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Assessing the leanness in product design: A model for planned design reuse

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Abstract

Shrinking product lifecycles, tough international competition, swiftly changing technologies, ever increasing customer quality expectation and demanding high variety options are some of the forces that drive next generation of development processes. To overcome these challenges, design cost and development time of product has to be reduced as well as quality to be improved. Design reuse is considered one of the lean strategies to win the race in this competitive environment. Design reuse can reduce the product development time, product development cost as well as number of defects which will ultimately influence the product performance in cost, time and quality. However, it has been found that no or little work has been carried out for quantifying the effectiveness of design reuse in product development performance such as design cost, development time and quality. Therefore, in this study we proposed a systematic design reuse based product design framework and developed a design leanness index (DLI) as a measure of effectiveness of design reuse. The DLI is a representative measure of reuse effectiveness in cost, development time and quality. Through this index, a clear relationship between reuse measure and product development performance metrics has been established. Finally, a cost based model has been developed to maximize the design leanness index for a product within the given set of constraints achieving leanness in design process.

Keywords: Lean manufacturing, Design reuse, Product development performance metric, Design leanness index

1.0 Introduction

Competitive advantage for many manufacturing companies now lies in their ability to effectively implement on-going product and process innovation, superior manufacturing, continual improvement of quality and reliability (Q&R) of existing products and developing a continual stream of quality new products [1-2]. Moreover, market pressures have forced companies to emphasise cost, speed, quality, agility, flexibility and most importantly leanness of their manufacturing facilities [2-3]. These can only be accomplished by developing and producing quality products and bringing them to the market quickly at a reasonable price, in order to meet or exceed customer expectations. During development of a new product, it is necessary to make careful decision as to what to change and what to reuse in future of this product. Keys [4] reported that some 75-90% of opportunity to influence the entire product development cost is gone by the time a design is released to production. Moreover, around 20% of the designer's time is spent searching for and absorbing information, and this figure is even higher for technical specialists [5]. As a result, decisions made during initial concept development can inevitably fix many of the critical cost factors of a product and hard to significantly reduce development costs later on. It is also recognized that not paying enough attention to product design early in the product life cycle potentially result in inefficiencies (wastes) throughout the product development (PD) process [6].

Lean manufacturing is a production strategy for organizational effectiveness focusing on waste reduction and improving productivity through application of various tools and techniques. The goal of lean manufacturing is to reduce the waste in human effort, inventory, time to market and manufacturing space [7]. Design reuse has been applied in industries to reduce the product development wastes [8-9]. It is reported that design reuse can reduce the product development time, product development cost as well as number of defects which will ultimately influence the product performance in cost, time and quality. However, despite the fundamental importance of design reuse, only a few reports of their systematic adoption in the product design process of manufacturing industries exist.

In order to support the decisions made for design reuse implementation in product design process, a systematic procedure of design reuse implementation in product development process needs to be developed. Moreover, the effectiveness of design reuse implementation in product development should be quantitative. The effectiveness measure and the effectiveness target should lead to improvement actions that can enhance leanness of the design process in order to succeed in the competitive market.

Nomenclature:

I - Design leanness index
n - Number of times an item can be reused
C_R - Retrieval cost
C_m - Modification cost
C_{Net} - Networking cost
C_I -Integration cost
C_v - Validation cost
C_N - Normal development cost
C_{dfr} - Design for reuse cost
C_{dbr} - Design by reuse cost
$C_{\Delta dfr}$ - Extra development cost per reuse term
N - Repository size in number of components
a - Number of search attributes in catalogue
q - Number of search criteria in a query
c - Cataloguing coefficient
s - Standardisation coefficient
d - Data brokerage coefficient
t - Documentation overhead coefficient
f - Fit coefficient
ρ - Probability of component or artefact being reused
k - Complexity coefficient
z - Query effectiveness coefficient
m - Modularity coefficient
i - Coefficient of interfacing elements
β_r - Retrieval cost constant
β_m - Modification cost constant
β_{net} - Networking cost constant
β_I - Integrating cost constant
β_v - Validation cost constant

The research attempts to investigate the benefits of design reuse in a more systematic manner with a view to gaining a better understanding of design reuse in product development process. This research proposes a design reuse based product development framework, and developed a design leanness index to measure the effectiveness of design reuse. A decision model has been developed for manufacturers using C# and Microsoft Access to evaluate the various conditions of the design leanness index.

The rest of the paper is structured as follows: Section 2 provides a brief overview of lean product design process, design reuse in product development, and design reuse measures and limitations. A systematic design reuse based product development framework, design leanness index and decision model are presented in Section 3. Research findings are discussed in Section 4. Limitations and extensions of this work round out the paper.

2.0 Lean product design process

Design and operation of manufacturing systems are of great economic importance [10]. Many organisations, academia and research institutes have realized the potential of applying lean thinking to the product development process and are now implementing the idea that applying lean principles will result in:

- ✓ The development of more products with the same resources
- ✓ Completion of new products on time, every time
- ✓ Creation of more winning products
- ✓ Development of products those are more reliable
- ✓ Reduce new product development timeframe by as much as 30% to 50% [11].
- ✓ Faster supported product redesign supported by knowledge management framework

Studies into lean thinking have focussed primarily on developing and deploying lean approaches and methods for product development in the hope of reducing cost and cycle time. These practices are emerging rapidly as product development practitioners attempt to apply lean principles from the manufacturing environment to product development activities. Additionally, existing or emerging best practices in product development have provided benefits in cycle time and cost and are converging with what is becoming accepted as "lean product development" [11].

