them in redesign their processes and flows. Axiomatic Design may be an appropriate approach to confront new challenges of organizational structure redesign.
- Second, relationship within supply chain and between manufacturers becomes more complicated and adoption capability to the environment plays a crucial role in the survival of companies (Hammer et al., 1993). The ability of AD in systematic propagation of functional requirements to the different facets of a system's design makes it a suitable approach in system design.
- Third, the separation of Whats and Hows in the AD results in flexibility, which is its great advantage versus other design methods. AD is flexible enough to come up with design decisions in a wide variety (Houshmand et al. 2002).
- Forth, during the process of design of a new component, product or system using AD, the path focuses on the process and process mapping (Suh, 1990) so AD seems to be a useful tool for evaluation of flow and applying changes to the processes.

To show the capabilities of axiomatic design, in this paper the design of logistics flow and processes in IranKHODRO (IKCO) is evaluated as a case.
Supply Chain and logistics play a crucial role in today's market and industry. Lean logistics is a new approach to improve the abilities of supply chain. Lean concept was developed by Toyota. The story of what Toyota did to revolutionize automotive manufacturing was first told in the 1990 book: The Machine That Changed the World by James P. Womack, Daniel T. Jones and Daniel Roos. The title referred not to Toyota's automobiles, but the Toyota Production System, a system designed to "provide best quality and lowest cost, and to shorten lead time through the elimination of waste," according to a lexicon developed by the Lean Enterprise Institute.
In the years since, the lean approach has spread beyond the production line to broader applications in the retail and service industries: auto repair, airlines and computer support, to name a few. And it's not just about manufacturing anymore. In their latest book, Lean Solutions, published last year, Womack and Jones outline how lean principles apply to logistics and distribution as well (Bradley, 2006).
It's important to note that applying lean principles is not a matter of pushing people harder or automating the operation. It's about designing good processes. Many of the steps would limit travel time. What distinguishes Toyota's lean model from other waste-reduction programs is the level of detail and its fixation with accurate location information. "Toyota obsesses with it to get darn near 100-percent storage accuracy,"
Lean logistics is a new approach to eliminate waste in supply chain. The approach we have selected, evaluates the Logistics processes to see if it can be improved or not and if there is a problem what should be done. Before describing the method, a brief review of AD methodology is useful.

2 AXIOMATIC DESIGN

Axiomatic design is a principle based design method focused on the concept of domains (Suh, 1990). Suh (1990) defines The Process of design as "the creation of synthesized solution in the form of products, processes or systems that satisfy the perceived needs …", the area of application reaches from the design of physical entities to complex systems like the organization structure (Lenz et al. 2000). In Axiomatic Design, the first step is definition of the problem. Definition of the problem is in terms of Functional Requirement (FR). In the development of a basis for lean logistics, the main FR is to eliminate any type of waste within the processes. While defining FRs, we might encounter some constraints. For example, the restriction of time and budget might be considered as the constraints for the mentioned FR. In the study of each problem, many FRs arose. If a designer confronts many FRs at once, he won't be able to represent a good method for satisfying them all. Therefore Axiomatic Design provides designer with the hierarchy. Hierarchy is a tool for classification of FRs at different levels of detail and importance, thus at the same time designer has to think on few FRs. The hierarchy makes the creative process of design simpler.
FRs are defined in the functional domain. Functional domain is completely separated from physical solutions. Definition of FRs without considering the available Design Parameters (DPs) is the best way for creating an ideal structure to attain the perceived needs of the problem. DPs are tools that satisfy FRs. As an example, to satisfy the "elimination of waste in logistics processes" (FR), the DP can be "implementation of lean logistics". FRs and DPs both have hierarchies. The hierarchy of FRs is placed in the functional domain and the hierarchy of DPs is placed in physical domain. The design process is mapping FRs from functional domain to DPs in physical domain with zigzagging. When applying Axiomatic Design to systems and organizational design, the nature of functional requirements and design parameters requires a more detailed description. In general, a functional requirement encompasses a requested functionality that a specific entity is obliged to fulfill. The requirement is stated in the nature of a function, mainly by defining an output and assuming that the entity will receive the necessary input. However, this object to which a functional requirement can be referred to might be of different nature. A design parameter is solely embraces a physical entity. In Axiomatic Design, a design parameter is a closed entity, able to provide the requested FR, and free in its nature, therefore either of a physical or a conceptual nature. A top-level DP will encompass even conceptual and physical sub-systems, but when moving down the hierarchy towards more detailed systems, the DP mainly state physical solutions with the same class of elements, e.g. machinery, a CAD-system or human resources (Lenz et al. 2000). When the design is ready, it is the time to evaluate it. Evaluation is done by comparing the purposed design with the Axioms. The two axioms are as follow (Suh, 1990):

