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NEW CONCEPT IN LEANNESS DEVELOPMENT AND ASSESSMENT IN PLANT LIFE CYCLE (PLC)

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Abstract: *At the last decade of the 20th century, Womack et. al introduced lean concept to the industrial world. Since 1990 up to now, existed studies mostly have focused on lean production conception manufacturing process, but in this research leanness concept has developed in the plant life cycle. In this paper leanness concept will be described as elimination of wastes in the phases of investment, plant design & construction(hardware) and organization together with systems design (as software. These steps were added to eliminate the previously described seven wastes in production step. For this purpose at first, the types of wastes in the above mentioned phases were defined by using Axiomatic Design Methodology (ADM). After defining the types of wastes, a model for assessment of leanness is submitted. In this quantitative model, the amounts of leanness in each phase were determined and combined to make a unique measure for total leanness. Dimensions of leanness were presented for quick understanding, by using a spider diagram. In the last section of the paper, the results of an example for the application of this model in fan industry were given. This example shows the simplicity and strength of the model to determine the leanness before production phases.*

Keywords: *Leanness, Plant Life Cycle, Assessment, Lean Investment, Lean Manufacturing*

1. Introduction

Lean concept began in early 1990 by Womack ey. al. [1] and researchers expanded its principles and described the steps of moving from traditional mass production toward lean manufacturing. As mentioned by Sanati and Seyed hosseini [32], the summary of literature review on lean concept development can be shown as below and recent belief of Womack is added as well [34].

But, reviewing the Evolution of Leanness Concept Development in Plant Life Cycle shows that there is a gap in present studies, that is the need for elimination of first type wastes before starting the production by the plant.

In other words, the wastes are divided into two categories that the first one is accepted as the constraint of production phase, but second type category included seven wastes as below [3,6]:

- Over production: waste through the producing too many goods or producing too early.
- Defects: waste through excess cost added to products because of rework or scrap.
- Transportation: waste through moving material through the facility or double and triple handling material.
- Waiting: waste from workers waiting for material or machines.
- Inventory: waste through excess costs managing space, material, paperwork, people, and wasted interest charges associated with the extra inventory (semi finished parts between operations).
- Motion: waste through unnecessary worker movements.
- Processing: waste through unnecessary processing steps.

And these wastes should be eliminated immediately. In this paper first type wastes are discussed and it will be show that constraints could be avoided in previous phases of plant construction.

Therefore if there are some wastes because of plant location and in the production phase it is a constraint and accepted, then these wastes could be eliminated in the phase of plant design, and selection of plant location. So, if the lean concepts considers in the phase of plant construction, first type wastes will convert to second type, and can be eliminated.

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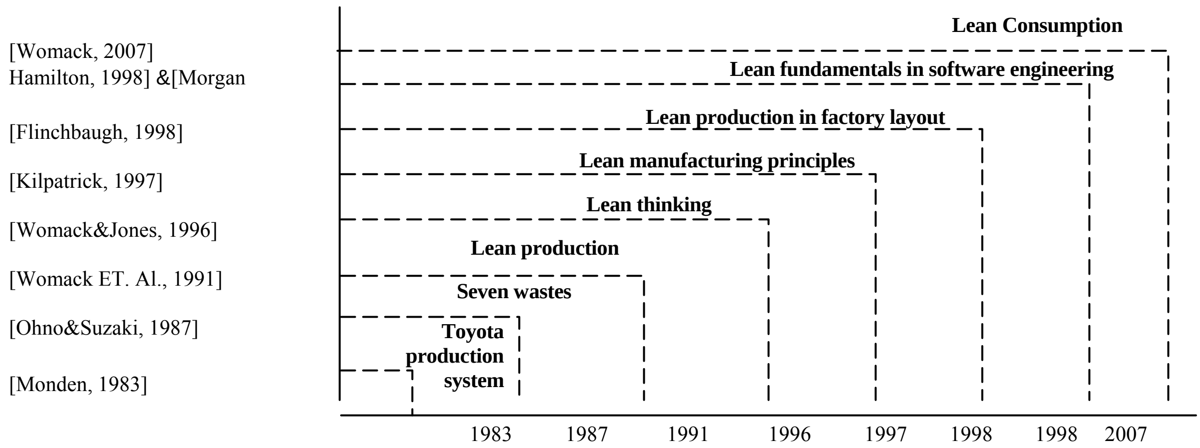