Baines et.al., [12] performed an extensive literature review on all major publications associated with lean in product design. Major findings of the study are:

- ✓ The Toyota approach of applying set-based concurrent engineering provided an effective base for lean design
- ✓ A truly successful application of lean required organisation-wide changes in systems practice and behaviour
- ✓ Value in the product development process needs to be defined clearly as it is not necessarily the same as value in production operations
- ✓ The extent to which the entire product development workflow needs to be reengineered in the adoption of lean needs to be better understood.

The report however, did not go into some of the finer details such as common lean tools, design reuse in the design process to reduce waste.

The Lean Enterprise Resource Centre [13] reported that design must allow future modifications or evolution of product, the re-use of certain elements such as previous designs, information about customer needs and the technology required for a certain product. It was said that this strategy could be used to simplify the new PD process and facilitate flow of information. Furthermore, modular designs that maximise re-use of standard parts and flexible manufacturing systems and technologies support implementation of lean in new PD processes. This was a valid insight as it is the concept of standardization and re-use of components that can considerably reduce product development time and thus time-to-market. May et.al., [14] found that coordination is achieved through a global database with appropriate control mechanisms to access information in the database. It was added that lean can be facilitated by systems such as document control, central databases, knowledge based systems, project management systems, CAD/ CAM/ CAE/ PDM systems and web-based sharing and communication tools. This would be an effective method to ensure that people in different locations can access data and documents in a timely manner. Schuh et.al., [15] conducted a study on Lean Innovation Introducing Value Systems. This study focused primarily on applying lean thinking to the research and development process. The content of the report was predominantly based on a survey conducted with 143 companies in Germany in 2007. Results from the survey were as follows. It was found that 42% of the companies surveyed had not defined targets for the use of common parts across production lines. The authors detailed that to manage the increasing variety of parts, a specific standardization and clever product architecture is a necessary element of lean innovation. Creating such a basis for all products provides freedom to focus on customer value. Furthermore, within the survey 141 innovation managers indicated that their customers use only 70% of the provided functionalities. The authors stated that the remaining 30% was attributed to over-engineering.

To reduce the over engineered work, design reuse is introduced to make the product development process lean [8]. Design reuse is defined as the ability to select a section of a design, save it as a unique entity or element, and then pull it into a new design database or replicate it in an existing design. Busby [16] stated that in engineering design, design reuse has mainly been treated as a purely technological problem, a problem that can be solved with the development and application of various computer applications. However, Markus [17] reported that design reuse is not simply a matter of developing a reuse technology for the design engineers. He stated that special attention is needed to systematically organize the product design process and maintaining the design repository to facilitate knowledge reuse. Gautam et.al., [9] proposed a model based seamless product development which is instrumental for removing process waste and making the product development process lean. They proposed a reuse based process framework by recycling the design knowledge and development artefacts in a seamless development process. However, they did not consider the quantitative measures of design reuse so that manufacturers can understand the benefits or costs of design reuse.

Sharma et.al., [18] proposed a knowledge-based manufacturing and cost evaluation system for product design/re-design. This system allows the designer to estimate manufacturability metrics such as time and cost and also to explore different scenarios of parametric variation in the design. However, they did not focus on the effectiveness of design reuse in product development perspective. Many cost-based models that examine the economics of software reuse are available in the literature [19-20]. The vast majority of these models seek to quantify the benefits accrued through a software reuse process, using standard costing techniques comparing development without reuse and development with reuse, moderated by its accompanying costs. However, it is found that most of these presented models in literature are limited to the software development area and not focused on product development in the manufacturing area. Therefore, there is currently little empirical information about the efforts needs to make the design reusable and the benefits achieved by these efforts in product development process. Currently in the auto industry only one measure of reuse is commonly used to measure the benefits achieved by reuse and it is based on the reuse of physical end-items during product assembly [8].

Reusability index = (number of end-items (components) reused/total number of components) *100

Some risks are involved during selection or implementation of metrics in this form. Often participants may alter their behaviour to optimize something that is being measured, rather than focus on the real organization or corporation goal. For example, if a number of reused components are considered representative measure of reuse, it may be completely misleading and developers would try to skip the reuse of complex components. Instead they may focus on simple components. As a matter of fact, all the components do not require the same amount of development and testing efforts. Therefore, considering reuse of a simple and complex component same is completely misleading from a reuse count perspective.

From the literature reviewed, it can be seen that there has not been sufficient research done on the topic of design reuse in lean product development perspective. While some of the research details employed a lean tool, such as value stream mapping, to become lean, there has been a little research into identifying how design reuse can make the product development process lean. Furthermore, a little research could be found that quantitatively evaluate the benefits of design reuse in product design process.