- Axiom 1: the independence axiom: Maintain the independence of Functional Requirements (FRs)
- Axiom 2: the information axiom: Minimize the information content of design.

Designs that do not violate axiom 1 are acceptable. Among acceptable designs, the one with less information content is the best one. Axiom 1 focuses on the interdependence and thus linked to coordination theory1 which has recently been suggested as the basis for process analysis [Cotoia et al. 2001]. The Independence Axiom ensures that within a design with more than two FRs the FRs have to be defined in the way that satisfying one FR doesn't affect the fulfillment of the other FRs. The specifications of beloved entity that is to be designed are shown by a set of FRs that can be treated as a vector {FR}. The same thing is applicable about DPs. The relationship between {FR} and {DP} is shown with design matrix [DM]. For a design with n FRs and n DPs, design equation is as follow:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ \vdots \\ FR_n \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ \vdots \\ DP_n \end{Bmatrix}$$

The left side of the equation represents the goals we want to achieve, while the right side represents how we want to achieve (Suh, 1990). Aij element of design matrix shows the relationship between FRi and DPj. Each design is coupled, uncoupled or decoupled. When all the nondiagonal elements of design matrix

[1] In coordination theory, a process is described in terms of two types of activities: tasks that achieve process outcomes and coordination activities that are carried out to manage the interdependencies between tasks (Cotoia et al., 2001).

are zero, we have the uncoupled design in which means that there is one DP for each FR. It means that FRs are independent from each other and axiom 1 is satisfied. When design matrix is triangular, the design is decoupled. It means that to satisfy the independence axiom, FRs have to be set up in a particular arrangement. When the design matrix is neither a diagonal nor triangular and the design is coupled. This system does not work. Coupled designs violate axiom 1 and are not acceptable designs. When there are insufficient amount of DPs for FRs, the design is couple. By adding extra number of DPs, this situation could be healed. When there are two or more DPs for one FR, the design is redundant. In such cases, DPs can be integrated to form a DP in one physical solution, so that the amount of information will be reduced.

The second axiom, the Information Axiom, is based on the idea that the success of a design is determined by the probability associated with achieving the FRs. This probability decreases with the amount of information necessary to fulfill the FRs (Suh, 1990). If a system is selected so that it acts within design range (i.e. range of normal and well designed systems), the probability of success in its mission is one and if it does not cover the design range, it can't achieve its mission.

3 LEAN PROCESS

In a lean system, there must be no type of waste. Queues, inventory, idle machines and labors are different types of waste. Lean process is a process within which wastes are distinguished and eliminated. Authors unanimously agree on 8 steps in lean process. First of all, management must be behind the project. The second step is team arrangement and learning about lean. Then an appropriate value stream must be selected. The selected stream should be mapped. Improvement indexes should be determined in the next step. Desirable processes should be drawn and based on the gap between the current situation and desired one; some KAIZEN projects should be identified. These projects will enable corporation to attain its desired situation. In the final step, identified projects should be launched (Womack et al. 1991, 1996)

It is necessary to identify and schedule appropriate projects. The first projects should bring great deal of improvement in a short time. This will gain management support and excite employees to join lean team and cooperate with the team.

4 METHODOLOGY

A major obstacle to lean organization is lack of a scientific and systematic framework for implementation methodology (Askin and Goldberg, 2002). Using AD, a comprehensive approach to determine projects is presented here. This approach, in addition to determine projects, helps to schedule projects.