Fig 1. Summary of literature review on leanness concept

For identifying wastes in plant construction phase, construction process is divided into three steps included:

- Investment
- plant design & construction
- organization & systems design

And therefore the fourth step will be the exploitation.

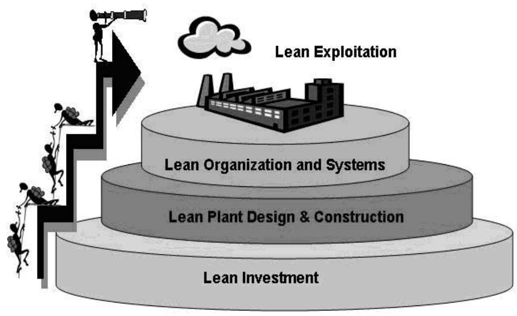

Fig 2. Leanness in plant life cycle

By this means, ADM can be used for derivation wastes in each step. In this way the authors introduce wastes of above steps and finally submit a model for assessment of leanness.

This text is divided to four parts as below:

- Part one: axiomatic design methodology
- Part two: derivation of wastes in plant construction steps
- Part three: leanness assessment model development
- Part four – examples of model application

2. Part One–Axiomatic Design Methodology

This research uses Axiomatic Design as the framework for leanness concept development. This design methodology was developed in the late 1970's by MIT professor Dr. Nam p. Suh [38]. Axiomatic Design is a methodology for developing solutions in the form of products, processes or systems that satisfy customer needs through a logical framework. Suh named the approach "Axiomatic Design" because it is based upon axioms which are fundamental facts that are observed to be valid and for which there are no counterexamples or exceptions.

The Axiomatic Design process is shown in figure 3. As indicated, the design process involves mapping through four design domains. Each translation or transition to a new domain is a refinement of the design. The design process begins by translating Customer Wants (CWs) in the customer domain into Functional Requirements (FRs) in the functional domain.

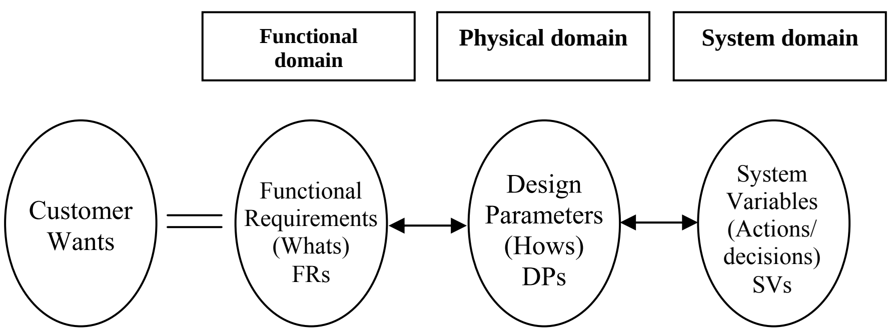

Fig 3. The axiomatic design process

FRs represent what you want the system to do – *the objectives*. Design Parameters (DPs) are generated in the physical domain that satisfy the FRs. DPs represent how you accomplish the objectives– *the physical embodiment*. In systems design, the DPs are mapped to system variables (SVs) that would satisfy the DPs. The SVs are actions or decisions used to control the system [38].

Axiomatic Design is based on two axioms: 1) The Independence Axiom, and 2) The Information Axiom. The design approach provides a scientific basis for design with the goal of independently satisfying the functional requirements (to eliminate coupling) by the proper selection of Design Parameters which serve to implement the physical aspects of the design.