3.0 A systematic product design framework

The core of lean product development is not only reducing the cycle time and cost, but also increasing value and improving product quality by enterprise integration and elimination of the process waste. Much has been said in theory, but very little has been done in practice to make product development processes lean in the manufacturing organizations [21]. In this research, an attempt has been made to make the development process lean using the simple concept of design reusability. Therefore, design reuse goals shall be aligned to the product development goals. Any reuse goals not contributing to product development goals shall not be considered further for the evaluation. Product development performance goals can be summarized as follows:

- ✓ Reduce development time
- ✓ Reduce development cost
- ✓ Reduce product cost
- ✓ Reduce the number of defects
- ✓ Increase parts interoperability

In the above list, all goals are pertinent to reusability goals as well as lean product design process. Therefore, to properly organise the lean design process, a comprehensive design reuse process model is required. Systematic design reuse model can achieve the above mentioned product development performance goals. In this research, systematic design reuse process involves two interrelated processes: information preservation and information reuse [22]. The information preservation refers to 'design for reuse', which involves information modelling and information processing to identify relevant knowledge. The information reuse refers to 'design by reuse', which aims at the effective utilization of the information. Design by reuse is mainly concerned with information retrieval, solution synthesis and evaluation. Four issues concerning the design reuse process, namely, representing, capturing, organizing, and retrieving have been identified by Ong et.al., [22]. Similarly, this proposed design framework considers that each part design can have two aspects of reusability '*design for reuse*', which indicates the amount of extra considerations and effort needed during its development so that it can be shared/adapted for successive designs and '*design by reuse*,' which indicates the amount of development effort required to make use of existing design resources and adapt them into the new product environment.

It is also considered that a component or design does not offer reusability until it is designed for reuse. Therefore, this component or design needs extra consideration in the form of design generality, flexibility, clear and concise interface definition, elaborated documentation, rigorous testing plan, and a reliable, efficient, and easy information retrieval system. These considerations add up to additional costs during the development of a reusable component and need more development effort than regular "one-time-use" designs.

On the other hand, a reusable component offers saving when it is used in multiple designs. The number of times reuse is expected for a component is based on how easy it is to integrate or modify an existing design into the new group. The proposed systematic product design and associated costs is described in the above Figure 1.

3.1 Mathematical model for design leanness index

A systematic design reuse based product design process is presented in Figure 1. There are two types of costs involved in design reuse.

Design for reuse costs are associated with cataloguing and documenting reusable assets, standardization and modularization of the design and maintain them in the repository for future use. Extra cost commitment is needed in order to make the assets reusable. Design by reuse costs are associated with searching reusable assets from the database, it may need to be modified, or made generic, then it may need to be integrated and validated for the final use, all of which involve additional costs. The benefits of reuse represent the development effort saved through reuse as opposed to new development. In this study, design leanness index is defined as the ratio of normal development cost to the development cost considering design reuse.

Design Leanness Index (DLI) = development effort without reuse/development effort with reuse...... (1)

This factor is generally one or more than one. When it approaches to one or less than one, there is no direct cost advantage of reuse. However, due to some indirect advantages such as the form of reduced variability, complexity, increased maturity, and interoperability, reuse is still encouraged.

Evaluation of development effort with reuse

In this proposed framework, there are two types of effort involved with the systematic product design process. One is making the design reusable for future use and another is effort needed to recover the design from the repository system.

Design for reuse cost components

Design for reuse costs components are (Figure 1):

