ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/296037900

Cost model for evaluating component standardization: A case study

Article · January 2000

CITATIONS
0

READS
77

3 authors, including:

Chandana Perera
Sri Lanka Institute of Information Technology
36 PUBLICATIONS **265** CITATIONS
SEE PROFILE

M. T. Tabucanon
Asian Institute of Technology
96 PUBLICATIONS **1,376** CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project Multi-Criteria Process Planning for PCB Asembly View project

All content following this page was uploaded by Chandana Perera on 30 June 2017.

The user has requested enhancement of the downloaded file.

Engineering Valuation and Cost Analysis, 2000, Vol. 3, pp. 9–25
Reprints available directly from the publisher
Photocopying permitted by license only

© 2000 OPA (Overseas Publishers Association) N.V.
Published by license under
the Gordon and Breach Science
Publishers imprint.
Printed in Malaysia.

A Cost Model for Evaluating Component Standardization: A Case Study

H. S. C. PERERA[a], N. N. NAGARUR[b,*] and M. T. TABUCANON[b]

[a]*Department of Mechanical Engineering, University of Moratuwa, Moratuwa, Sri Lanka;* [b]*Industrial Systems Engineering Program, Asian Institute of Technology, P.O. Box 4, Klongluang, Pathumthani 12120, Thailand*

(Received 18 June 1998; Revised 10 February 1999; In final form 20 September 1999)

As manufacturing industry tries to grapple the often-conflicting objectives of increasing product variety and reducing the production costs, one of the strategies oft contemplated is component standardization or using common components. However, developing and using standard components may sometimes push the overall costs actually higher. This paper proposes an evaluation model for decision making in the context of component standardization. First, it discusses various types of costs to be considered for selecting desired components. Then the paper presents a specific case study in which some purchasing parts are considered for standardization. An evaluation model is developed for the relevant costs of the case. The solution and sensitivity analysis are presented and discussed.

Keywords: Cost evaluation, component standardization, component commonality, product redesign

INTRODUCTION

Rapid technological changes, increased globalization and variability in customer tastes are some of the common phenomena experienced by today's manufacturing enterprises. Product proliferation is an inevitable consequence in such an environment. Companies can no longer follow the Henry Ford's strategy of manufacturing large volumes of standardized products to capture market share and earn high profits. However, increase in a product variety degrades the performance of a manufacturing system. Excessive product mix in a manufacturing system creates both managerial and operational complexities resulting in poor performance which would lead to increased product costs.

Component standardization (in the present paper it is also addressed as component commonality) is one of the powerful strategies proposed by various researchers and practitioners to solve the problems associated with product variety. This strategy results in smaller number of standardized evaluation models by considering all the relevant costs which are important in making a decision on component standardization. Also we point out other decision areas to be reviewed when making a decision in similar situations. Finally, we formulate our models to analysis a real life case, and the methodology is illustrated

*Corresponding Author: E-mail: nagarur@ait.ac.th

with real data. These models and the decision framework are however applicable in a general way to other cases as well.

DECISION MAKING ENVIRONMENT FOR COMPONENT STANDARDIZATION

In this section, we qualitatively discuss the costs to be considered which would provide the basis for formulating the evaluation model for our case study to achieve the component standardization. The components can be basically divided into two groups in evaluating the cost: purchased components and manufactured components. More often, the components pass through the component inventory after purchasing or manufacturing and then are sent to the assembly as shown in Figure 1. The component inventory cost is common to both purchased and manufactured components and affects the lot size decision in purchasing and manufacturing. The costs involved in purchasing, manufacturing and inventory are basically running costs and are measured as cost per period (monthly cost, annual cost, etc.). In addition to these costs, when the common component is a new design, a one time design and reconfiguration cost should be considered.

Inventory Costs

The component inventory cost can be divided into two major categories: cycle inventory cost and safety stock cost. The cycle inventory cost of a component depends on the order quantity. Under economic order quantity policy, there is a possibility of reducing the cycle inventory cost since total order quantity for the standardized component is usually less than the sum of the quantities ordered for unique components. The safety stock mainly depends on factors such as service level, and review policy. It is generally held that component standardization reduces the safety stock cost by risk pooling. In the literature, the safety stock benefits to assemble to order systems are widely discussed. However, it can be seen that even for produced to stock systems there are benefits due to standardization when the system maintains both component and product inventories. Van Donselaar and Wijngaard (1987) and Van Donselaar (1990) deal with the inventory problem of common component in divergent systems where stock points are maintained at both component and product level. They derive simple equations for safety stock under integral reorder rule in which inventory level of both component and product are considered in placing an order. Even though integral reorder rule assures the optimal inventory level, this is rarely used in practice due its computational complexity. In practice, it can be seen that many

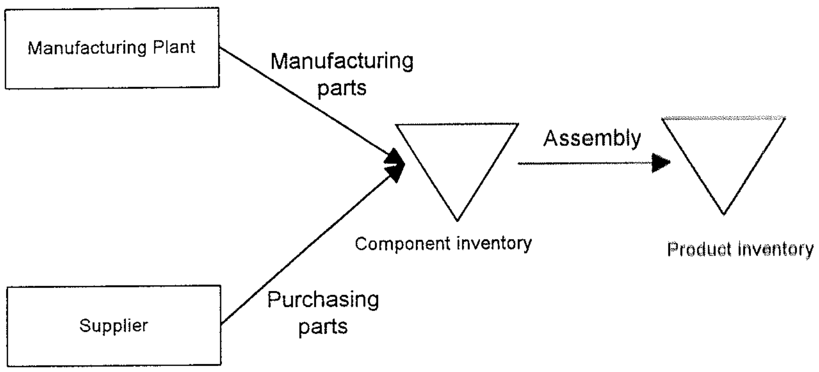

FIGURE 1 Total Production System.

manufacturing systems maintain safety stocks of components and products individually. Safety stock cost of the component can be reduced even in these situations by standardization.

