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THE APPLICATION OF PRODUCT PLATFORM DESIGN TO THE REUSE OF ELECTRONIC COMPONENTS SUBJECT TO LONG-TERM SUPPLY CHAIN DISRUPTIONS

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ABSTRACT

Component reuse in multiple products has become a popular way to take advantage of the economies of scale across a family of products. Amongst electronic system developers there is a desire to use common electronic parts (chips, passive components, and other parts) in multiple products for all the economy of scale reasons generally attributed to platform design. However, the parts in electronic systems (especially those manufactured and supported over significant periods of time), are subject to an array of long-term lifecycle supply chain disruptions that can offset savings due to part commonality depending on the availability of finite resources to resolve problems on multiple products concurrently. In this paper we address the application of product platform design concepts to determine the best reuse of electronic components in products that are subject to long-term supply chain disruptions such as reliability and obsolescence issues. A detailed total cost of ownership model for electronic parts is coupled with a finite resource model to demonstrate that, from a lifecycle cost viewpoint, there is an optimum quantity of products that can use the same part beyond which costs increase. The analysis indicates that the optimum part usage is not volume dependent, but is dependent on the timing of the supply chain disruptions. This work indicates that the risk and timing of supply chain disruptions should be considered in product platform design.

Keywords: Platform design, design reuse, electronics, total cost of ownership, lifecycle cost, supply chain

1 INTRODUCTION

Conventional wisdom dictates that the reuse of design components across a family of products generally leads to cost reductions and should be encouraged. Platform design (design reuse) means that a common platform is reused across a product family, where a platform is a set of common components, modules, or parts, which are shared within a product family, [1]. The concept of platforms is commonly used in the automotive, computer, aircraft and other industries. The potential advantages of multiple products using a common platform include reductions in [2]: inventory, part proliferation, design lead-time, and the number of different manufacturing (assembly) processes required. Platforms are in essence a policy of component reuse that attempts to take advantage of the economies of scale across a family of products, [3].

Many aspects of platform design have been addressed in the literature, [4-8]. Existing work on platform design can be divided into three general categories: 1) Platform Specification - for a given set of products, find the optimum platform [3]. Products within a product family may share common features and can be divided into sub-categories called "variants". The commonality shared between products across a class or market segment is referred to as "leveraging" [3]. The leveraging strategy implemented depends on balancing performance criteria with a desired level of standardization. 2) Product Family Optimization – This method is divided into two categories, top-down and bottom-up approaches [9]. For a given platform, one may design a product family or estimate an optimum set of products that should be used for a given platform. This is referred to as a top-down approach [9]. The bottom-up approach involves finding the optimum platform for a given set of products where product architectures and components are extracted from existing products for reuse in subsequent products [9], i.e., optimizing the platform content (common components and architectures). 3) Number of Platforms - For a wide market segment, what is the optimum number of platforms to use [3]?

The particular problem addressed in this paper is the following: We have a large database of parts, a subset of which could be used to fulfill a design requirement that is common to multiple products. We wish to benefit from the advantages offered by reusing the same part (i.e., "common component" as defined in [10]) in multiple products as opposed to using different parts to fulfill the same design requirement. We essentially have a platform consisting of one part and we want to determine, what the optimum product family for this platform is. For the context addressed in this paper, the potential drawbacks to using the same part in multiple products are finite resource limitations caused by the risk and timing of long-term supply chain disruptions for the common part. Long-term supply chain disruptions refers to problems that make it impossible for an organization to continue using the part, e.g., reliability issues, changes made to the part by the part manufacturer, and unforeseen obsolescence of the part that make it un-procurable.[1] Unlike many non-electronic parts, electronic parts are generally not custom produced for customers and they are quickly obsoleted (see Section 2). Therefore it is not uncommon for parts and supply chains to change outside the control of all but the largest customers. Because the type of supply chain constraints we are focused on are part-specific, not product-specific, and because we are interested in optimizing the breadth of use of the part, the cost that is minimized is the total ownership cost of the part as used across multiple products. This differs from previous platform design approaches that have sought to minimize the cost of a family of products. In our case, product-specific data is included (e.g., manufacturing volumes as a function of time, end of product support, etc.), but it is the cost of ownership of the part that is minimized. Unlike most previous platform design work, we are also dealing in detail with a lifecycle cost, as opposed to a manufacturing cost. The lifecycle cost is composed of non-recurring design and part selection/qualification activities, product manufacturing activities, product field support activities, and long-term supply chain disruptions.

The model proposed by Huang, et al. [11] quantifies platform design benefits by comparing supply chain cost at varying levels of product platform commonality. This is done by assessing the supply chain in its entirety; a supply chain cost and inventory level is calculated at each stage of the supply chain to obtain a total supply chain cost. Su, et al. [12] propose a method for calculating the total supply chain cost and customer waiting times in order to study the performance of mass customization postponement structures (time postponement and form postponement). Huang et al. and Su et al. provide a complete view of the supply chain from a manufacturing organization's viewpoint, however, it is insufficient for assessing long-term disruptions during the part's lifecycle since it does not account for field failures, maintenance, and manufacturing defects that play a role in warranty returns and product reliability decisions (post-manufacturing problems). Rather than considering a particular supply chain configuration, this paper will discuss the use of a total ownership cost model from a part rather than a product view to minimize the lifecycle cost associated with part reuse. The approach used by the total ownership cost model is to consider all expenses incurred by an OEM organization in addressing long-term supply chain problems over the life of an electronic part.