The mapping between FRs and DPs, and DPs and SVs can be described mathematically as a vector. The Design Matrix [DM] describes the relationship between FRs and DPs, and DPs and SVs. A design equation should be written for each transition between domains as below:

$$\{FRs\} = [A].\{DPs\}$$
$$\{DPs\} = [B].\ \{SVs\}$$

Each element in [DM] is defined as: $A_{ij}= \delta FR_i / \delta DP_j$, $B_{ij}= \delta DP_i / \delta SV_j$ which is constant in linear design.

To satisfy the Independence Axiom, the [DM] must be a *diagonal or triangular*. A design with a diagonal matrix is an uncoupled design and is ideal. A design with a triangular matrix is a decoupled design and is acceptable, but not ideal. The decoupled design satisfies the Independence Axiom provided the DPs are set in a specific sequence. All other forms of [DM] are coupled design and are unacceptable. See figure 4 for matrix types [38].

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \end{Bmatrix} = \begin{pmatrix} XOOO \\ OXOO \\ OOXO \\ OOOX \end{pmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \end{Bmatrix} \begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \end{Bmatrix} =$$

Uncoupled

$$\begin{pmatrix} XOOO \\ OXOO \\ OOXO \\ OOOX \end{pmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \end{Bmatrix} \begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \end{Bmatrix} =$$

Coupled

$$\begin{pmatrix} XOOO \\ XXOO \\ XXXO \\ XXXX \end{pmatrix} = \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \end{Bmatrix} \qquad (1)$$

Decoupled

Fig 4. Design matrix & coupling

Information content in Axiomatic design is defined in terms of the probability of successfully achieving FRs by a given design and use to compare two designs. Information is defined as:

$$I = \Sigma \quad \log_2 (1/P_i) \qquad i = 1, \ldots, n \qquad (2)$$

Where p_i is the probability of DP_j satisfying FR_i. Log can either be base 2 or base e. with a total of n FRs, the total information content of a design is the sum of each probability. This axiom states that the best design is the design with the smallest I – the least amount of information to satisfy the FRs[38].

3. Part Two–Derivation of Wastes in Plant Construction Steps

In this research, based on Axiomatic Design process, in customer domain, **customer want is defined as manufacturing leanness.** Regards to this subject, authors submit Functional Requirements (FR) for manufacturing leanness as below:

- FR1 = lean investment
- FR2 = lean plant design & construction
- FR3 = lean organization & systems design
- FR4 = lean production

As mentioned before, seven wastes are defined in lean production (FR4), but there is a gap in considering lean concepts in other steps and for other functional requirements, we need to introduce new wastes. These wastes will define Design Parameters (DPs) for manufacturing system in the steps of: 1) investment, 2) plant design & construction, 3) organization & systems design, and 4) production. Literature review on lean production studies shows that up to now, nobody studied lean investment and therefore no wastes are defined for this subject. In the other hand, we can not apply defined seven wastes for industrial investment, and new wastes must be defined. Indeed there is not any material and inventory to indicate wastes in the investment step.

For defining wastes in investment phase, authors considered many investment activities and finally submitted six wastes for investment phase as below:

- DP11: Wastes due to selecting industries and products different from global trends
- DP12: Wastes due to selecting industries and products different from national strategies
- DP13: Wastes due to selecting out of dated products
- DP14: Wastes due to selecting out of dated production technology
- DP15: Wastes due to over capacity
- DP16: Wastes due to malfunction in feasibility study.

With the above definition of wastes, we can gain lean investment (FR1). It should be noted that the effects of these wastes in the next steps, like production are constraints of that step. For example if a capitalist chooses a foundry plant for his investment, in the step of production, he can do nothing with its less value added. Indeed he looses some profit because of his choice and accepts the waste due to selecting industries and products different from global trends. Today, global trends show that other industries like electronics and computer, aerospace and satellite, genetic technology and ocean logy are the industries with more value added [35]. National strategies define some facilities like bank supports for specific industries that are selected for country development. Disuse of these facilities is waste due to selecting industries and products different from national strategies.