The main FR is "Elimination of any type of waste in flows and processes". Wastes are caused in three different disciplines: organization, information systems and physical flow. As described before, "Lean process" is the common DP used for waste elimination. Therefore lean organization which is supported by appropriate information systems and physical flow is the solution. As shown in figure 1, improvement of organization comes before redesign of information systems. Traditional information systems are based on organizational functions while they must be based on processes. To achieve appropriate information systems, the organizational chart should support processes instead of functions (Hammer, 1993).

Some types of waste in flow are formed because of different stockholders performing the same task (eg: each department might have its own warehouse, offices and … cooperating and monitoring the same task). Hence improvement of physical flow can be performed when organization is redesigned and information systems become compatible with the organization.

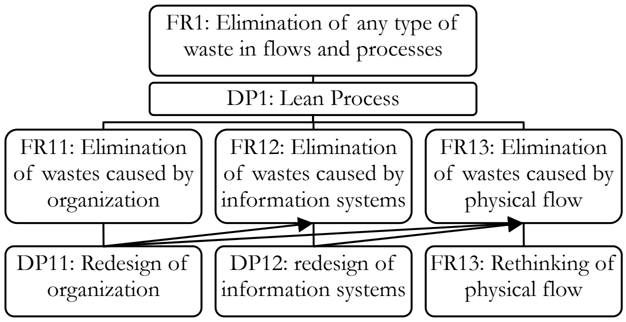

Figure 1: Decomposition of first level FR and DP

The design matrix of the first level decomposition is:

$$\begin{bmatrix} FR11 \\ FR12 \\ FR13 \end{bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ 0 & X & X \end{bmatrix} \times \begin{bmatrix} DP11 \\ DP12 \\ DP13 \end{bmatrix}$$

As the design matrix indicates, design is decoupled. This must be considered in implementation process. If the relationship is not considered in scheduling, the schedule will lead to rework. For example one might improve the layout of a warehouse while the warehouse is redundant and won't be kept during the organizational change.

The organization must be redesigned in the way that the material can have its smooth and level flow. Redesign of information system is decomposed in figure 2. The same as first level, design is decoupled in different levels of this hierarchy.

Rethinking of material flow decomposition is presented in figure 3. Same as before, this hierarchy presents decoupled design.

The hierarchy shown in Fig. 3 can be further decomposed (Fig. 4, Fig. 5 and Fig. 6).

The sequence of achieving lean logistics based on the decomposition is determined by combining design matrices of different levels of hierarchy (figure 1 to 6). Fig. 7 shows the sequence of projects.

Redesign of logistic flows and processes can be started based on designed structure. It has to be mentioned that in each situation some of the decomposed levels might not be applicable. Only those that are applicable (in selected case) should be considered in lean process.

5 PROCESS MAPPING AND DIAGNOSIS

A significant step in redesign is process mapping. After the processes are mapped, it is easy to see wastes and plan for their removal (Tapping et al, 2002). Fig. 8 presents the value chain selected for redesign in IKCO.