Purchasing Costs

Purchasing related costs mainly consist of three major components: purchasing cost (price), order cost and transportation cost. Quantity discount is a major issue of component standardization to be considered in the context of purchasing cost. Large quantity orders through component standardization lower unit costs. On the other hand, additional material and processing for the standardization also affect the costs of the component. In the literature relevant to quantity discounts, different types of discount models are discussed. "All units" and "incremental quantity" discount models are the ones widely used in practice. The specific type of quantity discount offered by the suppliers has great impact on component cost. Hence it is important to consider the form of quantity discount when evaluating the cost of standardized component.

The second component of purchasing costs, ordering cost, if taken as cost per order, is generally independent of the order quantity. It is possible to reduce the total ordering costs through component standardization avoiding frequent orders because of smaller component variety.

Transportation cost is also a major cost component involved in purchasing. Large quantity orders lower the transportation cost per unit through quantity discounts similar to the price quantity discounts. So component standardization reduces the transportation cost through quantity discounts. Jucker and Rosenblatt (1985), Lippman (1969) and Hwang *et al.* (1990) among others describe the different types of transportation quantity discounts models. Using these models it can be seen that transportation cost is reduced through larger lot sizes resulting from component standardization.

Manufacturing Costs

The costs incurred in manufacturing can be identified as production cost, setup cost and work-in-process cost. The material and processing costs come under production cost. Processing cost depends on the labor, tooling, machine, etc. If the standardized component is a new design, then the costs of design needs to be included in the cost of the component. A standardized component tends to be more costly due to its multifunctionality. The production cost of a component depends on its attributes. At early design stage, it is not possible to determine the exact cost for each standardized components since there are many possible combination for standardized components and the detailed design is not available, and hence at this stage it is very difficult to get a good estimate of production cost. A particular manufacturing method used to produce it also effects the production cost. Learning and forgetting also affect the production cost of a component. Larger lot sizes and less interruptions resulted by component standardization can reduce the production cost of components (Perera *et al.*, 1999).

Setup cost is another important cost to be considered in manufacturing phase. Component standardization reduces the number of setups and changeovers resulting in lower setup cost. Work-in-process cost can also be major cost factor in manufacturing, which is affected by component standardization decisions. Reduced variety achieved through component standardization can substantially reduce the WIP inventories.

Design and Reconfiguration Cost

In general, component standardization or component commonality problems consider the situation where two or more components are replaced by a common or component which can satisfy the requirements of all the components replaced, and this standardized component is usually a new component. However, we have experienced the situations where the common component not necessarily is a new one; one of the existing components can be used as a standardized component. If the standardized component is not an existing component, in addition to above mention costs, design cost and reconfiguration cost should be considered. More often, some of the facilities such as dies, fixtures, etc. used for existing components cannot be used for the new standardized components. These facilities should be replaced by new facilities or reconfigured to suit the standardized component. In such situations, the cost of new facilities or cost of reconfiguration should be taken into account. If any existing facility is obsolete the salvage value also should be considered in the analysis. This cost is applicable for both manufacturing and purchasing components. In the case of manufacturing, the applicability of cost is obvious. In the case purchasing, if the component is manufactured according to the specifications given by the company, (i.e. design is provided to supplier) the design cost is applicable.

Assembly Cost

Assembly cost of a particular component type depends on the general characteristics of the type as a whole, and on the specific characteristics of the individual variants. In this study, the cost is divided into two categories: functional (fixed) cost and variety cost. Functional cost is the cost related to performing assembly of a particular component type, which depends on the general characteristics of the type and is independent of the number of component variants of that particular component. Variety cost, which depends on individual characteristics of the variants, is incurred due to number of changeovers, number of tools, etc., and it depends on the number of variants of the component. In making a component standardization decision, due consideration should be given to the variety cost of assembly since the standardization decision affects this cost.

Modification Cost of Related Components

The components in a product have several kinds of relationship with each other in terms of assembly, alignment, dimensional concordance, etc. So, some of the other components in a product may also have to be modified to accommodate the new standardized components. If there going to be any change in the cost of these components due to modified design it should be taken into account in making a decision on standardization as mention above. The modification cost can be divided into two major categories: one time design and reconfiguration cost, and running cost which includes change in cost of material, processing, inventory etc.

Logistic Decisions to be Considered in Component Standardization

In standardizing the components, it is important analyze the logistics issues connected to the supply of the component. This is due to the fact that the standardization increases the demand of individual component, necessitating careful study of make or buy decisions, choice of manufacturing method, and choice of suppliers.

When the demand for a component increases, more often, marginal cost or incremental cost (additional cost per unit) for manufacturing costs is smaller than the marginal costs for purchasing. Then, it may be economical to produce a component in house rather than buying from external supplier if there is enough capacity. The make-or-buy decision can be made by comparing sum of running cost and periodic equivalent design and reconfiguration cost at each case. The economy of manufacturing method which is used to produce a component may change with the production volume. As an example, at a low demand rate it is more economical to produce a metal part by machining rather than casting to avoid larger fixed cost such as setup cost, die cost, etc. But at a high demand rate it is economical to produce the same part by casting. Therefore it is necessary to analyze the alternative manufacturing methods from an economic point of view for standardized components. Another important decision to make about component is the choice of a supplier. Since different suppliers offer different quantity discounts, prices, lead times, etc. the suppliers who provide the unique components may not be economical for the standardized components. The suppliers need to be re-evaluated for the standardized component.

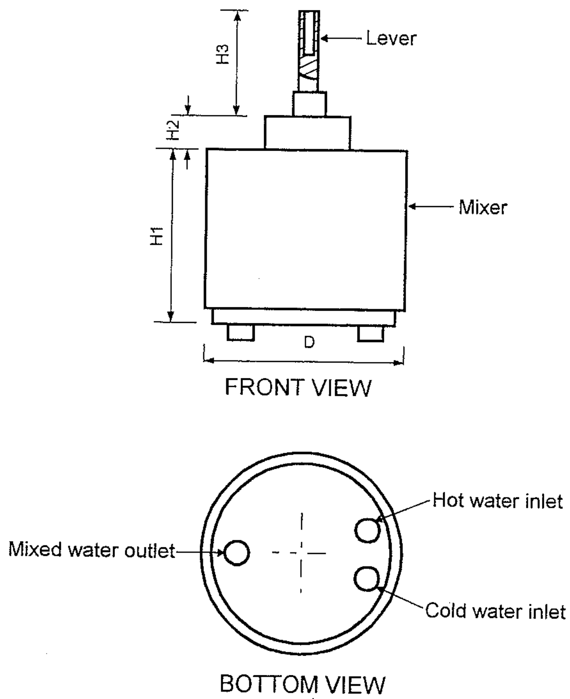

FIGURE 2 Diagram of Cartridge and Major Dimensions.