- Modularization cost
- Standardization cost
- Documentation cost

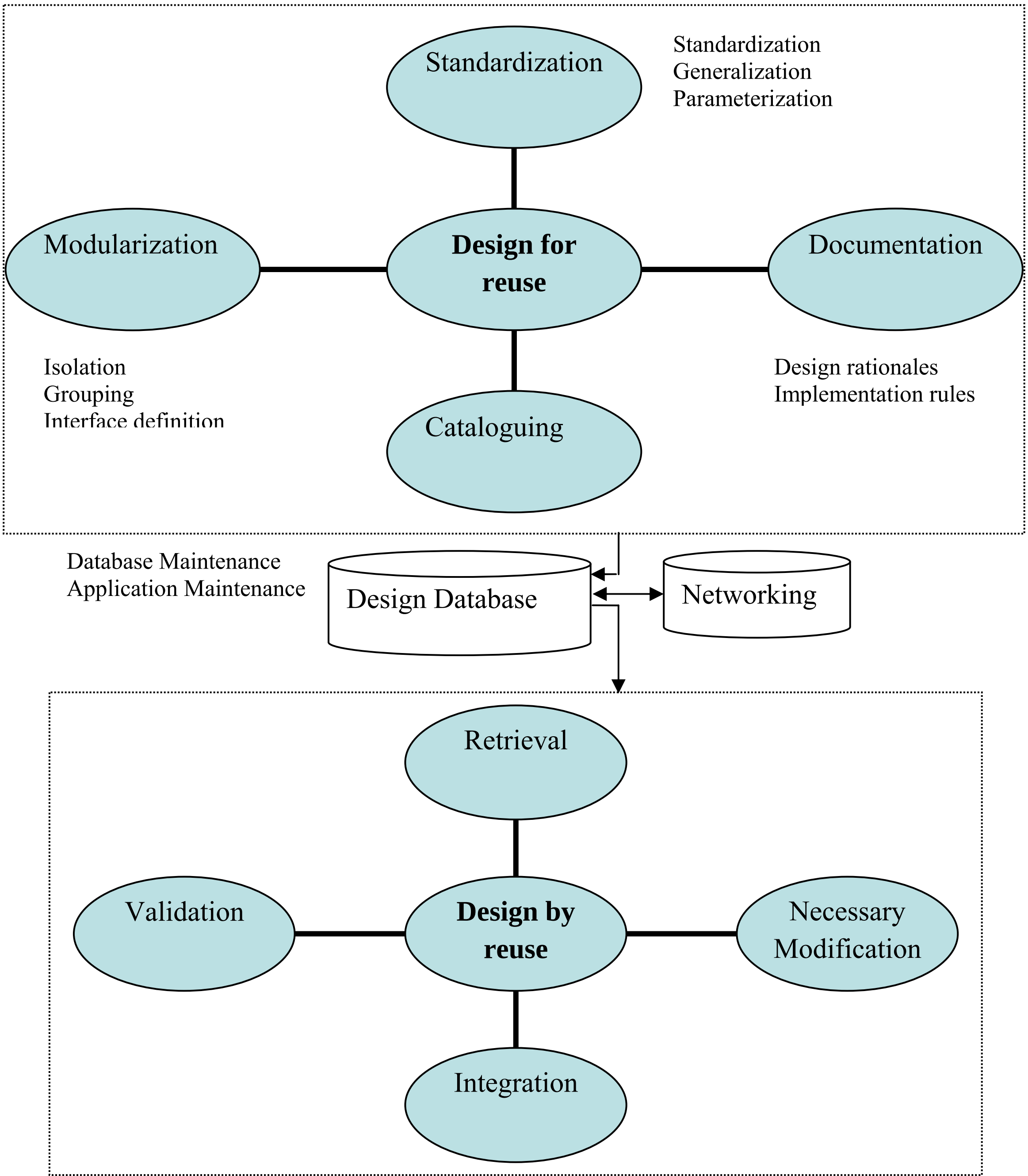

Figure 1: Systematic design reuse based product design framework

- Cataloguing cost
- Database maintenance cost

Therefore, Design for reuse cost = Normal development cost + Modularization cost + Standardization cost + Documentation cost + Cataloguing Cost + Database Maintenance cost

All these cost dependencies are calculated in the form of coefficients, as relative extra effort needed in comparison to the normal development. Extra cost commitment is needed in order to make the assets reusable.

Cataloguing cost

Cataloguing cost is a function of the number of design attributes being used to populate the database. Cataloguing cost is a function of number of attributes (a) to be filled out while uploading the design item. As for example, the following ten attributes can be used to archive the model artifacts in the database:

Document name, Document type, Author's name, Status, Version, Date created, Date modified, Best practice, Key words, Brief Description

Therefore, the cataloguing cost can be expressed as;
Cataloguing cost constant*γ

$= \beta_1\gamma$ (2)

γ = Cataloguing coefficient based on the number of attributes (a)

In this research, we assumed, $\gamma = a/10$;

Data brokerage cost

Data-brokerage cost is a function of server maintenance, user interface application development as well as maintenance. Higher server speed and user friendly application increases the data-brokerage cost but reduces the data retrieval cost. The data brokerage cost coefficient (d) is used to represent this type of cost with constant. Therefore, database maintenance cost can be expressed as;

Database cost constant*d

$= \beta_2 d$ (3)

d =Data brokerage coefficient or retrieval system efficiency 0 to 1

High server speed and high level user friendliness = 1

High server speed and medium user friendly application = 0. 8

Medium server speed and high user friendly application = 0. 8

Medium server speed and medium user friendly application = 0. 6

Low server speed and medium user friendly application = 0. 4

Medium server speed and low user friendly application = 0. 4

Low server speed and low level of user friendliness = 0. 2

Design modularity cost

Modularity in design is potentially the most powerful design tool available. Morgan [23] categorically emphasized that Toyota has achieved a significant leap in productivity, quality and speed to design, and engineering and manufacturing by employing fundamental principles of modularity. Langlois [24] also pointed out that an important strategy employed by design engineers for increasing efficiencies of both the product development process and the resulting design is modularity. It is a very general set of principles for managing complexities, by breaking up a complex system into discrete pieces, which can then communicate with one another only through standardized interfaces within a standardized architecture. Lau Antonio et.al., [25] work details the costs and benefits of modular products. The benefits of modularity they discussed include component economies of scale, ease of product updating, increased product variety, decreased order lead-time, and ease of design and testing. The costs of modularity they discussed included: static product architecture, lack of performance optimization, increased unit variable costs, and excessive product similarity. In this research, modularity cost coefficient (m) is primarily considered a function of the amount of modularity offered in the design. The higher the modularity offered, the higher the cost of modularity. However, this cost is offset by payoff while a complex component is reused.