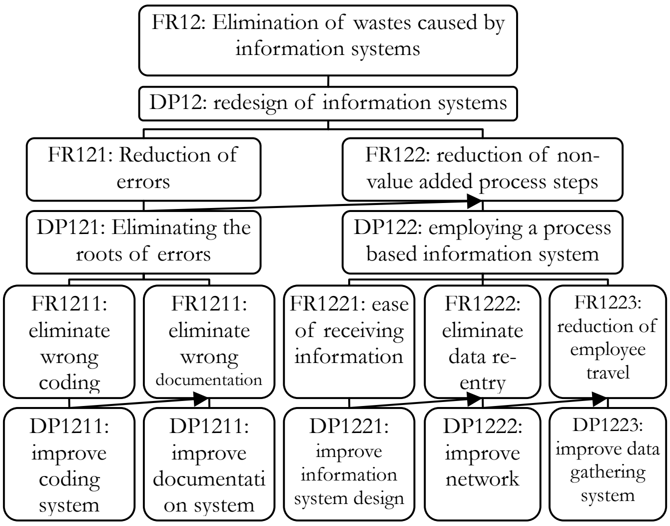

Figure 2: Decomposition of FR12 and DP12

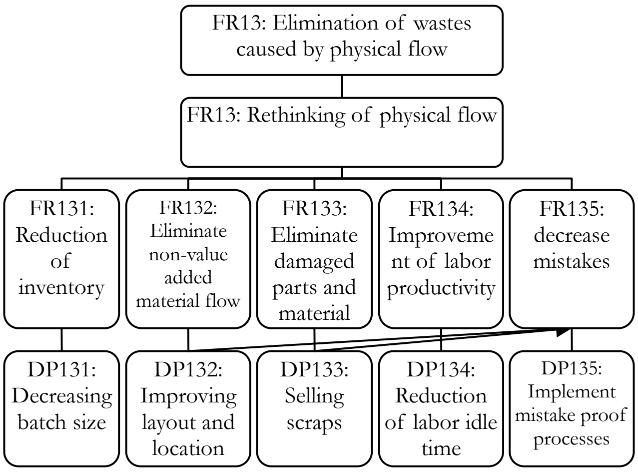

Figure 3: Decomposition of FR13 and DP13

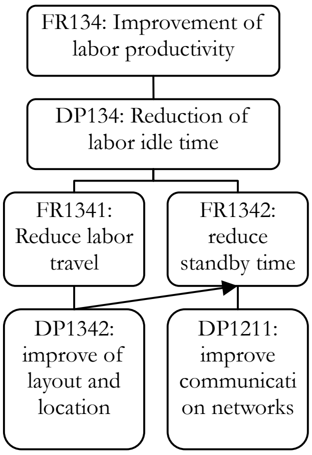

Figure 4: Decomposition of FR134-DP134

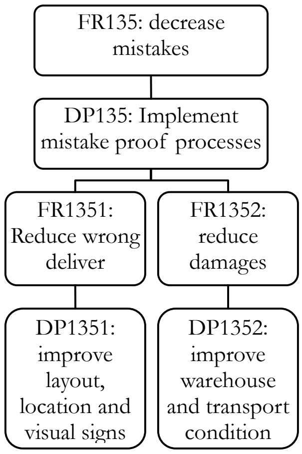

Figure 5: Decomposition of FR135-DP135

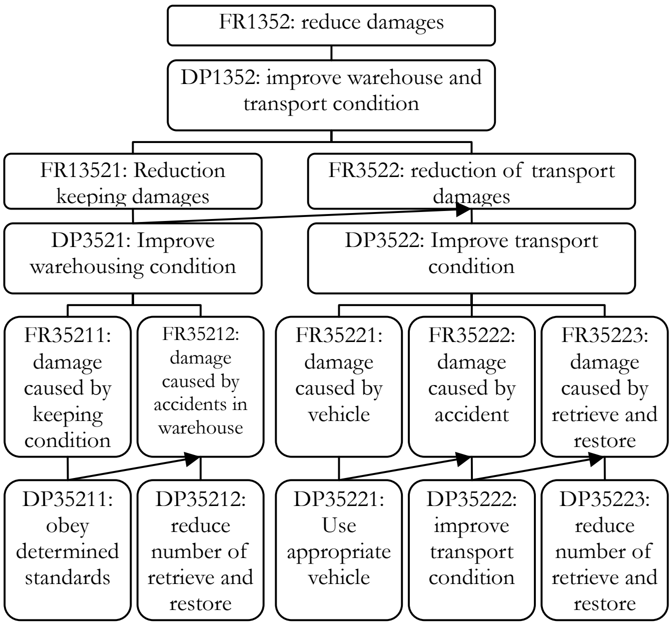

Figure 6: Decomposition of FR1352-DP1352

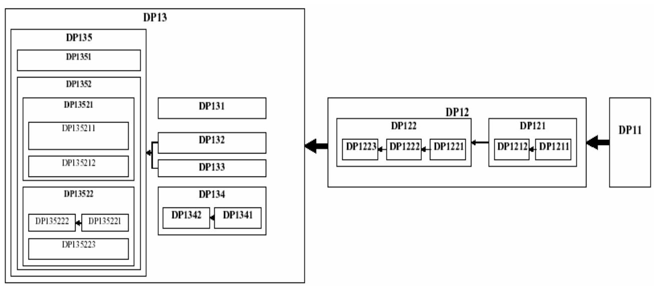

Figure 7: Sequence of performing projects.