In the next section, we will describe the problem addressed in this paper in more detail. In subsequent sections, the part total ownership cost model will be described and example results for different part usage scenarios provided.

2 THE ELECTRONIC PART SELECTION AND REUSE PROBLEM

Electronic systems OEMs (Original Equipment Manufacturers) maintain databases that consist of hundreds of thousands of electronic parts, [13]. There is a desire to reuse parts in multiple products for all the economy of scale reasons generally attributed to platform design. In addition, there are several other advantages of commonizing electronic parts that include: reduction in the number of Product Change Notices (PCNs) that must be managed, reductions in part-specific qualification testing, and consolidation of obsolescence resolution and in some cases subsequent lifetime buys.

PCNs are issued by electronic part manufacturers to indicate that their part, or the process for fabricating their part, has changed. In 2006, over 340,000 PCNs were issued for active and passive electronic parts [14] where the changes ranged from modifications to the part marking and delivery packaging, to parametric changes and lead finishes. Over 18% of all the procurable electronic parts will have PCNs issued on them in any given year, [14]. The change indicated by a PCN on a part used in a particular product may or may not be relevant, but every PCN must be evaluated to determine if action is needed. Electronic parts are also subject to high-frequency involuntary procurement obsolescence, [15]. Many electronic parts are only procurable from their original manufacturer for a few years, then they are discontinued in favor of newer, higher performing parts – approximately 3% of the global pool of electronic parts become obsolete every month, [16]. When parts become obsolete, considerable resources must be expended to resolve the problem.

A potential drawback of reusing the same component in multiple products that has been articulated by electronics system manufactures is described by the following scenario: All of your products use (depend on) a common part. An unexpected problem develops with the part. Instead of fighting a fire for one product, you are simultaneously in trouble on every product, i.e., you may have effectively created a "single point of failure" scenario by reusing the part. This situation occurs, for example, when the part becomes obsolete and an acceptable resolution must be found for each of the products that use the part – note, a resolution that is acceptable for one product may not always be acceptable to another. This scenario becomes an issue when there are a specific finite set of resources available to resolve problems across all products, which is often the case after a product enters manufacturing. Those resources cannot address every product simultaneously and as a result manufacturing or support delays occur. It is not the fact that problems with parts occur – they always will, it is not that there are insufficient resources to solve all the problems, it is the timing

[1] Shorter-term supply chain issues encountered by product manufacturing organizations such as lead-time, inventory, bad lot problems are not the focus of this paper. This paper focuses on optimal part management for part selection and management organizations within electronic systems OEMs (Original Equipment Manufacturers). Electronic systems OEMs such as Ericsson, Motorola, Honeywell, etc., have part selection and management groups who's primary focus is identifying and selecting parts, qualifying the manufacturers and distributors of those parts, qualifying the parts for specific products, determining the procurement status of the parts, creating and managing purchase orders for the parts, dealing with part reliability issues if and when they occur, maintaining the parts in databases, and resolving long-term availability problems with the parts. Individual product manufacturing is generally performed by other organizations (external or internal) that are outside the control or role of the part selection and management groups.

of the problems – there are not sufficient resources to solve all the problems simultaneously. Finite resources (people, equipment, etc.) to address problems becomes an issue when multiple problems or the same problem in multiple products occur concurrently and the resolution to one or more problems or products has to be delayed due to a lack of resources.

Several types of supply chain problems can occur. Short-term (temporary) problems that usually only affect a limited number of products that share the part for a short period of time, e.g., you receive a bad *batch* or *lot* of parts. Lead-time issues and inventory management are considered to be temporary supply chain disruptions that impact a manufacturing or product-specific organization, and are therefore not the focus of this paper. Long-term problems such as a fundamental supply chain or wear out problem that affects all products that share the part and for which a permanent solution (often a replacement part) must be found. Examples of long-term problems are discontinuance of the part (obsolescence), a functional design error in the part, and a reliability problem with the part. For long-term problems, under some conditions, the financial penalties associated with the delays may offset savings due to part commonality.

3 PART TOTAL OWNERSHIP COST MODEL

Total ownership cost modeling requires an understanding of the product's lifecycle costs.[2] Lifecycle cost represents the total cost of acquisition and ownership of a product over its full life, including the cost of planning, development, acquisition, operation, support, and disposal. General lifecycle cost analysis of products has been treated by many authors, e.g., [17] and [18]. The context of this paper is electronic parts for which lifecycle costs (besides procurement) include the assessment of part manufactures and distributors [19], qualifying and screening parts [20], the impacts of part reliability [21], warranty [22], sparing and availability, obsolescence management [23], and maintenance [24].