Therefore, modularity cost = modularity cost constant*m

$= \beta_3 m$ (4)

The following values are assumed to measure the level of design modularity.

m = Modularity coefficient (0 to 1, 0 for fully integrated design and 1 for fully modular design)

Low – 0.2 (Each feature is one model, features have defined interfaces via I/O)

Medium – 0.5 (Major customer functions are grouped as sub model)

High – 1 (each customer function is exposed as sub model – activity chart)

Design standardization cost

Design standardization has implications for the manufacturing firm in the areas of cost, product performance and product development. The use of standard components or design can lower the complexity, cost and lead time of product development. An existing standard design represents a known entity and therefore can reduce the number of uncertain issues of the development team must cope with. An existing standard design also requires no development resources and so can lower both the cost and component development lead time of a product.

The standardization cost coefficient (s) can be linked with the level of discipline followed during the generalization and parameterization of the item. Any process maturity measure along with a check list can be used as a representative measure of the standardization. Therefore, design standardization can be expressed as:

= standardization cost constant*s

= β_4s (5)

The following values are assumed to measure the level of design standardization.

s = Standardization coefficient 0 to1, based on level of standardization, 0 for no standardization, 1 for maximum standardization

Low - 0.2 (Naming)

Medium - 0.5 (Signal/variable names, data types)

High - 1 (Signal/ variable names, data types, variable defaults, initialization, fault maturation, common constants)

Documentation cost

Documentation of reusable parts design is the key to the success of the design reuse. Recent research has shown that technical communicators add value to organizations and that good documentation can provide substantial corporate cost savings [26]. Documentation in design accounts for activities such as requirements rational, change requests, change rational, change log, and use cases of design. Documentation must describe how to use a design without disclosing how it is build internally. The documentation cost coefficient (t) is a representative measure of the extent of available documentation. More elaborate documentation on implementation rules and rationales is recommended for a complex object in order to promote its reuse. Therefore, documentation cost can be expressed as:

Documentation cost constant*t = β_5t (6)

The following values are assumed to measure the level of design documentation.

t = Documentation over head coefficient 0 t o1

Low – 0.2 (Only few documents are maintained as on need basis)

Medium – 0.5 (At least half of the documents are maintained)

High - 1 (all above documents are maintained current)

Therefore, total design for reuse cost can be expressed as,

$$C_{dfr} = C_N + C_N(\beta_1\gamma + \beta_2 d + \beta_3 m + \beta_4 s + \beta_5 t) \quad (7)$$

In the above expression, cumulative coefficients (i.e.$\beta_1\gamma$) represent the proportion of extra effort needed to make the assets reusable by doing more than normal development. The extra cost committed during development will be recovered over multiple reuses (*n*) of the assets.

Extra development cost n reuse,

$$C_{\Delta dfr} = \frac{C_N(\beta_1\gamma + \beta_2 d + \beta_3 m + \beta_4 s + \beta_5 t)}{n} \quad (8)$$

Where β_1 to β_5 are constants for converting various coefficients into costs

Design by reuse cost component

When a product is designed based on previous design, it needs some cost commitment in order to retrieve the best fit per need. Then, it may be necessary to modify the retrieved design and integrate and validate it in the new environment.

Design by reuse costs involve with (Figure 1);

- Retrieval cost
- Necessary modification cost
- Networking cost
- Integration cost
- Validation cost

Therefore, design by reuse cost = Networking cost + Retrieval cost + Necessary modification cost + Integration cost + Validation cost

Networking cost

Cost of networking is dependent on degree of fit, level of networking, and design standardization and documentation of the reusable design.

$$C_{Net} = C_N \{\beta_{Net}(1-f)\kappa^{d+s+t}\} \quad (9)$$

Retrieval cost

In this research, retrieval cost is primarily composed of three components: availability, selectivity, and retrievability. Searching cost is composed of selecting and filling out attributes for search criteria in the form of creating a query and then filtering the information to find the best fit to suit the needs of the new product. As more search criteria are included in the query, it becomes more expensive to create. However, it provides limited search results with high selectivity of those components which are best fit for reuse. Therefore, searching cost can be expressed as,

$$C_s = C_N.\beta_r\left(v_2q^2 - v_1q + v_0\right) \quad (10)$$

Retrieval cost is also dependent on the effectiveness of the retrieval system. Therefore, retrieval cost can be expressed as,

$$C_r = C_N.\beta_r(1-z)\frac{q}{a} \quad (11)$$

Here availability cost is considered as a gamma function of repository size where α and β are shape and scale parameter for the gamma function. Therefore, availability cost can be expressed as,

$$C_a = C_N.\beta_r.N^{\alpha-1}\frac{e^{\frac{-N}{\beta}}}{\beta^{\alpha}\Gamma(\alpha)} \quad (12)$$

However, anytime when a search is performed it is not necessary that a suitable design is retrieved. Therefore, in our study we use a probability function for design retrieval. Moreover, the extra cost of retrieval is distributed over a period of time until a suitable design can be retrieved. Probability function (ρ) can be assigned based on number of design components archived, cataloguing attributes, and query criteria. Therefore, the value of probability function can be calculated as, ρ = f (N, q, a). Therefore, total retrieval cost can be expressed as;

$$C_R = C_N.\frac{1}{\rho}\left[\beta_r\left\{N^{\alpha-1}\frac{e^{\frac{-N}{\beta}}}{\beta^{\alpha}\Gamma(\alpha)} + \left(v_2q^2 - v_1q + v_0\right) + (1-z)\frac{q}{a}\right\}\right] \quad (13)$$