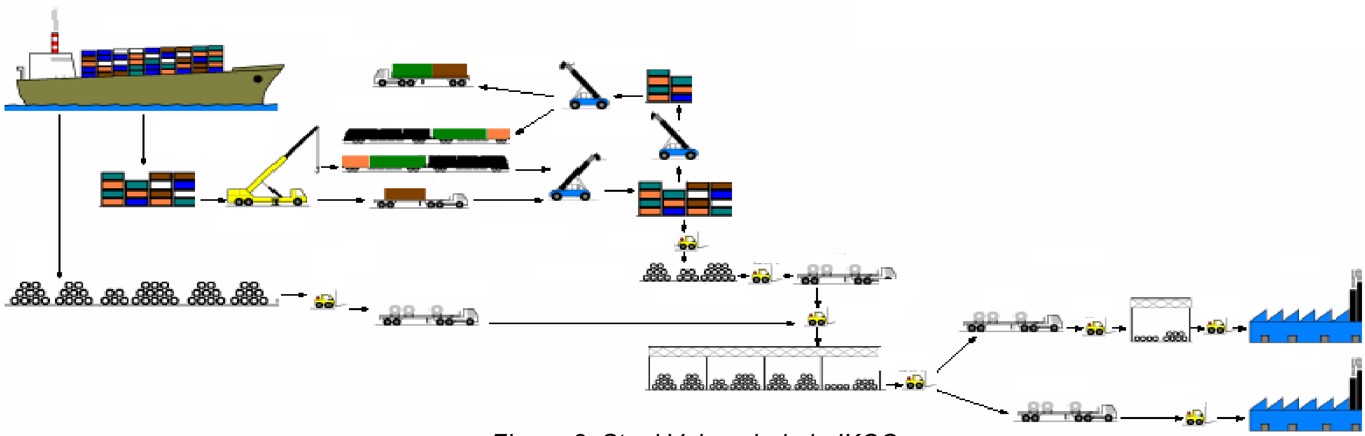

Figure 8: Steel Value chain in IKCO.

As shown in the Fig. 8, steel roles are imported both in container and striped, by ships. They are kept in the customhouse unless the duty of import is paid. Then the roles and containers are brought to IKCO by train and trailer. Containers are unloaded in IKCO. The steel roles strip in the next step. Steel role go to steel warehouse loaded on trailers. Empty containers are returned to the owner company (usually placed in the port). The steel roles unloaded from ship are moved to steel warehouse directly.

To benefit from economy of scale, IKCO orders for its suppliers too. Therefore a part of steel roles in the warehouse belong to suppliers and are moved to them. The remained roles are used in press lines of the company. Different department holds the responsibility of production lines. This department has its own warehouses. The steel roles go to the second warehouses and there they feed press lines.

As it is obvious in Fig. 8, the material flow confronts many obstacles. Several warehouses and depot are used because of different stockholders. The purpose of material handling system is to provide steel roles to press lines when it needs. Since the roles are produced in the batch form, they have to be purchased in the batch form and thus there must be one warehouse to keep these batches. Different divisions which play role in this flow, has its own warehouse (5 warehouses can be seen). This number can be reduced to 2: one warehouse in the port (belongs to customhouse) and the other in IKCO.

6 IMPLEMENTING AD IN LEAN PROCESS DESIGN INCREASE THE PROBABILITY OF SUCCESS

Success of lean process depends on Support of employees and management. Project team can't have the strong support unless it can prove the capabilities of lean logistics to improve the present processes. To do so, the sequence of projects must be designed in a way that:

1- Lean process is lean itself (no waste and rework during the project)
2- Projects are easy to accomplish

Lean process: An important concept which must be considered during the definition of projects is value engineering. Value engineering indicates that value stream of a project must be designed in a way that reworks are crossed out. Axiom 1 provides an appropriate framework to prevent rework. Considering sequence of Fig. 7 while scheduling sub projects of lean process minimizes rework.