After refinement of investment about wastes, it is supposed that investment is lean and free from wastes. Lean investment leads to have less constraint in the next steps and avoid and prevent wastes in the production phase.

In the next step, plant design and construction was under consideration. Wastes of this step define as below:

- DP21: Wastes due to selecting non lean equipments
- DP22: Wastes due to non lean lay outs and site plan
- DP23: Wastes due to over design
- DP24: Wastes due to under estimate design
- DP25: Wastes due to plant location
- DP26: Wastes due to design deviations and long duration of plant construction

Lean equipments are those ones which have the following specifications:

- Minimum set up time
- Fast change over
- Simple and easy for training
- Minimum energy consumption
- Minimum scrap materials
- Maximum efficiency and productivity
- Maximum quality of products (precision etc.)
- Cheaper tools and moulds
- Lower investment
- Lower cost of production
- Flexible application
- Fast installation
- Movable and minimum foundation structure
- Lower batch sizes

Lack of above specifications means, confirming wastes due to non lean equipments. Technology professionals must consider these specifications when decision making about production equipments.

After equipment considerations, wastes due to plant layout should be controlled. Flinch baugh [8], in his research mentioned that there are three principles in factory layout for lean production:

- Establishing *independent departments* with physical line segments will preserve throughput while pushing decision making and problem solving further down the hierarchy close to the root causes of manufacturing problems.
- *Decentralizing* essential manufacturing support activities will make them more responsive to on-going production, problem solving, and continuous improvement activities on the assembly line.
- *Modular, scalable, and interchangeable* physical processes, tools, and facilities will allow the facility to evolve with the roll-over of new products and continuous improvement activities without significant penalties to cost or downtime.

It is obvious that, traditional process layout can not satisfy above specifications and for these means cellular layout is needed. So, if the designer of layout, maps the process without above considerations, we will have some wastes in the production phase which could not be eliminated in that stage.

Over design and under estimated design occurs when we have not enough information in the design phase. Hasty or rash designing lead to use estimation and coefficients instead of calculations and real values in designing. Therefore over design, buries many capitals without any use and leads to some wastes. And under estimated designs lead to more compensation costs and increase wastes. Some examples of these wastes include:

- Estimation of factory ground more or less than real requirement.
- Estimation of the weight of structure more or less than needed.
- Calculation of the foundations and floor dimensions and specifications more or less than needed.
- Use of expensive materials which have not any effect on performance.
- Estimation of utilities more or less than real requirement.
- Estimation of machinery and equipments more or less than line balancing.

Really, above wastes occur when there is not enough information for designing and calculations, but after construction, when all of the parameters are determined, these wastes will be appeared and nobody can do anything for their elimination. In this case for lean plant design and construction, it must be avoided and prevented of estimated designing and let design process to progress when all parameters are determined.

Plant location is the next decision which can affect on wastes. Indeed when selecting plant location, political considerations have important role and can bring any industry to any state. So if technical considerations like nearness to materials, suppliers , market, and easy employment of professional and technocrat personnel do not favor, we will have many wastes when production phase. No suitable plant location leads to:

- Increasing construction costs,
- Increasing equipment transportation, installation and commissioning costs,
- Increasing material and suppliers costs when exploitation,
- Increasing product transportation to market costs,
- Increasing wages when exploitation and,
- lose tax exemptions.

Duration of plant construction project determine the bank profit value. If the plant is constructed in two years, bank profit differs from five years plant construction. The value of bank profit adds to fix investment and depreciate in the exploitation years. Share of depreciation costs in annual costs, absorb by product price and increase the prices. Therefore in exploitation phase the costs due to wastes in past phases should be considered.