Necessary modification cost

Necessary modification costs are modeled using the degree of fit of the retrieved design, the complexity and the documentation of the reusable design. As with development, this cost is also subject to modularity and standardization of the reusable design. The cost associated with modifying a single component is specified as;

$$C_m = C_N\{\beta_m(1-f)\kappa^{m+s+t}\} \quad (14)$$

Integration Cost

Cost of integration is a function of the amount of modification required due to lack of fit in the retrieved design. Integration cost also depends on change in interfacing requirements. In this study, integration cost is modeled as a linear function of modification and an exponential function of interfacing coefficient. The interfacing coefficient can be defined as the ratio of modified interfacing elements to the total number of interfacing elements in the design.

$$C_I = C_N\{\beta_I(1-f)ie^i\} \quad (15)$$

Validation Cost

Any modification in the component introduces potential issues. Therefore, modified design needs to be revalidated. Validation cost is considered as the function of modification requires fitting the design in new product and complexity of the design. This cost is modeled as a linear function of degree of fit of design and an exponential function of complexity coefficient.

$$C_v = C_N\{\beta_v(1-f)e^{\kappa}\} \quad (16)$$

Design Leanness Index (DLI)

Therefore, the cost based design leanness index can be expressed as;

$$I = \frac{C_N}{C_{\Delta dfr} + \left(C_R + C_m + C_{Net} + C_I + C_v\right)} \quad (17)$$

Final form of design leanness index can be expressed as equation (18);

$$I = \frac{1}{\left\{\frac{(\beta_1\gamma + \beta_2 d + \beta_3 m + \beta_4 s + \beta_5 t)}{n} + \left(\beta_r \frac{N^{\alpha-1}\frac{e^{\frac{-N}{\beta}}}{\beta^{\alpha}\Gamma(\alpha)} + (v_2 q^2 - v_1 q + v_0) + (1-z)\frac{q}{a}}{\rho} + \beta_m (1-f)k^{m+s+t} + \beta_{Net}(1-f)k^{d+s+t} + \beta_I (1-f)ie^{i} + \beta_v (1-f)e^{k}\right)\right\}}$$

(18)

Savings are computed as the difference between development cost assuming no reuse and costs with reuse [20].

Savings by design reuse = $C_N - C_{Reuse}$

3.2 Design reuse model for effective decision

A cost model has been developed to calculate different cost components of design reuse based product development process. Mycrosoft Access and C# is utilized to develop the user interface. Using this model, manufacturer can calculate the cost involved with design for reuse and design by reuse. Then, this model calculates the design leanness index as well as savings by design reuse. The value of design leanness index changes with the different values of the standardization coefficient, modularization coefficient, complexity coefficient, documentation coefficient, cataloguing coefficient, interfacing coefficient, query size, repository size, and retrieval effectiveness based on the context of application. This index describes the how lean the design process is and how much effort the design process needs to make the design more efficient. Finally, using this model one can understand which coefficient needs to achieve the desired leanness level.

3.2.1 Illustrative example:

This example explains the how the design reuse model can be applied to measure the leanness of a product design process of manufacturing organizations. Input and output values are presented in table 1 and table 2.

Number of search criteria in a query	1500
Cataloguing coefficient	1
Modularization coefficient	0.5
Standardization coefficient	0.5
Documentation coefficient	0.5
Complexity coefficient	0.5
Interfacing coefficient	0.6
Networking coefficient	0.8
Retrieval effectiveness	0.5
Number of times an item can be reused	3
Fit coefficient	0.6
Number of search attributes in a catalogue	10
Probability of component being reused	0.4