TABLE I Existing Variants of Cartridge

Variant index	1	2	3	4
Part no.	34033	34057	34050	34058

CASE STUDY

The concepts expressed in the above section were applied to a real life situation. The company concerned was experiencing a price competition together with complicated production control problems. They were interested in the possibility of reducing the complexity by component standardization.

Problem Description

The company is a sanitary fitting manufacturing company and the case study was carried out for a product group consisting two sisters products namely, single lever faucet and single lever shower which are high growing products. Each product has a number of series, models and options such that the single lever faucet has 16 variants and the single lever shower has 26 variants. Even though these products maintained certain degree of component standardization, preliminary studies (marketing and design) showed the potential for some of components to be further standardized if it would be economically viable. The component called cartridge used for mixing hot and cold water is a possible candidate for standardization, which bears 28–31% cost of the single lever faucet and 18–21% cost of single lever shower. The technical managers expect that a significant portion of the manufacturing cost could be saved by standardizing the cartridge. A general design of the cartridge is shown in Figure 2.

Presently, four variants of the cartridge are used to serve the single lever faucet, and single lever shower as in Table I.

Standardization Feasibility of Variants of the Cartridge

By studying the design goals and constraints of the product variants which are served by the above variants of the cartridge, it is found

TABLE II Feasible Alternatives of Standardized Cartridge Variants

Variant index	5* = S(1, 2)	6 = S(1, 2)	7 = S(3, 4)	8 = S(3, 4)
Part no.	34033	34057	34050	34058

*5 = S(1, 2) means that variant 5 is a standardized variant of variants 1 and 2.

that the following sets of component variants are technically feasible to be standardized.

(i) variants 1 & 2
(ii) variants 3 & 4

In each case it is possible to use one of the existing parts as a standardized variant with modification of the main body or some sub-components. This option seems to be more economical than using an entirely new component part as a standardized variant since such an entirely new component requires modification of all the bodies of the product group which would require higher capital investment than the former case. The number of parts to be modified depends on the choice of standardized component. Feasible alternatives of the standardized cartridge variants are shown in Table II. It is to be noted that the part used as component variant 1 is referred to as variant 5 when it is considered to be used as a common component to replace variants 1 and 2. Similarly parts used as variants 2, 3 and 4 are referred to as variants 6, 7, and 8 respectively when they are considered as common components.

Now, the problem faced by the decision-maker is whether components need to be standardized and if they are to be standardized which of the new standardized variants should be selected. In other words one has to select an optimal set of component variants among 1 to 8, for all the products that are originally served by variants 1 to 4.

A Model to Evaluate Component Standardization

In this section, we formulate a cost model which is useful to management to determine whether the standardization is cost effective, and if so which variant to be used as the common component. Such decisions would be based on the total costs to the system under different options. Mathematically it would be a combinatorial optimization problem. However, since the options or the decisions are so few in the present case, the solution would be obtained simply by enumerating the total costs under different variants, and selecting the variant or variant combination that yields the minimum value. In enumerating the total costs, it would be assumed that the system would be operated under optimal conditions for each scenario, and so the cost components would be computed for such optimal conditions. For example, in a scenario where two components are standardized by a common component, the optimal lot size that yields the minimum total running (periodic) cost, which includes purchasing costs and inventory costs, is computed and the vendor whose supply yields this minimum costs is selected for the supply of the component.

The main stages of the total system, which are useful to identify the cost drivers influencing the periodic component cost, and hence the component standardization decision, were shown in Figure 1.

As explained earlier, we can identify three major types of costs related to the components considered for standardization: purchasing cost, or manufacturing cost, inventory cost and assembly cost. In addition to these costs, since some of the related parts are to be modified to accommodate the new standardized components, the relevant modification cost should be considered. For the case considered, the components are obtained from suppliers, and so manufacturing costs are not considered. Similarly, since only the existing component parts are considered to be used as the common components, design and reconfiguration cost are not applicable. All the applicable costs are expressed as per period costs or as periodic equivalent costs for comparison, period being the basic time unit for planning and which in the present case, is taken as a month. The costs considered for the evaluation are presented below.

The following notations are used to in the expressions developed in this section.

Indices

- l — products
- i — variants of component considered for standardization (existing or standardized)
- j — related parts to be modified

Parameters

- A — total assembly cost associated with considered component type per period
- A^0 — fixed assembly cost independent of number of variants
- A^v — variable assembly cost
- ACS_i — savings of assembly cost due to standardized variant i
- $C_i(Q_i)$ — purchasing cost of quantity Q_i of variant i
- D_l — demand of product l per period, period being the time unit for planning
- D_i — demand of variant i per period
- DC_i — equivalent design cost of variant i per period
- E_j — one time investment for modifying part j
- ED_i — one time design cost of variant i
- r — company interest rate per period
- h_i — unit holding cost of variant i per period
- HC_i^c — cycle inventory cost of variant i per period
- HC_i^s — safety stock cost of variant i per period
- IC_j — increased periodic cost of part j due to modification
- k — safety factor of the safety stock for given service level
- L_i — replenishment lead time of variant i
- MC_i — total modification cost of related parts of variant i per period
- MRC_j — equivalent design and reconfiguration cost of modified part j per period
- N — expected life of time of products
- NV — number of variants of component type considered for standardization
- N_i — number of original variants which could be replaced by variant i
- O_i — order cost of variant i per order
- OC_i — total order cost of variant i per period
- PC_i — total purchasing cost of variant i per period
- Q_i — order quantity of variant i
- R — review period
- SS_i — safety stock of variant i
- TC_i — total transportation cost of variant i per period
- $T_i(Q_i)$ — transportation cost of quantity Q_i of variant i
- TPC_i — total running (periodic) cost of variant i
- TSC_i — total cost of variant i per period
- V_j — salvage value of equipment which are obsolete due to modification of part j
- α — service level
- σ_{Di}^2 — demand variance of variant i
- σ_{Dl}^2 — demand variance of product l
- σ_{Li}^2 — lead time variance of variant i
- $\rho_{ll'}$ — coefficient of demand correlation between product l and l′