After investment, designing and construction of the plant, and before exploitation, organization and systems must be designed. Adizes [36], mentioned that organizations like bio creatures have a life cycle with stages of Courtship, Infant ,Go-GO, Adolescence , Prime, Stable, Aristocracy, Early Bureaucracy, Bureaucracy, Death. Authors believe that, although in mass production age, above stages could be existed, but in lean production age, organizations must act as prime and stable organizations in their infant time. Indeed, today traditional organizations are not efficient and new models are needed for this purpose. Toffler [35], believes that third wave organizations have specifications as below:

- Shorter hierarchy
- Flexibility in structure
- Network performance
- Auto coordination

Also, he introduces the third wave models for organizations as below:

- Pulsating organization
- Bifacial organization
- Proparz organization
- Commissary organization
- Feudal chamber organization
- Mole organization
- Self-starting team
- Network organization
- Mosaic organization

Finally, Hesselbin [37], introduces the organizations of the future, as below:

- Network organization
- Circle organization
- Reconfigurable organization
- Borderless organization
- Mondragon organization
- Chameleon organization

It is obvious that new organizations need new tools, workflows and relationships. Computer systems development and new concepts like CAD/CAM, CIM, ERP and so on, are new tools for lean organizations which change performance of administration, production, maintenance, quality control, accounting, planning, and inventory systems.
Therefore wastes due to organization and systems design, divided into two categories; 1) wastes of systems without computer consideration, 2) wastes due to computer application.
In the first category wastes include:

- DP31: Wastes due to Inflexibility of the organization against internal and external conditions changes
- DP32: Wastes due to slow decision making process
- DP33: Wastes due to increasing the number of personnel and decreasing personnel efficiency
- DP34: Wastes due to lack of information for decision making which lead to errors in decisions
- DP35: Wastes due to overlaps in departments functions which lead to departments challenges

Above wastes could be occurred in procurement and purchase, sale, inventory, production and other departments and systems and lead to non lean performance of new factory.
In the second category which computer applications are used, wastes include:

- DP36: Wastes due to disuse of computer applications in common areas
- DP37: Wastes due to out of dated hardware and software
- DP38: Wastes due to lack of integration in systems
- DP39: Wastes due to skill less employees in computer works
- DP310: Wastes due to lack of suitable telecommunication

Non lean organization and systems design lead to wastes in exploitation phase and designers must prevent them when systems designing. Indeed after production starts, elimination of these wastes is costly and more expensive.
Finally, lean exploitation will complete the past phases, and as mentioned before, Womack et. al. [1], defined lean production as below:

- DP41: Wastes due to performance in the factory floor include; *Over production*, *Defects*, *Transportation*, *Waiting*, *Inventory*, *Motion*, *Processing*
- DP42: Wastes due to non lean design and development of products
- DP43: Wastes due to non lean Supply chain
- DP44: Wastes due to non lean Sale system
- DP45: Wastes due to non lean management

Because of many studies on lean production, authors only bring above design parameters for their model completion. Following Axiomatic Design methodology, in this stage System Variables (SVs) should be defined to satisfy Design Parameters (DPs).
Reviewing Design Parameters show that for each DP, minimum one System Variable can be determined which will satisfy that DP, also in each industry, System Variables differs. Therefore it could not be defined; some fix System Variables for all of the production systems. This means that in petrochemical industries, System Variables differ from Auto industries, but the goal of all forms of System Variables is to eliminate wastes that define in the related Design Parameters. By this reason, the authors dispense with defining System Variables.
Respected to Design Parameters validation, design matrix, forms as below:

$$\left\{\begin{matrix} \mathbf{FR1} \\ \mathbf{FR2} \\ \mathbf{FR3} \\ \mathbf{FR4} \end{matrix}\right\} = \begin{pmatrix} \mathbf{A_{11}} & \mathbf{A_{12}} & \mathbf{A_{13}} & \mathbf{A_{14}} \\ \mathbf{A_{21}} & \mathbf{A_{22}} & \mathbf{A_{23}} & \mathbf{A_{24}} \\ \mathbf{A_{31}} & \mathbf{A_{32}} & \mathbf{A_{33}} & \mathbf{A_{34}} \\ \mathbf{A_{41}} & \mathbf{A_{42}} & \mathbf{A_{43}} & \mathbf{A_{44}} \end{pmatrix} * \left\{\begin{matrix} \mathbf{DP1} \\ \mathbf{DP2} \\ \mathbf{DP3} \\ \mathbf{DP4} \end{matrix}\right\} \quad (3)$$