Table 1: Decision making variables

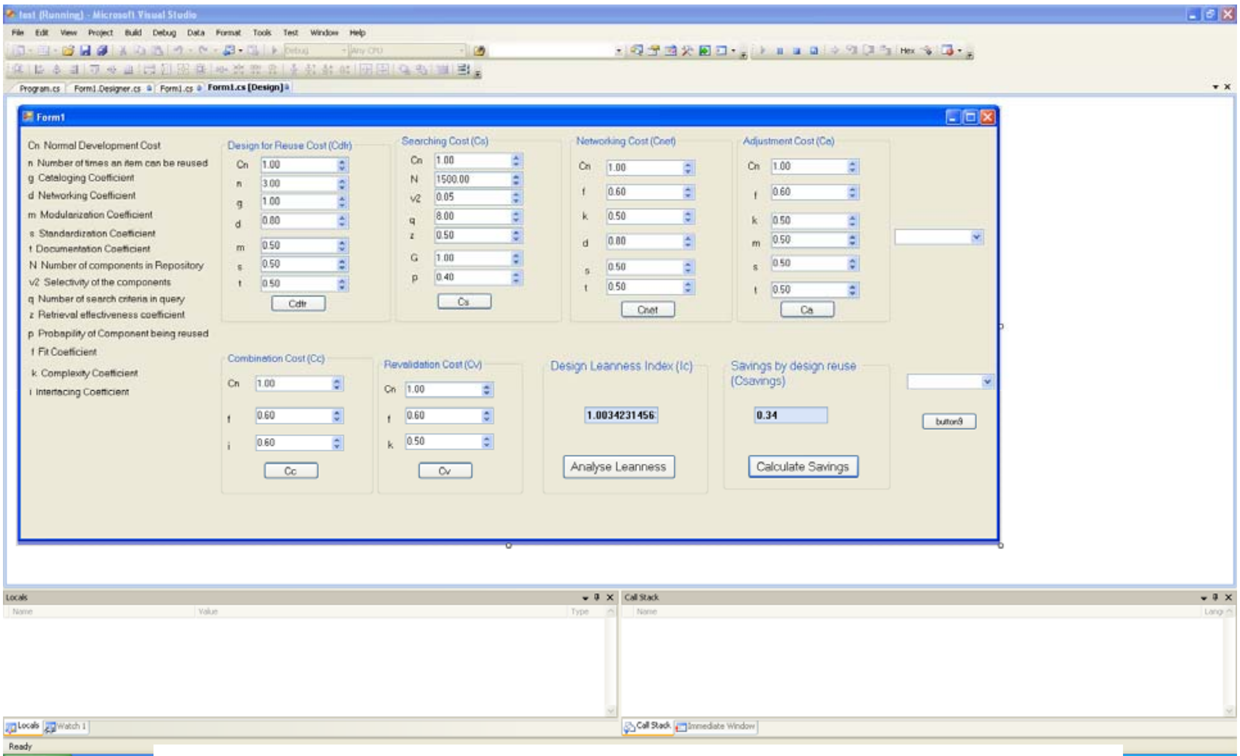

Figure 2: Cost based design reuse model for effective decision making

Cost Components	
Normal development cost	1
Design for reuse cost	0.0933
Searching cost	0.1560
Networking cost	0.0574
Adjustment cost	0.1414
Combination cost	0.21865
Validation cost	0.3297
Design Leanness Index (DLI)	**1.0034231456**
Savings by design reuse	**34%**

Table 2: Results

Design Leanness Index (DLI) vs. Modularization Coefficient (m)

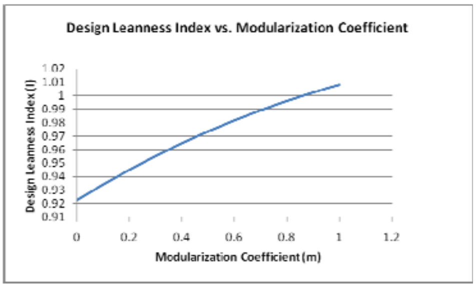

Figure 3: DLI vs. m

From the Figure 3, it describes the effects of design modularization on design leanness. This graph shows that modularization has positive effect on design effectiveness. Modularity makes modification easy due to reduced interaction. As a result, modularization positively influences the necessary modification cost. From equation (14) it shows that the higher the modularization coefficient, the lower the necessary modification cost. Therefore, the higher the modularity coefficient is higher the effectiveness of product design process.

Design Leanness Index (DLI) vs. Standardization Coefficient (s)

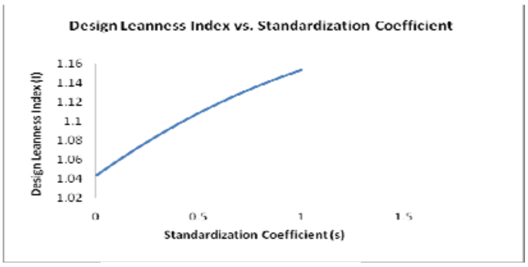

Figure 4: DLI vs. s

Figure 4 presents the effect of design standardization on the product design process. It shows that standard design procedure helps to make the product development process efficient. Modification and networking costs are related to standardization coefficient. Equation (9) and (14) explain the effect of design standardization on product development cost. These equations show that the higher the standardization is the lower the networking and adjustment costs are. Thus standard design can reduce the product development cost and product development time which positively influence the product cost. Therefore, design leanness increases with the increases of standardization coefficient.

Design Leanness Index (DLI) vs. Documentation Coefficient (t)

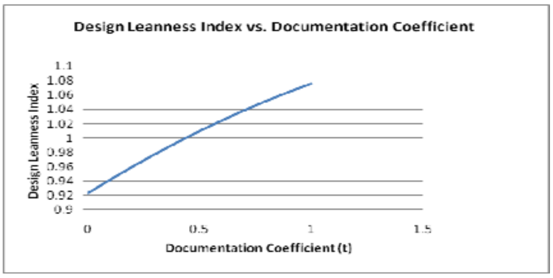

Figure 5: DLI vs. t

Figure 5 above shows that the proper documentation of design increases the leanness of product development process. Documentation has positive influence on the modification cost and networking cost. Equation (9) and (14) describe the effect of documentation on product design cost. Proper documentation greatly reduces the searching time of design from the database as well as it reduces the cost of new design.