Sets

- M_i — set of parts to be modified to accommodate variant i
- SP_i — set of products served by variant i

Inventory Costs

The component inventory cost can be divided into: cycle inventory cost and safety stock cost. The cycle inventory is the inventory turnover per cycle and its average value equals the expected demand per period of replenishment cycle. The cycle inventory cost of component variant i per period can be approximated as follows, independent of inventory policy.

$$HC_i^c(Q_i) = \tfrac{1}{2}Q_i h_i \qquad (1)$$

The safety stock mainly depends on factors such as service level, review policy, etc. As mentioned before, the case company maintains two stock points, one each for components and finished products. Presently, the component stock maintains a component safety stock proportional to the standard deviation of the demand of component triggered by the assembly station, which is computed as k times the standard deviation due to component demand and replenishment lead time. Under this situation, reorder levels of the component stock and final product stocks are not coordinated and individual reorder rule is adopted by the both stock points to trigger an order from the previous station.

The safety stock cost of variant i is expressed as follows.

$$HC_i^s = SS_i h_i \tag{2}$$

$$\text{where,} \quad SS_i = k\sigma_i \tag{3}$$

The safety factor k depends on the service level of component i and assuming that the demand of component is normally distributed, the safety factor k is determined such that $\phi(k) = \alpha$. σ_i depends on the inventory review policy and can be expressed as follows (see, for example, Peterson and Silver, 1979):

$$\sigma_i{}^2 = \sigma_{Di}^2 L_i + D_i^2 \sigma_{Li}^2 \quad \text{for continuous review policy} \tag{4}$$

$$\sigma_i^2 = \sigma_{Di}^2 (L_i + R) + D_i^2 \sigma_{Li}^2 \quad \text{for periodic review policy} \tag{5}$$

$$\text{where, } D_i = \sum_{l \in SPi} D_l \tag{6}$$

$$\sigma_{Di}{}^2 = \sum_{l \in SPi} \sigma_{Dl}^2 + 2 \sum_{l \in SPi} \sum_{l' > l} \rho_{ll}' \sigma_{Dl} \sigma_{Dl}' \tag{7}$$

The value expressed in Equation (7) gives the variance of the sum of demands when the demands are correlated, and can be obtained from any standard textbook on statistics.

The company uses the continuos review policy and hence the Equation (4) is applicable in this case.

Purchasing Related Costs

The three categories of purchasing related costs are analyzed:

Purchasing cost (buying cost): The purchasing cost of variant i per period can be expressed as

$$PC_i = C_i(Q_i)\left[\frac{D_i}{Q_i}\right] \tag{8}$$

In the above expression, we consider that purchasing cost depends on the order quantity. This representation is relevant when the quantity discounts are available.

Ordering cost: The ordering cost per order is generally independent of the order quantity. The order cost of variant i per period can be expressed as

$$OC_i = O_i\left[\frac{D_i}{Q_i}\right] \tag{9}$$

Transportation cost: Similar to purchasing cost, transportation quantity discounts are also possible. The transportation cost of variant i per period can be expressed in general as

$$TC_i = T_i(Q_i)\left[\frac{D_i}{Q_i}\right] \tag{10}$$

Assembly Cost

The assembly cost related to a particular component type can be considered as the sum of a fixed amount for the type as whole and a variable cost due to the variety in the type that depends on the number of variants, and is expressed as follows:

$$A = A^0 + A^v.NV \tag{11}$$

It is possible to reduce the assembly cost by using the standardized component variants and saving of assembly cost due to standardized variant i can be expressed as

$$ACS_i = A^v(N_i - 1) \tag{12}$$

It should be noted that this saving could be treated as a negative cost.

Out of above two assembly cost categories, variety cost (A^v) is the important cost for the component standardization decision. By estimating how much assembly cost (variety cost) increases (decreases) by adding (reducing) a component variant to (from) the system, it is possible to determine the variable assembly cost.

Modification Cost of Related Components Caused by Standardization

Total cost of modification can be divided into two cost categories: one time design and reconfiguration cost of modified part and change in running cost. Total modification cost of related parts per period due to standardized variant i can be expressed as follows:

$$MC_i = \sum_{j \in Mi} MRC_j + \sum_{j \in Mi} IC_j \tag{13}$$

By considering the time value of money discounting factor, periodic equivalent design and reconfiguration cost of the modified parts can be expressed as

$$MRC_j = [E_j - V_j]\left[\frac{f(1+f)^N}{(1+f)^N - 1}\right] \tag{14}$$

Total Cost of Component Variant Relevant to Component Standardization

Total cost of a component variant can be divided into several categories. The running (periodic) component cost which is usually known as component cost consists of purchasing and inventory cost. This cost is useful to determine the economic order quantity and to select the component supplier. As mentioned above other costs are design cost, modification cost of related parts and assembly cost (savings).

Total cost of component variant i, which is relevant to component standardization decision can be expressed as

$$TSC_i = TPC_i + MC_i - ASC_i \tag{15}$$

where,

$$TPC_i = PC_i + OC_i + TC_i + HC^c{}_i + HC^s{}_i \quad \text{(periodic component cost)} \tag{16}$$

EVALUATION AND SELECTION OF COMPONENT VARIANTS OF THE CARTRIDGE

There are eight variants of cartridge to be evaluated as in Table III. Out of these cartridge variants, the optimal combination of variants should be selected.

Costs and Other Relevant Data

The costs are given in Baht, the local currency in Thailand in which the company of the case study is located. At the time of the analysis, 1 U.S. Dollar is equivalent to approximately 40 Bahts.