The new cost model described in this paper was developed from the part management organization perspective (as opposed to the product management or manufacturer perspective) and is intended to enable fundamental product-independent part management decisions such as retirement of parts from databases, organizational adoption of new parts, management of part-specific long-term supply chain disruptions, etc. Therefore, the model requires an understanding of the total ownership cost of a part. Existing models are manufacturing or product specific. The new model must comprehend long-term supply chain constraints that are associated with specific parts and flow down to products through their parts, therefore the cost that we wish to minimize is the effective total ownership cost of the part as used across multiple products.

The new part total ownership cost model is composed of the following three sub-models: maintenance model, manufacturing model, and a field use model. This model contains both manufacturing/procurement costs and lifecycle costs associated with using the part in products. The complete formulations of the models are too voluminous for inclusion in this paper; however, the following subsections describe the basic content and features of each of these sub-models.

[2] In this paper the effective total ownership cost refers to the lifecycle cost of the part from the part customer's point of view, which should not be confused with Cost Of Ownership (COO), which is a manufacturing cost modeling methodology that focuses on the fraction of the lifetime cost of a facility consumed by an instance of a product.

3.1 MAINTENANCE MODEL

The maintenance model captures all non-recurring costs associated with selecting, qualifying and purchasing the part (these costs may recur annually, but do not recur for each part instance). The total maintenance cost in year i (in year 0 dollars) is given by,

$$C_{maint_i} = \frac{\left(C_{ia_i} + C_{pa_i} + C_{as_i} + C_{ps_i} + C_{ap_i} + C_{or_i} + C_{nonPSL_i} + C_{design_i}\right)}{(1+d)^i} \quad (1)$$

where

C_{ia_i} = initial part approval and adoption cost. All costs associated with qualifying and approving a part for use (i.e., setting up the initial part approval). This could include reliability and quality analyses, supplier qualification, database registration, added NRE for part approval, etc. The approval cost occurs only in year 1 (i = 1) for each new part.

C_{pa_i} = product-specific approval and adoption. All costs associated with qualifying and approving a part for use in a particular product. This approval cost would occur exactly one time for each product that the part is used in and is a function of the type of part and the approval level of the part within the organization when the product is selecting the part. This cost depends on the number of products introduced in year i that use the part.

C_{as_i} = annual cost of supporting the part within the organization. All costs associated with part maintenance activities that occur for every year that the part must be maintained in the organization's part database such as database maintenance, PCN (product change notice) management, reclassification of parts, and services provided to the product sustainment organization. This cost depends on the part's qualification level, which can change over time.

C_{ps_i} = all costs associated with production support and part maintenance activities that occur every year that the part is in a manufacturing (assembly) process for one or more products such as volume purchase agreements, services provided to the manufacturing organization, reliability and quality monitoring, and availability (supplier addition or subtraction).

C_{ap_i} = purchase order generation cost, which depends on the number of purchase orders in year i.

C_{or_i} = obsolescence case resolution costs - only charged in the year that a part becomes obsolete.

C_{nonPSL_i} = setup and maintenance for all non-PSL (Preferred Supplier List) part suppliers – depends on the number of non-PSL sources used.

C_{design_i} = non-recurring design-in costs associated with the part – only charged in years of new product introduction using the part; includes: cost of new CAD footprint and symbol generation if needed.

d = discount rate on money.

i = year – starting at year 0.

C_{ia_i}, C_{pa_i}, C_{as_i}, and C_{ps_i} are determined from an activity based cost model in which cost activity rates can be entered or calculated by part type.[3]

3.2 MANUFACTURING MODEL

The manufacturing model captures all the recurring costs associated with the part: purchase price, assembly cost (assembly into the system), and recurring functional test/diagnosis/rework costs. The total manufacturing cost (for all products) in year i is given by,

$$C_{manuf_i} = \frac{N_i C_{out_i}}{(1+d)^i} \tag{2}$$

where

N_i = total number of products manufactured in year i

C_{out_i} = output cost/part from the model shown in Figure 1. C_{out} is a function of C_{in}

C_{in_i} = incoming cost/part $= P_i + C_{a_i}$

P_i = purchase price of one instance of the part in year i

C_{a_i} = assembly cost of one instance of the part in year i.

This model uses a previously developed test/diagnosis/rework model for electronic systems assembly process modeling described in Figure 1 and Table 1, [25]. The approach includes a model of functional test operations characterized by fault coverage, false positives, and defects introduced in test, in addition to rework and diagnosis (diagnostic test) operations that have variable success rates and their own defect introduction mechanisms. The model accommodates multiple rework attempts on any given product and enables optimization of the fault coverage and rework investment during manufacturing tradeoff analyses.

The model discussed in this paper contains inputs to the test/diagnosis/rework model that are specific to the part type and how the part is assembled (automatic, semi-automatic, manual, pre-mount, after mounting, after mounting SAC, extra visual inspection, special ESD handling – see [26]). The output of the model is the effective procurement and assembly cost per part site. This model assumes that all functional and assembly introduced part-level defects are resolved in a single rework attempt, i.e., Y_{rew} = 1 (which implies only a single rework attempt is needed), that there are no defects introduced

[3] Part type definition are: Type 1 – resistors, capacitors, inductors, and mechanical parts; Type 2 – integrated circuits, oscillators, filters, board connectors; Type 3 – ASICs, RF connectors, RF integrated circuits, DC/DC, synthesizers, opto TRX; and Type 4 – RF transistors, circulators, isolators.