When DPi = {DPij j= 1,2,…,n }
The design equations for transition between FRs and DPs can be written as:

$$FRi = A_{i1}\,DP1 + A_{i2}\,DP2 + A_{i3}\,DP3 + A_{i4}\,DP4 \qquad i = 1,\ldots 4$$

Now, it must be noticed that when defining Design Parameters, each Functional Requirement for leanness, is affected by the DPs of the same and previous stages. This is because of timing difference of various phases. Indeed when lean factory design and construction occurs, lean organization and systems design has not occurred yet. This means that DPs for investment phase, effect on all four phases, and lean factory design & construction has not any relation with investment DPs but has effect on next phases. Therefore [DM] could be written as equation (4):

$$\mathbf{A=} \begin{pmatrix} \mathbf{A_{11}} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{A_{21}} & \mathbf{A_{22}} & \mathbf{0} & \mathbf{0} \\ \mathbf{A_{31}} & \mathbf{A_{32}} & \mathbf{A_{33}} & \mathbf{0} \\ \mathbf{A_{41}} & \mathbf{A_{42}} & \mathbf{A_{43}} & \mathbf{A_{44}} \end{pmatrix} \qquad (4)$$

This shape of [DM] is triangular and means the design is decoupled and feasible, and as a result the independence axiom is satisfied.

After defining System Variables, Design Matrix for transition between DPs and SVs will be like the above matrix and could be written as equation (5):

$$\begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \end{Bmatrix} = \begin{pmatrix} \mathbf{B_{11}} & \mathbf{B_{12}} & \mathbf{B_{13}} & \mathbf{B_{14}} \\ \mathbf{B_{21}} & \mathbf{B_{22}} & \mathbf{B_{23}} & \mathbf{B_{24}} \\ \mathbf{B_{31}} & \mathbf{B_{32}} & \mathbf{B_{33}} & \mathbf{B_{34}} \\ \mathbf{B_{41}} & \mathbf{B_{42}} & \mathbf{B_{43}} & \mathbf{B_{44}} \end{pmatrix} * \begin{Bmatrix} SV1 \\ SV2 \\ SV3 \\ SV4 \end{Bmatrix} \qquad (5)$$

When $DPi = \{DPij \quad j = 1,2,\ldots,n\}$
And $SVi = \{SVij \quad j = 1,2,\ldots,n\}$

The design equations for transition between DPs and SVs can be written as:

$$DPi = B_{i1}\,SV1 + B_{i2}\,SV2 + B_{i3}\,SV3 + B_{i4}\,SV4 \quad i = 1,\ldots 4$$

Because of the same reason, this matrix could be written as:

$$\mathbf{B=} \begin{pmatrix} \mathbf{B_{11}} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{B_{21}} & \mathbf{B_{22}} & \mathbf{0} & \mathbf{0} \\ \mathbf{B_{31}} & \mathbf{B_{32}} & \mathbf{B_{33}} & \mathbf{0} \\ \mathbf{B_{41}} & \mathbf{B_{42}} & \mathbf{B_{43}} & \mathbf{B_{44}} \end{pmatrix} \qquad (6)$$

This shape of [DM] is triangular and means the design is decoupled and feasible, and as a result the independence axiom is satisfied.

4. Part Three–Leanness Assessment Model Development

To define an assessment model for leanness, the concept of ESCAP model for defining technology level has been used [38]. In this model four dimensions of leanness are presented as below:

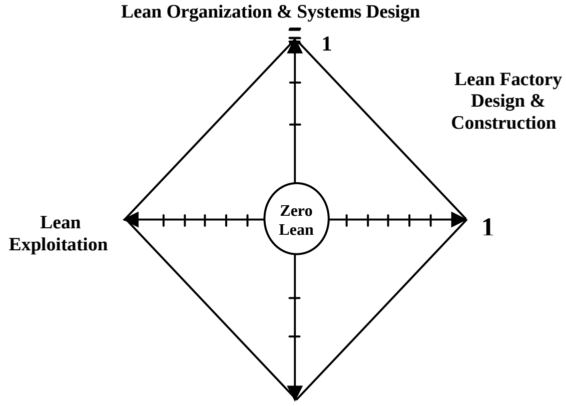

Fig 5. Four dimensions of leanness

Therefore if leanness values of a factory based on each dimension, be scale less and normalized and show on a vector and take a value between zero and one, then we can calculate leanness measure by using a Cubb-Duglas production function as below:

$$TLL = IL^{W_{IL}} \times PDL^{W_{PDL}} \times OPL^{W_{OPL}} \times EL^{W_{EL}} \qquad (7)$$

When; TLL = Total Leanness Level
IL= Investment Leanness
PDL= Plant Design & Construction Leanness
OPL= Organization & Procedures Leanness
EL= Exploitation Leanness
W= Weight of each dimension

For TLL calculation, value of leanness on each dimension must be measured, and therefore assessment is needed for System Variables (SVs) in each dimension based on its wastes.

Moreover partial leanness in each phase of factory life cycle can be measured. For this purpose next phases leanness parameters must be eliminated from the model. For example partial leanness of investment phase derived from the following formula:

$$TLL = IL^{W_{IL}} \qquad (8)$$

And partial leanness of a factory before exploitation can be measured as below:

$$TLL = IL^{W_{IL}} \times PDL^{W_{PDL}} \times OPL^{W_{OPL}} \qquad (9)$$

For calculation of Weight (W) values, which show the intense of effect of each dimension on total leanness level, it has been found that first phase gives the biggest weight, and by moving to next phases the intense of effect of that phase on total leanness decreases. Therefore the exploitation phase takes the smallest weight. So, in each phase the values of previous phases leanness are putting together with the same phase leanness.

Advantages of using a Cubb- Duglas production function for this model are as below:

- If a production system in one dimension was traditional and based on mass production (non lean), so its leanness value will be zero and TLL will be equal to zero. This means that the weakness of one dimension can not compensate with strong ness of other dimensions.

•If a production system in all dimensions takes a perfect score, then the value of total leanness level will be equal to one. In this case the Total Leanness perfection can be reached.

•Cubb-Duglas production function has simple calculation which causes easy application of the model.

•In this model, the leanness value of each dimension affected by the weight of that dimension, and composed with the other dimension weighted values. This means that the effects of values and weights are combined.

5. Part Four –Example of Model Application

Although lean concept developed in automobile industries, this model can be used for any industry and to show the simplicity of the model application, authors applied this concept in real conditions for a fan and blower manufacturer. For this purpose some check lists for lean investment, lean factory design and construction, lean organization and systems design, and lean exploitation were prepared and nine steps for leanness assessment model were defined as below:

Step 1. Determine the situation phase

In this step it should be determined that in which step the assessment will be done. There is four alternatives as investment, plant design and construction, organization and system design, and exploitation or production phase. Situation phase determines the model elements functional requirements).

Step 2. Determine the efficient types of wastes

Based on the industry's specification, there may exist some of the identified wastes. Some wastes may have not act in specific situations. For example in mould manufacturing that product is based on the order, waste due to out of dated product will not exist. Therefore some design parameters may be omitted from the assessment model.

Step 3. Determine the alternatives of system variables

Based on each type of waste (design parameter), there will exist rang of alternatives (system variables) from mass concept to lean concept, which professionals can determine. This is the technological aspect of the assessment.

Step 4. Rank the alternatives

For this ranking a bipolar scale method can be used In this method the smallest scale which belongs to mass situation gives zero (0) and the biggest one, ranks by ten (10) and belongs to lean situation. Technologists are authorized for this ranking and using names and values will be based on their idea. This must be done for all system variables and for all of the design parameters.

Step 5. Determine the rank of assessment subject

In this step the technologists should realize the situation of assessment subject and rank it. This ranked value will be between zero and ten and ranking should be done for all of the system variables.