TABLE III Cartridge Variants to be Evaluated

Variant index	1	2	3	4	5 = S(1, 2)	6 = S(1, 2)	7 = S(3, 4)	8 = S(3, 4)
Part no.	34033	34057	34050	34058	34033	34057	34050	34058

Purchasing and Inventory Details of Cartridge

Order cost/order = 2000 Baht

Fixed transportation cost = 10000 Baht (min 1000 items)

Variable transportation cost = 5 Baht/item (over 1000)

Interest = 26% per year

Holding cost = 0.26* (capital cost per unit per year)

Service level = 99.9%

Order policy: continuous review and economic order quantity (R,Q) policy

There are two possible vendors for purchasing the cartridge; details of the prices are given in Tables IV and V.

Lead time:

Vendor1: mean = 1.25 months; std. dev. = 0.5 months

Vendor2: mean = 1 months; std. dev. = 0.5 months

Modification Cost of Related Components

To accommodate the standardized component variants for the products, the bodies of some of the products should be modified. Based on the information provided by the case company, modification costs of the related components are estimated. When analyzing the product design the most significant modification cost is design and reconfiguration cost of the related components and no significant periodic cost is added or reduced to/from the modified component since there are no major modifications of the components which demand different material and processing. However, for the robustness of the decision some sensitivity analysis is later carried out.

The one time investment for modification and salvage value of the equipment due to modification are shown in Table VI.

TABLE IV Prices of Cartridge Vendor 1 (All Unit Quantity Discount)

Quantity	Part number (Variant)			
	34033 (1 & 5)	34057 (2 & 6)	34050 (3 & 7)	34058 (4 & 8)
1000–5000	199.50*	197.75	190.75	189.50
5000–10000	197.13	195.40	188.40	187.23
above 10000	195.51	193.80	186.94	185.71

*Prices in Baht (per/item).

TABLE V Prices of Cartridge Vendor 2 (All Unit Quantity Discount)

Quantity	Part number (Variant)			
	34033 (1 & 5)	34057 (2 & 6)	34050 (3 & 7)	34058 (4 & 8)
1000–10000	198.75	196.50	190.50	189.00
above 10000	194.78	192.57	186.25	185.22

*Prices in Baht (per/item).

Assembly Cost Savings

For the case company, there is no significant benefit to the assembly costs from reducing the number of component variants as the assembly stations are flexible and the change over cost is negligible. The contribution of marginal assembly cost is small compared to other costs involved and hence can be neglected in making a decision on component standardization.

Demand Data of Cartridge Variants

Based on the product demands, monthly demand and demand variance of the above component variants are calculated and presented in Table VII. It is to be noticed that the demand for the common component would be the sum of the demands of the individual components it is replacing. For example, the demand for variant 5 is the sum of the demands of variants 1 and 2. Further, it is assumed that there is no correlation between the demands of products.

TABLE VI Parts to be Modified Due To Standardized Variants and Respective Costs*

Variant index	Part no. to be modified	Description	Investment for modification	Salvage value
5	12039-2, 12040-1, 12041, 12042-1	New cores	9500*4 = 38000	0
6	12012-1, 12013-1, 12026-2, 12036-2, 12014, 12020-1, 12034, 12038	New cores	9500*8 = 76000	0
7	12051	New core	9500	0
	34059	Modify die and new core	18625	0
		Total	28125	0
8	12015, 12016, 12017	New cores	9500*3 = 28500	0

*(Costs are in Baht).

TABLE VII Demand of Cartridge Variants

Variant index (Part no)	1 (34033)	2 (34057	3 34050)	4 (34058)	5 = S(1, 2) (34033)	6 = S(1, 2) (34057)	7 = S(3, 4) (34050)	8 = S(3, 4) (34058)
Mean demand	1563	796	199	44	2359	2359	243	243
Demand var.	15345	4567	877	100	19912	19912	977	977

Solution and Sensitivity Analysis

In this section, models formulated in Section 3.2 and the data presented in Section 4.1 are used to select the most economical cartridge variants. Since there are two vendors for the cartridge, it is required to find the most economical vendor for each variant. (In the analysis, it is assumed that replenishments are uncoordinated among the cartridge variants)

Determination of Economic Order Quantities and Periodic Costs

Economic order quantities and total periodic (monthly) costs of cartridge variants are calculated based on purchasing and inventory details.

Total monthly cost of purchasing part

$$TPC = PC + OC + TC + HC^c + HC^s$$

Purchasing cost, $PC = P.D$ (at price P)

Order cost,

$$OC = O\frac{D}{Q}$$

Transportation cost,

$$TC = [FT + (Q - Q^0)VT]\frac{D}{Q}$$

where, FT = fixed transportation cost, VT = variable transportation cost, and Q' = minimum order quantity (variable transportation cost is charged above Q')

Holding cost, $HC^c = \frac{1}{2}Q.h$

Safety stock cost, $HC^s = SS.h$

$$TPC = P.D + O\frac{D}{Q} + [FT + (Q - Q^0)VT]\frac{D}{Q} + \tfrac{1}{2}Q.h + SS.h \qquad (17)$$

at economic order quantity,

$$\frac{d(TPC)}{dQ} = 0$$

Economic order quantity at price P,

$$Q^* = \sqrt{\frac{2(O + FT - Q^0 \cdot VT)D}{h}} \qquad (18)$$

This is somewhat different from traditional EOQ formula, because the transportation cost is included here. However, since there are quantity discounts and minimum order quantity consideration, economic order quantity derived in Equation (18) cannot be used without considering these aspects.

For example, in Figure 3, in case 1 economic order quantity derived in Equation (18) Q^* is less than the minimum order quantity, Q^0. In this case, it is required to purchase a quantity of Q^0. Similarly in case 2, it is more economical to buy quantity of Q' due to quantity discounts.

For comparison purposes, we use total costs, expressed as monthly equivalents. The costs are obtained under two categories. All the monthly or periodic costs such as holding costs and transportation costs are directly included into the category Total Periodic Costs (TPC), and one-time costs like modification costs are converted to their monthly equivalent costs and then added to the Total Periodic Costs to get the Total Costs. For converting the one-time costs the planning horizon, that is in this case, the estimated remaining life of the product is needed. A remaining life of 3 years is taken for the analysis, as it is the best estimate according to the company. However, the analysis is also carried out for different values to give a complete picture.