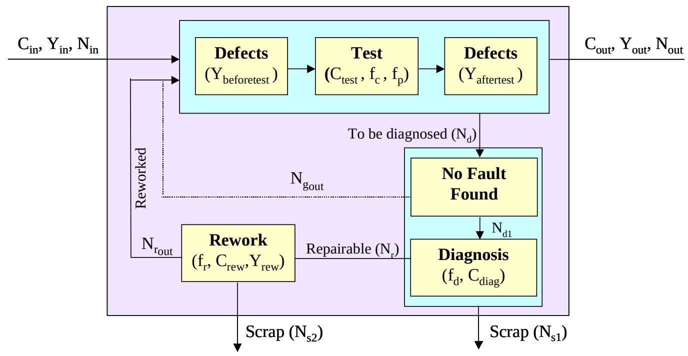


Figure 1. Test/diagnosis/rework model. Table 1 describes the notation appearing in this figure.

Table 1. Nomenclature used in Figure 1

C_{in}	Cost of a product entering the test/diagnosis/rework process	N_{in}	Number of products entering the test/diagnosis/rework process
C_{test}	Cost of test/product	N_d	Total number of products to be diagnosed
C_{diag}	Cost of diagnosis/product	N_{gout}	Number of no fault found products
C_{rew}	Cost of rework/product	N_{d1}	$N_d - N_{gout}$
C_{out}	Effective cost of a product exiting the test/diagnosis/rework process	N_r	Number of products to be reworked
f_c	Fault coverage	N_{rout}	Number of products actually reworked
f_p	False positives fraction, the prob-ability of testing a good product as bad	N_{s1}	Number of products scrapped by diagnosis process
f_d	Fraction of products determined to be reworkable	N_{s2}	Number of products scrapped during rework
f_r	Fraction of products actually reworked	N_{out}	Number of a products exiting the test/diagnosis/rework process, includes good products and test escapes
Y_{in}	Yield of a product entering the test/diagnosis/rework process	$Y_{aftertest}$	Yield of processes that occur exiting the test
$Y_{beforetest}$	Yield of processes that occur entering the test	Y_{out}	Effective yield of a product exiting the test/diagnosis/rework process
Y_{rew}	Yield of the rework process		

by the testing process, i.e., $Y_{beforetest} = Y_{aftertest} = 1$, and that there are no false positives in testing, i.e., $f_p = 0$. These yield assumptions guarantee that Y_{out} will always be 1.

3.3 FIELD USE MODEL

The field use model captures the costs of warranty repair and replacement due to product failures associated with the part. Equation (3) gives the field use cost in year i assuming that no product instance fails more than once during its field life.

$$C_{\text{field use}_i} = \frac{\left(N_{f_i}(1-f)C_{repair} + N_{f_i} f C_{replace} + N_{f_i} C_{proc_i}\right)}{(1+d)^i} \qquad (3)$$

where

N_{f_i} = number of failures under warranty in year i. This is calculated from 0-6, 6-12 and > 12 month FIT rates for the part, the warranty period length (an ordinary free replacement warranty is assumed), and the number of parts sites that exist during the year.

f = fraction of failures requiring replacement (as opposed to repair) of the product.

C_{repair} = cost of repair per product instance

$C_{replace}$ = cost of replacing the product per product instance

C_{proc_i} = cost of processing the warranty returns in year i.

3.4 LIFETIME BUYS

As discussed in Section 2, electronic parts become obsolete quickly and are no longer procurable for manufacturing in as little as 18 months from their introduction. When an electronic part in a high-volume product becomes obsolete, there are two viable resolution actions that can be taken: 1) replace the part with a newer part, or 2) buy enough parts to satisfy your future needs and store them until they are needed (lifetime buy), [27]. Replacement of the part carries with it potentially significant costs associated with finding a new part, approving the part for use possibly qualifying the supplier of the part, and product-specific qualification tests.

When the obsolescence events are resolved using lifetime buys, in order to include the costs of lifetime buys, the number of years to obsolescence (YTO) must be determined,

$$\text{YTO} = \left(1 - \frac{L}{6}\right) T_{PL} \qquad (4)$$

where,

L = lifecode for the part in year 0, L =1 (introduction), 2 (growth), 3 (maturity), 4 (decline), 5 (phase out), and 6 (obsolete), [28,29]. Commercially available databases provide lifecodes for electronic parts.

T_{PL} = total procurement lifespan of a particular part type in years.

When the year of obsolescence occurs, a procurement of all remaining part (plus a buffer quantity, usually ~10% of expected need) happens in that year at that year's part price. In subsequent years the cost of procuring parts becomes zero, but the cost of inventory for the lifetime buy of parts is included.