Easy to accomplish: To be able to accomplish in a project, its information content must be low. If a project has high information content, it should be done spending a great deal of time and money, employing consultants, purchasing new devices and methods. This will disappoint management and will reduce the support. As an example, projects such as reduction of labor are of very high information contents. According to Iranian rules, firing workers is very hard and expensive. In addition it will cause fear and lack of support among employees. Projects that lead to change organizational culture are also of high information content. Projects that need new investments are of high information content too. Projects with high information content are vulnerable to failure. The scheduler should avoid such projects in the schedule. If they are unavoidable, they must be placed in low priorities.

These two concepts are considered while determining kaizen projects.

7 PRESENTING SOLUTIONS IN THE FORM OF PROJECTS

A short review of this flow reveals many redundancies (most of them are because of redundant design). To analyze this situation with AD, it must be indicated that we have to FRs: "unloading and paying duty" and "keeping batches". There are 5 DPs to satisfy these 2 FRs:

$$\begin{bmatrix} unload\ and\ pay\ duty \\ keep\ batches \end{bmatrix} = A \times \begin{bmatrix} customhouse\ warehoose \\ IKCO\ dock\ warehouse \\ IKCO\ striped\ role\ warehouse \\ main\ steel\ warehouse \\ press\ line\ warehouse \end{bmatrix}$$

These 4 warehouses can be combined to form a better design.

The above improvement can be applied trough:

1- Combination of organization divisions: Different departments are responsible for the same task (one FR and several DPs).
2- Redesign information system: lack of communication between divisions causes manufacturing department need to have its own warehouse to prevent deficiencies.

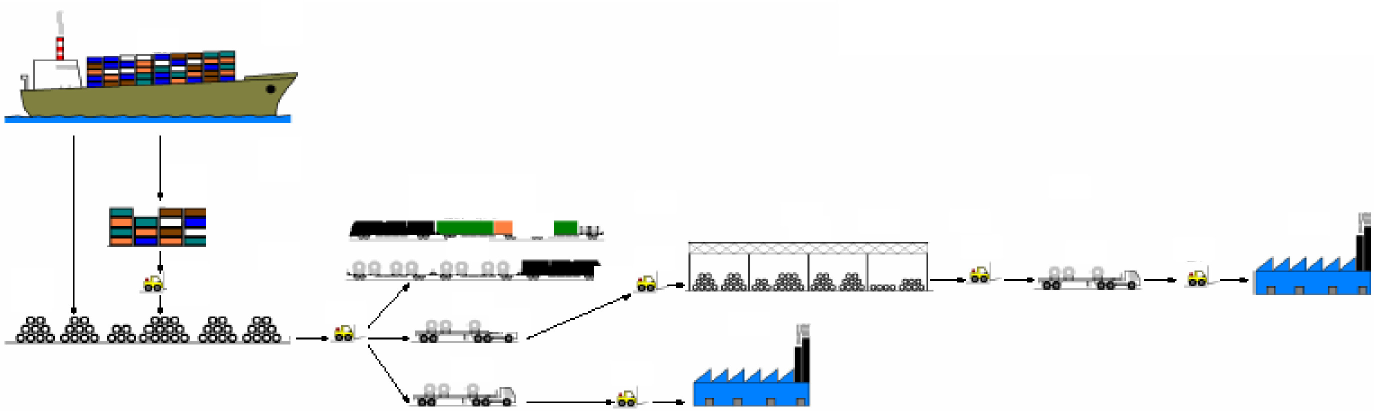

Figure 9: Redesigned chain

3- Rethink of material flow: two warehouses are placed in one organizational division (IKCO dock warehouse and IKCO striped role warehouse). They can be combined and form one warehouse.

Considering the 3 mentioned points, it becomes obvious that considering the mentioned sequence in Fig. 7 is vital while applying changes.

Another sample of redundant design is moving containers to IKCO. The containers contain steel roles. Steel roles are needed in IKCO and containers belong to their owner placed in port. Bringing containers to IKCO and returning back the empty containers is a costly procedure. Stripping the containers in the port reduce deliver costs to half of its present value.