An important assumption that was made for the comparison is that any decision or policy will be formulated and carried out under optimal conditions. Hence the relevant costs that are derived represent optimal costs for each situation. Based on this assumption, the order quantities used for all the scenarios are their respective economic order quantities (EOQ).

For computation, the Total Periodic Costs is considered first, and the EOQ that minimizes this cost is derived and the Total Periodic Costs at this EOQ is calculated. Then the monthly equivalent costs of one-time costs are calculated and added to the Total Periodic Costs to obtain the Total Costs.

The data concerning the price for the two vendors is presented in Tables IV, and V, and the demand is shown in Table VII. From these data, Economic Order Quantities, and the corresponding Total Periodic Costs are derived for each vendor. The vendor, whose Total Periodic Cost is minimum, is selected as the supplier for that component, to the given scenario. The selected vendors, the respective EOQ's, and costs are presented in Table VIII. It may be recalled that variants 1, 2, 3, and 4 represent the existing components, and are specified as 5, 6, 7, and 8 respectively when they are used as new standardized components. The results in Table VIII show that it is more economical to purchase the variants 1, 2, 3, 4, 7 and 8 from vendor 2, whereas it is more economical to purchase variants 5 and

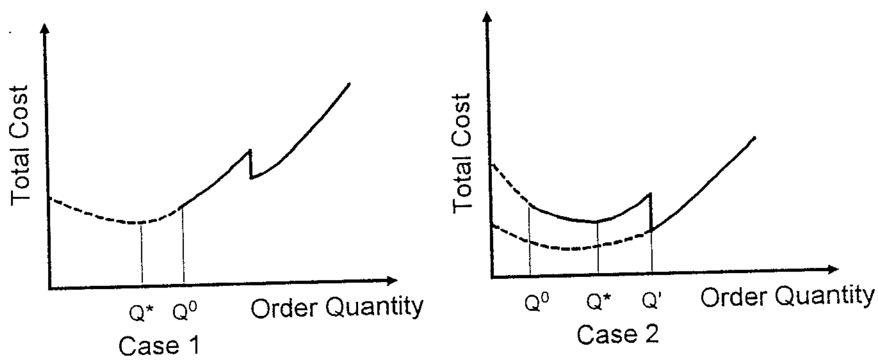

FIGURE 3 Total Cost vs Order Quantity.

TABLE VIII Periodic Costs of Cartridge Variants Under Selected Vendor (in Baht/Month)

Variant (Part No)	1 (34033)	2 (34057)	3 (34050)	4 (34058)	5 (34033)	6 (34057)	7 (34050)	8 (34058)
PC	310,646	156,414	37,820	8,316	465,030	460,949	46,182	45,927
OC	1,387	984	398	88	944	944	486	486
TC	11,282	6,440	1,990	440	14,154	14,154	2,430	2,430
HC^C	4,854	3,444	2,059	2,048	10,678	10,584	2,059	2,049
HC^S	10,529	5,311	1,321	306	15,706	15,568	1,596	1,587
TPC	338,697	172,593	43,588	11,197	506,511	502,198	52,753	52,478
Lot size	2,254	1,618	1,000	1,000	5,000	5,000	1,000	1,000
Vendor	2	2	2	2	1	1	2	2
Unit Price	198.75	196.5	190.05	189.00	197.13	195.40	190.05	189.00

6 from the vendor 1. So, when variants 1 and 2 are standardized and are used as the standardized component variants (i.e. as variants 5 and 6), changing the vendor from 2 to 1 is economical. This is a case in point where the component standardization necessitates the contemplation of changes in the overall logistics decisions. Further analysis in this section is based on the selected vendors. However, in actual implementation, the vendor selection is also based on additional factors such as vendor reliability, quality, etc. At the computed level of EOQ, the other periodic costs are calculated and these values can be seen in the same Table VIII.

The comparison of periodic costs is shown in Table IX, as savings in the costs if the common components are used. The savings for variant 5, for example, would represent its savings compared to the variants 1 and 2, which it is to replace. From the figures it can be seen that for all the standardized components, there is a positive saving in TPC. This is in line with the general belief that if the purchasing costs of the standardized component are not too high, then there could be considerable efficiency in terms of costs in all phases of operations. In this particular case, there were savings in purchasing costs (PC) also due to quantity discounts. It may be pointed out that the savings in certain categories may be higher than the savings in total inventory related costs, which as noted, has been the main subject of analysis in literature. In the case study, the savings in cycle inventory costs were sometimes even negative due to larger lot sizes prompted by quantity discounts.

TABLE IX Savings of Periodic Cost Due to Standardization (in Baht/Month)

Variant index. (Part no.)	5 = S(1, 2) (34033)	6 = S(1, 2) (34057)	7 = S(3, 4) (34050)	8 = (3, 4) (34058)
PC	2,031	6,112	−46	209
OC	1,427	1,427	0	0
TC	3,568	3,568	0	0
HC^C	−2,380	−2,287	2,048	2,059
HC^S	134	272	30	39
TPC	4,779	9,092	2,032	2,307

Periodic Equivalent Modification Cost

The one-time (present) expenses are now converted to periodic (monthly) equivalent costs to be compatible with the Total Periodic Costs. For the case study, there is only one cost in this category, the modification costs of related parts. Based on one-time costs shown in Table VI, their monthly equivalents are computed for different values of remaining product life and are presented in Table X.

Since, there are no major modifications of the related parts, it is assumed that there is no periodic incremental cost. However, in the preceding section sensitivity analysis will be carried out to investigate the robustness of the decision.