Note, the type of obsolescence modeled in this section assumes that sufficient warning is received prior to the obsolescence event to enable a lifetime buy of the part. This is not always the case, some obsolescence events occur as unexpected long-term supply chain disruptions for which no warning is provided.

3.5 MODEL INPUTS

A part usage profile is provided as an input to the models. The profile describes the number of products using the part in each year and the total quantity of parts consumed by manufacturing each year. In all cases, inflation or deflation in cost input parameters can be defined (electronic part prices generally decrease as a function of time). Figure 2 shows a summary of inputs to the model that correspond to the example analysis presented in Section 5.

4 FINITE RESOURCE MODEL

A finite resource model has been developed to allow the assessment of the cost impacts of a part-specific problem occurring at a future point in time (at a user defined date). The effective finite resource limited cost of resolving a problem j quarters after the problem is introduced at date D is,

$$C_{FRM_j} = \frac{\left(N_{R_j} C_{res} + \left(N_{RT} - \sum_{k=1}^{j} N_{R_k}\right) C_{unres}\right)}{(1+d)^{D+j/4}} \qquad (5)$$

where

N_{R_j} = number of problems (products) resolved in quarter j (determined from the resolution rate dictated by the available resources)

C_{res} = cost of resolving the problem for one product

N_{RT} = effective total number of full resolutions that have to be done = 1+(1-Commonality)(N_c-1)

Commonality = commonality in resolutions (0 = no commonality, 1 = all activities common)

N_c = number of products using the part on the problem date

C_{unres} = cost of unresolved problems/product/quarter

D = problem date (in years measured from 0).

The cost in (5) is included until the problem has been resolved in all products. The model uses the Commonality to determine the effective number of full resolutions that have to be done and then performs them as quickly as the finite resources will allow, charging for the resolutions and penalties for unresolved problems as it goes. The model assumes that the problem resolution resources are busy 100% of the time doing something, i.e., no idle time is paid for.

5 MODELING RESULTS

The following results are presented in terms of the annual effective cost per part site given in (6) for year i, Part-Specific Inputs:

Parameter	Value
Part name	SMT Capacitor Test Case
Existing part or new part?	Existing
Part type	Type 1
Approval/Support Level	PPL
Maturity Level of Part (lifecode)	2
Number of suppliers of part	7
How many of the suppliers are not PSL but approved?	5
How many of the suppliers are not PSL AND not approved?	0
Part-specific NRE costs	0
Expected obsolescence resolution	LTB
Number of I/O	2
Procurement lifespan (years)	
Item part price (in base year money)	0.015
Are order handling, storage and incoming inspection included in the part price?	Yes
Handling, storage and incoming inspection (% of part price)	10.00%
Defect rate per part (pre electrical test)	5
Surface mounting details	Automatic
Odd shape?	No
Part FIT rate in months 0-6 (failures/billion hours)	0.05
Part FIT rate in months 7-18 (failures/billion hours)	0.04
Part FIT rate after month 18 (failures/billion hours)	0.03

General Inputs:

Part price change profile (change with time)	Monotonic
Part price change per year	-2.00%
Part price change inflection point (year)	5
Manuf. (assembly) cost change per year	-3.00%
Manuf. (test, diagnosis, rework) cost change per year	-3.00%
Admin. cost change per year	0.00%
Effective after-tax discount rate (%)	10.00%
Base year for money	1
Additional material burden (% of price)	0.00%
LTB storage/inventory cost (per part per year)	0.010
LTB overbuy size (buffer)	10%
Warranty length (months)	18
Fielded product retirement rate (%/year)	5.00%
Operational hours per year	8760
% of supplier setup cost charged to non-PSL, approved suppli	0.00%

Check all that apply:

- [ ] Component identification (including parameter review)
- [ ] Design adoption needed
- [ ] Special reliability/qualification testing
- [x] New volume and/or pricing negotiations
- [x] New CAD footprint and symbol needed
- [ ] Part never becomes obsolete
- [x] New supplier
- [ ] Include finite resource effects

Part and Product Usage Profile Inputs:

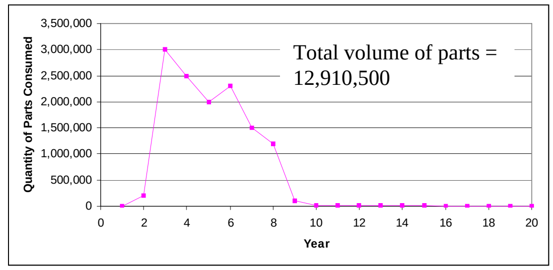


Figure 2. Example part total cost of ownership cost model inputs.

$$C_i = \frac{\left(C_{maint_i} + C_{manuf_i} + C_{field\ use_i}\right)}{\sum_{j=0}^{i} N_j} \qquad (6)$$

where N_j is the number of products manufactured in year j. We focus on the effective cost per part site, rather than the cost per part because when product repair and part replacement are considered there is effectively more than one part consumed per part site. All computed costs in the model are indexed to year 0.