Many other improvement opportunities can be seen if the chain is reviewed carefully. Total number of 16 improvement projects (KAIZEN) was defined in IKCO and the final result, the redesigned value chain, is shown in figure 9.

The defined projects are arranged in a way that does not surpass available facilities. For example consider that Dept. of logistics in IKCO has 5 logistics man. If a project needs 3 logistics man for its redesign process and the other needs 4, just one of them can be performed at a time. Additional information content (employing consultants) is needed to work on their both at the same time. The schedule is presented in Fig. 10.

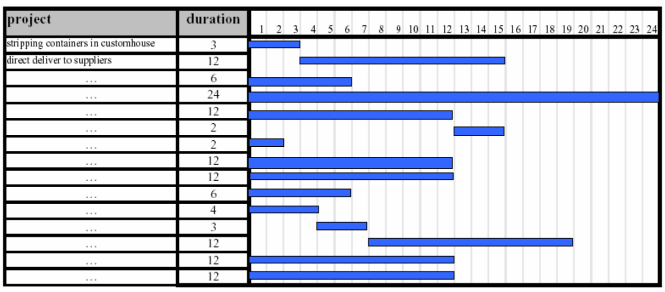

Figure 10: Scheduling program execution

8 CONCLUSION

AD is a useful concept to develop a plan and sequence to lean logistics. Some major benefits of presented methodology are:

1- uniform and integrated definition of sub projects
2- systematic relationship between engaged improvement teams
3- ability to expand the solution to other sections
4- increased probability of success

Many of lean projects confront failure because they are not well planned and scheduled. Using axiomatic design, an appropriate structure for lean logistics is presented. In practice, the outcomes of designed structure (and lean logistics project defined based on it) are unbelievable. One year after program execution, IKCO enjoys a great deal of improvement and cost reduction.

In this paper AD is engaged in two disciplines (mainly based on axiom 1):

1- Presenting sequence of performing tasks (Fig. 7) and
2- Analyzing the current state of chain and determining points of improvement.

The improvement points are then scheduled based on Fig. 7 to prevent rework. Implementing axiom 2 in scheduling helps level resources and prevent lack of information content.

In further investigation, such structures should be applied to other logistics value chain to see if it has the same results or not.

As showed in the paper, AD is a very useful tool in project management. Its axioms provide project management with ability of decomposing projects and implementing value engineering. Further research is needed in to determine the relationship between these two fields.

9 REFERENCES

[1] Askin, R.G., Goldberg, J.B., (2002), Design and analysis of lean production systems, John Wiley & Sons, Inc.

[2] BRADLEY, PETER, CHIEF EDITOR, the skinny on lean, LEAN LOGISTICS strategicinsight, March 2006, 31-36

[3] Cotoia, M., Johnson, S., (2001). Applying the Axiomatic Approach to Business Process Redesign. Business Process Management Journal, 7(4), 304-322.

[4] Engelhardt, F., & Nordlund, M., (2000), In Proceedings of ICAD2000, (pp: 267-290) Cambridge, MA.

[5] Hammer, M. & Champy, J., (1993). Reengineering the Corporation: A Manifesto for Business Revolution, Harper Business, New York, 1993.

[6] Hintersteiner, J.D. (2000), In Proceedings of ICAD2000, (pp: 306-412), Cambridge, MA.

[7] Houshmand, M., & Jamshidnezhad, (2002), B., In Proceedings of ICAD 2002, (pp: 118-131), Cambridge, MA.

[8] Lenz, R.K., & Cochran, D.S., (2000), In Proceedings of ICAD2000, (pp: 45-59), Cambridge, MA.

[9] Suh, N. P. (1990), The Principles of Design, New York: Oxford University Press.

[10] Tapping, D., Luyster, T., Shukere, T., (2002), Value Stream Management, Productivity Inc.

[11] Womack, J.P., Jones, D.T., Roos, D., (1991), The Machine That Changed the World: How Japan's Secret Weapon in the Global Auto Wars Will Revolutionize Western Industry, Perennial (HarperCollins).

[12] Womack, J.P. and Jones D.T., (1996), Lean Thinking: Banishing Waste and Creating Wealth in Your Corporation, New York: Simon & Schuster.