TABLE X Monthly Equivalent Modification Cost of Related Components (Baht/Month)

Product life (months)	Variant no. and part no. used as standardized component variant			
	5 34033	6 34057	7 34058	8 34050
6	6,822	13,644	5,049	5,117
12	3,630	7,260	2,687	2,723
18	2,572	5,144	1,904	1,929
24	2,047	4,094	1,515	1,535
30	1,736	3,472	1,285	1,302
36	1,531	3,062	1,133	1,148
42	1,387	2,774	1,027	1,040
48	1,281	2,563	948	961
54	1,201	2,401	889	900
60	1,138	2,275	842	853

Total Cost

The total cost is the sum of Total Periodic Costs (expressed per month) and the monthly equivalent costs of one-time costs. Since the equivalent modification cost varies with the expected life of the products, the relevant total cost of the standardized variants varies with the lifetime of products. Table XI shows total costs of standardized component variants. The total costs are, of course, very high, for low values of remaining product life.

Selection of Component Variants

The selection of component variants is now done based on the total costs. In the case of existing variants (1, 2, 3, and 4), the applicable cost is only the periodic component cost (TPC).

Sum of total cost of variants 1 and 2 = 511290 Baht/month

Sum of total cost of variants 3 and 4 = 54785 Baht/month

These costs are compared with the total costs of standardized variants. The comparison concentrates on total costs based on a remaining life of 3 years, as it is the most expected value. It can be seen that it is economical to standardize variants 1 and 2 and use variant 6 (part no. 34057) as the common component, and also to standardize variants 3 and 4 and use variant 8 (part no. 34058) as the common component. It may be stressed that the even though the savings in this case is only as little as 1% of the total cost, it would be much higher in terms of profit, and in any case, the above selection is recommended only if a purely economic criterion is used as the sole criterion.

The Table XI also provides necessary information for the decision-makers to achieve the standardization decision under various remaining life periods of the product group. As would be expected, standardization option becomes more attractive as the assumed value of remaining life

TABLE XI Total Costs of Standardized Variants and Optimal Set of Variants for Different Remaining Life Times

Remaining life (months)	Total cost (Baht/month)				Optimal set of variants	Total savings (B/month)
	5 = S(1, 2) 34033-common	6 = S(1, 2) 34057-common	7 = S(3, 4) 34050-common	8 = S(3, 4) 34058-common		
6	513,333	515,842	57,803	57,595	1, 2, 3, 4	0
12	510,141	509,458	55,440	55,201	3, 4, 6	1,832
18	509,083	507,342	54,657	54,407	6, 8	4,326
24	508,558	506,293	54,269	54,013	6, 8	5,769
30	508,247	505,670	54,038	53,780	6, 8	6,626
36*	508,042	505,260	53,886	53,626	6, 8	7,189
42	507,898	504,972	53,780	53,518	6, 8	7,584
48	507,792	504,761	53,702	53,439	6, 8	7,876
54	507,711	504,599	53,642	53,378	6, 8	8,097
60	507,648	504,474	53,595	53,331	6, 8	8,270

*Expected remaining life of the product group by the company.

increases. In fact, this option becomes more economical for as little as 12 months in the case of the first group, and 18 months in the case of second group of components. Considering the fact that the most expected value for remaining life is 36 months, it can asserted that the risk in decision making in favor of the standardized component is not high as far the assumption about the remaining life is concerned.

Sensitivity Analysis

In the above analysis, we have assumed that all the data are certain and accurate. However, we recognize that the information available may be uncertain and inaccurate due to estimation errors and unforeseeable future fluctuations. Therefore, it is important to carry out sensitivity analysis for check the robustness of the decision. Sensitivity analysis has been carried out for three types of costs, keeping the value of the remaining life at 3 years. The costs are:

(i) Periodic costs (i.e. order cost, transportation cost, holding cost, and price)
(ii) Incremental running cost of modified parts
(iii) One time modification cost for modified parts.

Sensitivity analysis was done for periodic costs and incremental costs for a range of −10% to +10% of error of estimated values. In the case of one time modification cost, the range was from −80% to +80% of error of estimated value. The broader range for this third case reflects the sentiments of the management that it is very hard to get an accurate estimate of the modification cost. According the results, the decisions made on the basis of estimated costs are less sensitive to the periodic cost and one time modification cost. However, the decisions are sensitive to the running costs of modified parts. If the costs of modified parts increase, variants 5 and 7 should be used as the standardized variants instead of variants 6 and 8. This is due to the fact that variants 5 and 7 require only a few parts to be modified, at low costs, to accommodate them as the standardized components. The corresponding results are shown in Table XII for variants 1 and 2, and in Table XIII for variants 3 and 4.

TABLE XII Sensitivity Analysis of Costs of Cartridge Variants (1 + 2), 5 and 6

Type of error	Range analyzed	Decision
% Error in periodic cost	−10%–10%	Variant 5 can be used as the standardized component for whole range analyzed
% Change in cost in modified parts	−10%–10%	−10% to 2.5%: variant 6 should be used as the standardized component 2.5% to 10% variant 5 should be used as the standardized component
% Error in one time modification cost	−80%–80%	Variant 5 can be used as the standardized component for whole range analyzed

TABLE XIII Sensitivity Analysis of Costs of Cartridge Variants (3 + 4), 7 and 8

Type of error	Range analyzed	Decision
% Error in periodic cost	−10%–10%	Variant 7 can be used as the standardized component for whole range analyzed
% Change in cost in modified parts	−10%–10%	−10% to 1%: variant 8 should be used as the standardized component 1% to 10% variant 7 should be used as the standardized component
% Error in one time modification cost	−80%–80%	Variant 7 can be used as the standardized component for whole range analyzed

CONCLUSIONS

For decisions regarding using common components so as to achieve cost efficiency in presence of product variety, relevant costs need to be analyzed. The bulk of the past research studies in component standardization have given emphasis to safety stock benefits only, however, some other benefits such as quantity discounts, savings in order cost and transportation costs, manufacturing related costs etc., need to be considered. At the same time decision-makers need to be aware that component standardization efforts may have adverse effects on total costs, due to high costs of components, designs, and any modification to designs of other components necessitated by the introduction of common parts. Hence any decision making based on costs need to consider the total costs to the system with or without the common components. This paper has shown the modeling approach to some of the most significant cost components in the total costs. Relevant situations and mathematical formulas were presented to obtain these costs.