5.1 BASE MODEL

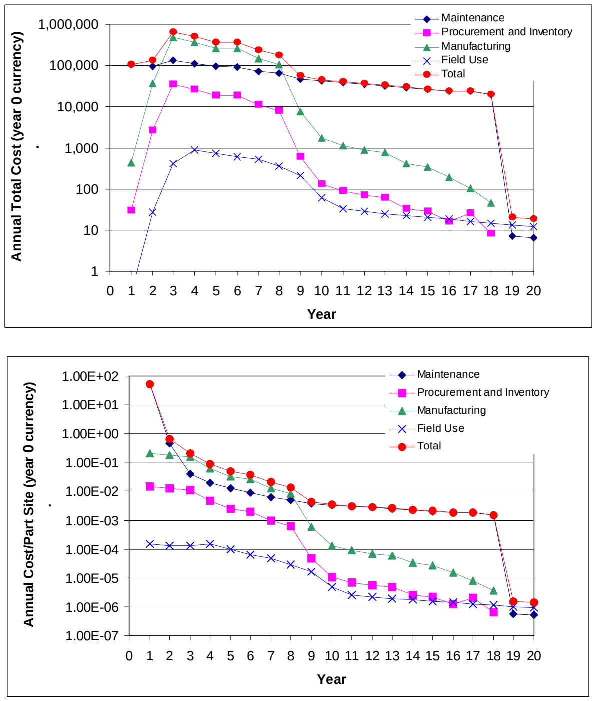
As an example of the part total ownership cost model (without the finite resource constraints included) consider the part data shown in Figure 2. For this part used in a single product (with the annual part usage profile shown in Figure 2), the results shown in Figure 3 are obtained. The plots on the left side of Figure 3 show that initially, all the costs for the part are maintenance costs, i.e., initial selection and approval of the part. Manufacturing and procurement costs approximately follow the production schedule shown in Figure 2. This example part becomes obsolete in year 17 and a lifetime buy of 4000 parts is made at that time indicated by the small increase in procurement and inventory costs in year 17 (a lifetime buy). Year 18 is the last year of manufacturing after which field use costs dominate.

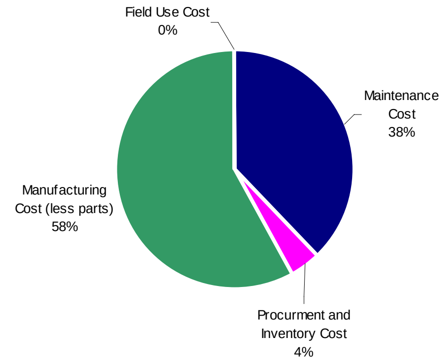
A sensitivity analysis was conducted to observe the effects of input parameters on the total effective cost per part site for the baseline case. In Figure 4 a variability of 10% for each input parameter was introduced to study the response of the model results for the base case with no part problems. SMT (Surface Mount Technology) cost per part, discount rate, maintenance fee for non-approved parts, and part price were the primary parameters contributing to changes in total effective cost per part site. The cost sensitivity due to part usage quantity, year of the supply-chain disruption, and the costs associated with the supply chain disruption are discussed in Section 5.2.

5.2 PART REUSE MODELING

We now consider the use of the example part described in Figure 2 in multiple products (the results in Section 5.1 are for its use in a single product). For simplicity, we have assumed that all the products have the same production schedule – given in Figure 2). If we first consider the case where no problems (that would be finite resource limited) are introduced, the results in Figure 5 are obtained. As products are added that use the part, the effective cost per part site drops. The right side of Figure 5 shows a comparison of the annual cost per part site for the 1 and 20 product cases. Nearly all of the difference between the annual costs is maintenance cost (economies of scale are kicking in).

Now consider the introduction of a disruptive problem whose solution could be limited by finite resources. In this case we will assume that the problem is not an obsolescence problem since the example part we are considering is forecasted to become obsolete in year 17 and a lifetime buy at





Procurement cost = \$0.015/part

Effective total cost of ownership = \$0.225/part

Figure 3. Base case modeling results (no finite resource limited problems included).

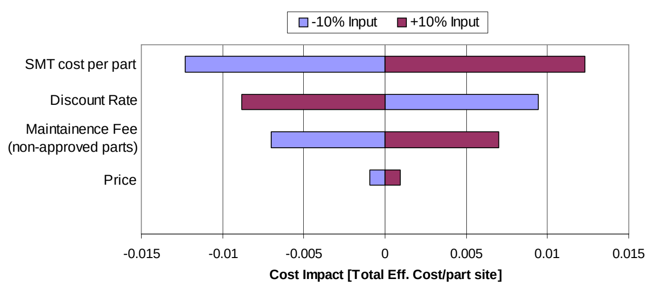


Figure 4. Tornado Chart of cost impact due to 10% variability in input values.

that time is already figured into the base model. If a problem is introduced in year 5,[4] the costs as a function of the number of products the part is in are given in Figure 6 for a range of solution Commonality. For one product, the cost is similar (slightly higher because the year 5 problem has to be resolved) than the results in Figure 5. If there is no commonality between products in the solutions to the problem, Figure 6 indicates that for this example, there is a 6 product optimum usage. As the commonality of problem solutions increases, the size of the optimum product usage increases until 100% commonality results in approximately the solution in Figure 5.