Step 6. Dimensionless the ranking values

Because of difference between dimensions of system variables, they should be scale less before combining them in a single value. For this purpose Norm dimensionless method with this formula can be used:

$$N_{ij} = \frac{r_{ij}}{[\sum r_{ij}^{2}]^{1/2}} \qquad (10)$$

Step 7. Identify the mean value of ranking values

In this step, different values of ranked system variables should be gathered in a mean value for each design parameter. When each of the design parameters has a mean value, show them on a spider diagram and then go to the next step.

Step 8. Determine the weight of each design parameter

In this step, decision maker or technologist should identify a weight for each design parameter. For this purpose minimum weighting squares method can be used. In this method, decision maker identifies the ratio between weights of two design parameters with a dual comparison and makes a matrix. If the judgments of decision maker be compatible and consistent, then the weight of each design parameter will calculate by this formula:

$$W_i = \frac{a_{ij}}{\sum a_{kj}} \qquad \begin{array}{l} i= 1,2,\ldots,n \\ k= 1,2,\ldots,n \end{array} \qquad (11)$$

Step 9. Calculate the Total Leanness Level (TLL)

Applying these nine steps lead to the following results:

Tab.1. Total leanness assessment

No.	Description	Score	weight
	Leanness assessment		
1	Lean investment	0.36	0.4
2	Lean factory design and construction	0.41	0.3
3	Lean organization & systems design	0.3	0.2
4	Lean factory exploitation	0.43	0.1
	Total leanness	0.37	1

Therefore, after assessment leanness in each dimension, resulted scores must be scale less and normalized (with the Norm method) and by supposing the equality of weight of all criteria the result can be shown on it's vector in figure 6.

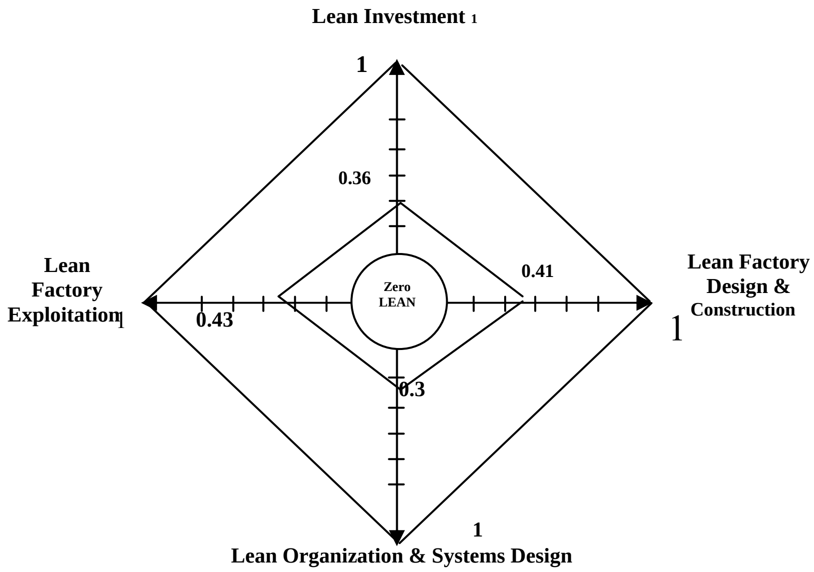

Fig 6. Four dimensions of leanness for fan manufacturer

Finally the amount of total leanness can be calculated by using a Cubb-Doglas production function as below:(weight of each dimension can be calculated by dual comparison)

$$TLL = IL^{W}{}_{IL} \times PDL^{W}{}_{PDL} \times OPL^{W}{}_{OPL} \times EL^{W}{}_{EL}$$

$$TLL = 0.36^{0.4} \times 0.41^{0.3} \times 0.3^{0.2} \times 0.43^{0.1} = 0.37$$

6. Conclusions

We can conclude that the most important benefits of submitted model are as below:

- Results of the leanness assessment can be used for strategic planning in each dimension
- A tool for competitor's evaluation
- A tool for industrial investment evaluation

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