A case study was presented to test the viability of the approach. It was found that for the case, manufacturing costs are irrelevant as the parts of interest are purchased parts. Besides the well established benefits of decrease in costs of safety stocks, there could be significant savings in other costs like quantity discounts, order costs, and transportation costs. However, it should be noted that the benefits of standardization may not simultaneously occur in all the categories of costs. Costs of some categories may even go up. As shown in Table IX, when the variants 5 and 6 are used, savings of cycle inventory costs are negative, under economic order quantity. This is due to the fact that purchasing larger lots with quantity discount is more beneficial, but larger lots would increase the cycle inventory costs. For standardization decisions, the management should be ready to change its existing suppliers and sources to achieve cost effectiveness. Standardization would result in larger lots, and that may show that the company may be better off manufacturing the part as opposed to the current practice of outsourcing, and vice versa. Or the larger lots may show that the company needs to change the suppliers. For the company in case study, it shows that the actual supplier in terms of costs, would depend on the component chosen as the standard component. If the company is striving for overall efficiency in an well-coordinated way, it should be aiming at reducing the overall costs for any decisions pertaining to commonality.

References

Baker, K. R., Magazine, M. J. and Nuttle, H. L. W. (1986). The Effect of Commonality on Safety Stock in a Simple Inventory Model. *Management Science*, **32**(8), 982–988.

Collier, D. A. (1981). The Measurement and Operating Benefits of Component Part Commonalty. *Decision Science*, **12**(1), 1296–303.

Collier, D. A. (1982). Aggregate Safety Stock Levels and Component Part Commonality. *Management Science*, **28**(11), 1296–1305.

Dogramaci, A. (1979). Design Common Components Considering Implications of Inventory Costs and Forecasting. *AIIE Transactions*, June, pp. 129–135.

Van Donsellar, K. (1990). Integral Stock Norms in Divergent Systems with Lot-Sizes. *European Journal of Operational Research*, **45**, 70–84.

Van Donsellar, K. and Wijngaard, J. (1987). Commonality and Safety Stocks, Engineering. *Costs and Production Economics*, **12**, 197–204.

Eynan, A. and Rosenblatt, M. J. (1996). Component Commonality Effects on Inventory Costs. *IIE Transactions*, **28**, 93–104.

Gerhack, Y. and Henig, M. (1986). An Inventory Model with Component Commonality. *Operation Research Letters*, **5**(3), 157–160.

Glassworth, G. D. (1994). *Smart, Simple Design Using Variety Effectiveness to Reduce Total Cost and Maximize Customer Selection*. Oliver Wrigth Publications, Inc., USA.

Hillier, M. S. (1992). The Effect of Commonality on Overall Costs in a Simple Inventory Model. *Working Paper*, Department of Industrial and Engineering Management, Stanford University, USA.

Hwang, H., Moon, D. and Shinn, S. W. (1990). An EOQ Model with Quantity Discounts for Both Purchasing Price and Freight Cost. *Computers and Operation Research*, **17**(1), 73–78.

Jucker, J. V. and Rosenblatt, M. J. (1985). Single-Period Inventory Models with Demand Uncertainty and Quantity Discounts: Behavioral Implications and a New Solution Procedure. *Naval Research Logistic Quarterly*, **32**, 537–550.

Lee, H. L. and Sasser, M. M. (1995). Product Universality and Design for Supply Chain Management. *Production Planning & Control*, **6**(3), 270–277.

Lippman, S. A. (1969). Optimal Inventory Policy with Multiple Set-up Costs. *Management Science*, **16**, 118–138.

Perera, H. S. C., Tabucanon, M. T. and Nagarur, N. (1997). Component Part Standardization: A Way to Reduce the Life-Cycle Costs of Products, Proceedings of the 14th

International Conference on Production Research, Osaka Japan, pp. 1514–1517.

Perera, H. S. C., Nagarur, N. and Tabucanon, M. T. (1999). Component Part Standardization: A Way to Reduce the Life-Cycle Costs of Products. *International Journal of Production Economics*, **60–61**, 109–116.

Thomas, L. D. (1992). Functional Implications of Component Commonality in Operation Systems. *IEEE Transcations on Systems, Man, and Cybernetics*, **22**(3), 548–551.

Thonemann, U. W. and Brandeau, M. L. (1997). Optimal Commonality in Component Design. *Working Paper*, Department of Industrial and Engineering Management, Stanford University, USA.

Biographical Sketches

H. S. C. Perera is a Senior Lecturer in Department of a Mechanical Engineering, University of Moratuwa, Sri Lanka. He received his bachelor's degree in mechanical engineering from University of Moratuwa, Sri Lanka (1990), master's degree in manufacturing systems engineering (1995) and doctoral degree in industrial engineering (1999), both from Asian Institute of Technology, Thailand. His research interests include operations and production management, and productivity analysis and improvements.

Nagen Nagarur is an Associate Professor in the Industrial Systems Engineering Program, Asian Institute of Technology, Thailand. He has a bachelor's degree in chemical engineering from Regional Engineering College, Waranga, India, a masters degree in Industrial Engineering from Wichita University, U.S.A., and a Ph.D. degree in industrial engineering and operations research from Virginia Tech, U.S.A. For the last ten years, he has been teaching at the Asian Institute of Technology, and he has several publications in the areas of production management, maintenance, and simulation. His current interests include strategies of flexibility and component commonality, and coordination in supply chains.

Mario T. Tabucanon is Provost and Professor of Industrial Systems Engineering, Asian Institute of Technology (AIT). He has been a faculty member of AIT since July 1978 and has held the positions of Vice President (Academic) from September 1998 to June 1999, Dean of the School of Advanced Technologies from September 1995–1998, and Chairman of the then Division of Industrial Engineering and Management from August 1986 to 1989. He obtained his education from the Cebu Institute of Technology (B.S.E.E. and B.S.M.E.) and the Asian Institute of Technology (M.Eng. and D.Eng.) He is an Editor of the International Journal of Production Economics, Associate Editor of the Journal of Manufacturing Systems, and Editorial Board Member of ten other international journals.

View publication stats