Figure 7 shows the breakdown of costs with year 5 problems results for 1 product and 6 products. The fraction of the part cost due to maintenance is much larger when one product uses the part than when 6 products use the part (economy of scale – shared qualification and approval costs). However, the problem resolution cost makes up a significantly larger portion of the cost of ownership of the part when 6 products are involved – the balance between the lower maintenance costs and the part resolution costs is key to finding the optimum number of products to share a part. The results seen in Figure 8 are a variation of the case shown in Figure 6 (problem introduced at year 5), wherein the cost associated with unsolved problems and problem resolution is reduced by 25%. The results show an optimum breadth of use at 7 products for no commonality and 15 products for 50% commonality, i.e., the optimum number of products has shifted to the right (larger number) as the costs associated with the problem resolution decreased.

The date of the introduced problem and the sensitivity of the results to total volume of part usage have been explored. The right side of Figure 6 shows that the optimum number of products to use the part in increases as the date of the problem is later (year 10). For the results in Figures 3-8, the total volume of parts is 12,910,500 parts/product. If this volume is decreased to 1,290 parts/product, the effective cost per part site increases substantially (the various non-recurring maintenance costs and the cost of problem resolution at year 5 increase it dramatically), but the optimum number of products to use the part in is the same as the high volume case, Figure 9. Note, in the example case used here (a capacitor), the price variation due to volume above a few thousand parts is negligible, but the relationship may be important in more expensive parts.

6 DISCUSSION AND CONCLUSIONS

The goal of the model developed in this paper is to enable the assessment of the optimum number of part uses within a large sea of products when the part's effective cost to a product is

[4] For the analysis results given here, we have assumed that the cost of the problem resolution in a single product is C_{res} = \$100,000, that we have resources to perform a maximum of one full resolution every 6 months (resolution rate = 0.5 resolutions/quarter), and the cost of unresolved problems is C_{unres} = \$50,000/product/quarter.

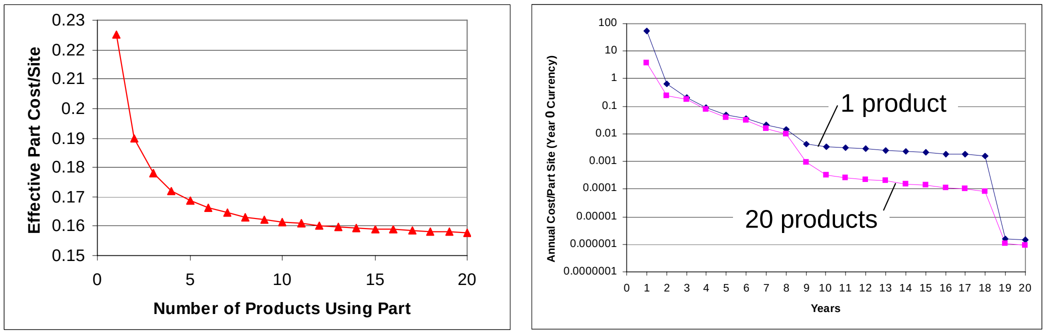


Figure 5. 1 to 20 products concurrently using the example part described in Figure 2. No finite resource limited problems.

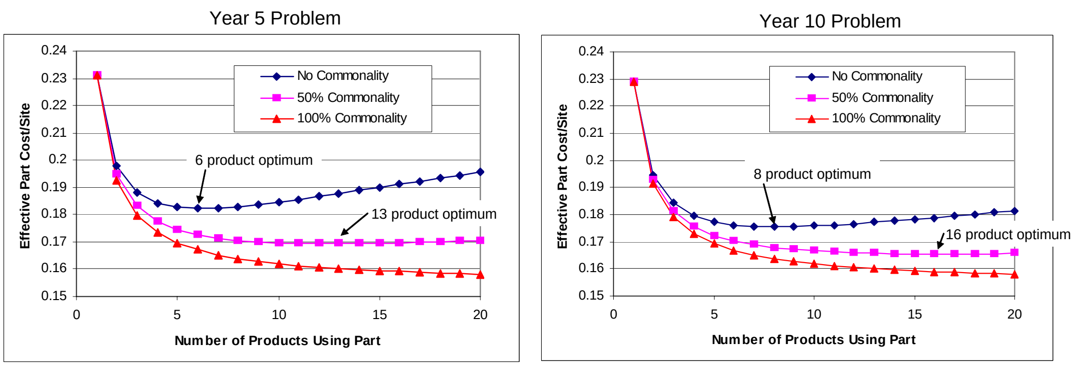


Figure 6. 1 to 20 products concurrently using the example part described in Figure 2. Problem introducted in year 5 (left) and year 10 (right).