Design Leanness Index (DLI) vs. Retrieval Effectiveness (z)

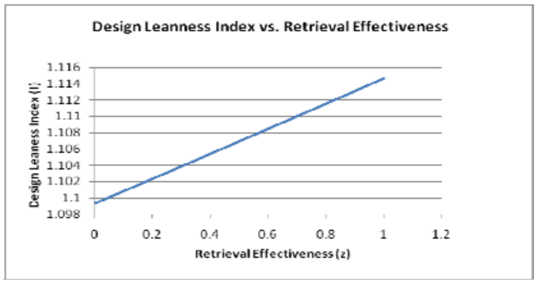

Figure 6: DLI vs. z

From Figure 6, it is evident that effective retrieval system reduces the cost of searching design from the repository. As a result, it reduces the searching time of previous design from the repository. Hence, the higher the system effectiveness is, the lower the time and cost required to develop a new product. Therefore, efficient server enhances leanness of the product development process.

Design Leanness Index (DLI) vs. Networking Coefficient (d)

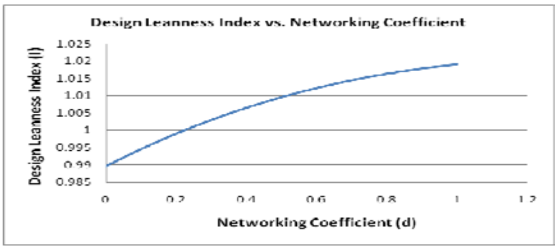

Figure 7: DLI vs. d

Figure 7 above shows that networking has positive impact on product development process. As networking gets fast, it makes the product design process more efficient. With the increase of networking coefficient, the design leanness gradually increases as networking increases the collaboration among the product development team.

Design Leanness Index (DLI) vs. Interfacing Coefficient (i)

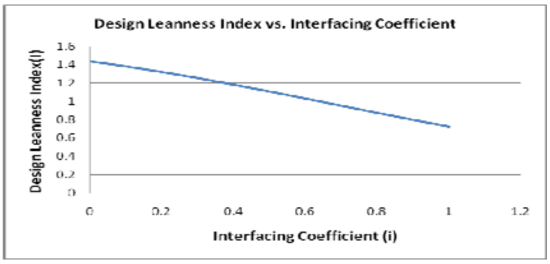

Figure 8: DLI vs. i

Above Figure 8 describes the effect of interfacing on design leanness. It shows that interfacing negatively influence the product design process. The higher interfacing coefficient means that this needs significant changes in the design. As a result, it involves higher integration cost as it needs to integrate many modified design. Therefore, design leanness of product development decreases with the increasing of interfacing coefficient.

Design Leanness Index (DLI) vs. Complexity Coefficient (k)

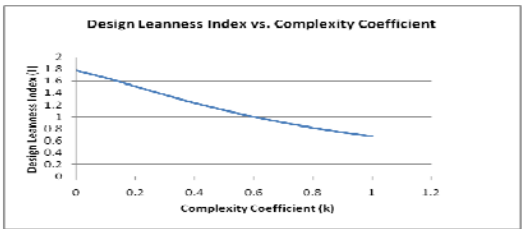

Figure 9: DLI vs. k

Figure 9 above shows that design leanness gradually decreases with the increases of the complexity of the design. The complexity of design increases the modification cost, networking cost, and validation cost of the new design. The more complex the design, the more the reuse cost. Therefore, complexity of design has negative effect on the lean product design process.

Design Leanness Index (DLI) vs. Fit Coefficient (f)

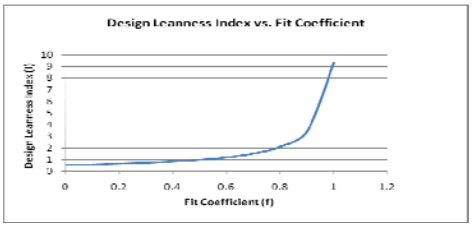

Figure 10: DLI vs. f

The degree of fit of a retrieved design represents the extent to which the design is utilized without modification. Therefore, the higher the value of fit coefficient is, the less effort needs to modify and reuse the design. The fit coefficient has positive influence on the all design reuse cost components. Therefore, the appropriate fit of the new design with the existing design reduces the new product development cost. Therefore, design leanness index increases with the increases of the fit coefficient.

Conclusions

The research attempts to investigate the benefits of design reuse in a more systematic manner with a view to gaining a better understanding of design reuse in product development process, provides a systematic product design framework, and developed a quantitative measure of design reuse effectiveness in product development process.

Design reuse based framework shows how to systematic product design can make the entire product design process lean. The design leanness index measures the effectiveness of design reuse in product design process. The reduction of cost comes through reduced engineering hours and reduced testing revalidation hours. Furthermore, due to reuse, potential rework requirement on reusable components can be also significantly reduced. Product cost is positively reduced when component reuse is increased in the final product. Furthermore, due to exhaustive testing and more stringent design criteria, a shared component proves to be more thoroughly validated before being put into production. Many defects identified during early production are usually fixed and do not show up during successive reuse. Product complexity grows as variety increases. With components share and reuse, variance of the product is reduced which helps in reducing product complexity for engineering manufacturing and service. Furthermore inventories can be substantially reduced due to reuse and sharing.

Future studies may consider the development of design leanness index based on time, and quality. It is expected that concept generated from this research would make a significant contribution to design reuse implementation in product design of manufacturing organizations.

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