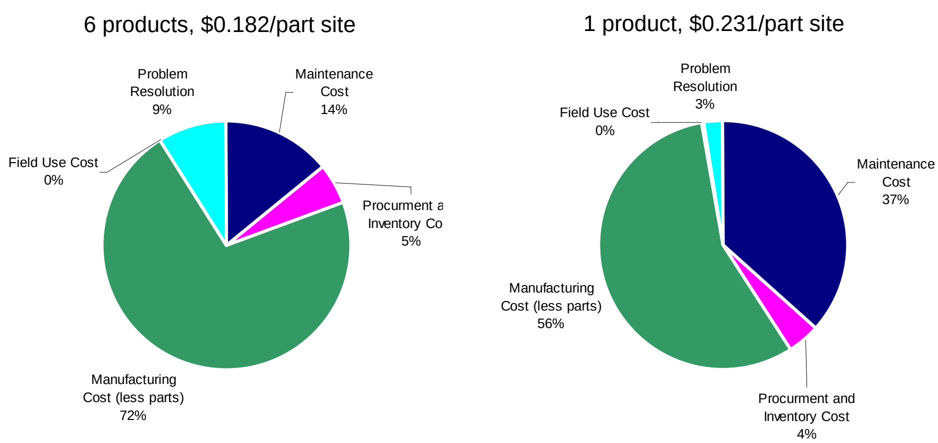


Figure 7. Year 5 problem cost breakdowns (0 commonality).

highly dependent on non-procurement, non-manufacturing lifecycle contributions and is subject to long-term supply chain disruptions (i.e., disruptions that make it impossible for an organization to continue using the part, such as reliability issues, changes made to the part by the part manufacturer, and unforeseen obsolescence of the part that make it non-procurable). The study is based on a part total ownership cost that includes cost models for manufacturing, maintenance, and field use of parts. Most product platform design analyses focus on manufacturing costs, with less attention paid to indirect costs and almost no attention paid to post-manufacturing lifecycle costs. A few authors have included indirect costs, such as non-recurring design, setup, and qualification costs, e.g., [30], but because they take a product view instead of a part view, effective part lifecycle costs are difficult to assess quantitatively (e.g., commonality indices and other such scales are used rather than actual costs). The product view also tends to lead to an incomplete picture of the effective lifecycle cost of parts because part-specific (as opposed to product-specific) supply chain effects are not easy to include. In fact, a recent compilation of industry needs and trends, [31], does not specifically identify either lifecycle costs

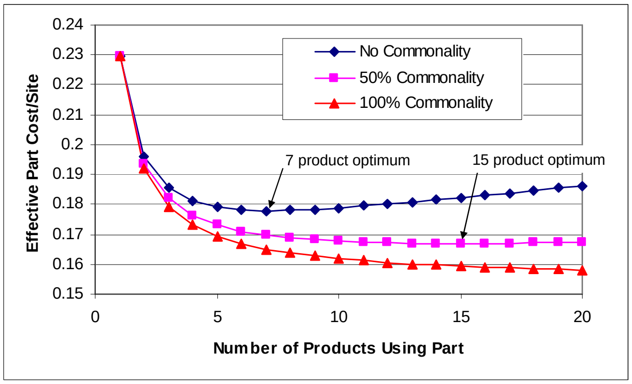


Figure 8. 1 to 20 products concurrently using the example part described in Figure 2. Problem introducted in year 5, Cost of problem resolution (C_{res}) = $75,000, Cost of unresolved problems (C_{unres}) = $37,500.

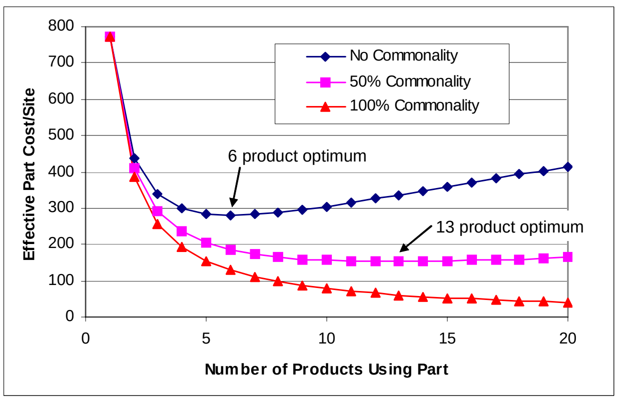


Figure 9. 1 to 20 products concurrently using the example part described in Figure 2. Problem introduced in year 5, total quantity of each product = 1,290.

(post-manufacturing costs) or long-term supply chain disruptions as contributors to product family development decision making.

In this analysis we have taken a part cost of ownership viewpoint as opposed to a product or product family optimization viewpoint, e.g., we are not using commonality indices, rather, the actual total ownership cost for parts is assessed, which unlike previous studies, accounts for available resources to address post-manufacturing lifecycle and long-term supply chain disruptions that are significant contributors to the cost of some types of products, e.g., electronic products.

Example results from our model demonstrate that, from a lifecycle cost viewpoint, there is an optimum quantity of products that can use the same part beyond which costs increase. The analysis indicates that the optimum part usage is not volume dependent, but is dependent on the timing of the supply chain disruptions. This work suggests that the risk and timing of supply chain disruptions should be considered as a criteria in product platform design.

7 ACKNOWLEDGEMENTS

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