Process Capability Database Usage In Industry: Myth vs. Reality

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1 Abstract

Process capability data (PCD) is needed for robust design, optimal tolerance allocation, and variation simulation analysis. Process capability databases (PCDBs) have been developed in many industries and are being used by the manufacturing community to monitor quality; however, they are not being effectively utilized by design. When the PCDBs[1] were developed, the intent was for design to use PCD for optimization and product cost minimization, but this ideal situation has not been realized.

A survey of a variety of design and manufacturing companies was circulated to determine both the state-of-the-art in PCDBs and the barriers preventing design from fully utilizing PCD. Two key barriers were identified for internal PCDBs: lack of a company-wide vision for PCD usage and poor communication between manufacturing and design. Supplier PCDBs have the additional barriers of lack of trust between suppliers and customers and time lag for data entry. Management support, training, database population, and common systems were identified as potential solutions to the identified barriers.

2 Introduction

Variation reduction in manufacturing has provided benefits to many companies. For example, a number of articles in the public press have described the benefit General Electric and AlliedSignal have accrued from implementing Six Sigma methods. However, most organizations realize that they can improve the cost and quality of their products even more dramatically by improving the design of their product (rather than waiting until production to reduce variation). There are two steps to making a product more robust: predict the end quality of the design and then optimize the design.

Predicting final product quality requires both a variation model and process capability data. The *variation model* takes the part and process variation as inputs, models how variation propagates through the system, and predicts the final product quality. Several tools are typically used to accomplish this: Variation Simulation Analysis (VSA), Design of Experiments (DOE) (Phadke 1989), and process modeling (Frey *et al*. 1998). The model must also be populated with *process capability data* (PCD). PCD is defined as the expected and obtained standard deviations and mean shifts for a feature produced by a particular process and made of a particular material. Without accurate process capability data, it is not possible to predict the end quality of designs or to improve product robustness.

Most of the academic literature on predictive modeling and robust design assumes the existence of complete and accurate data about process capability. However, this paper demonstrates that this assumption

[1] A process capability database includes target and actual tolerances for particular process, material, and feature combinations. The term process capability can also be used to describe geometric characteristics that a process can create, but this paper focuses on the first definition.

is more myth than reality. Although companies have created process capability databases (PCDBs), the data is not being utilized by design.

To better understand the current state of usage, as well as to understand why PCDBs are not being utilized by design, a survey was circulated to several major design and manufacturing firms. Twenty-nine people responded from fourteen companies including automotive, consumer, military, and aircraft industries. The survey was sent directly to the people who work with PCDBs, who helped develop PCDBs, and/or who are experts on robust design. Respondents included statistical consultants, mechanical engineering managers, design engineers, and manufacturing and quality engineers. The survey was divided into two parts. The first part investigated the use and development of internal databases and the second, databases of supplier capability. The survey contained questions requiring both numerical and textual responses, both of which are detailed in this paper.[2]

To provide a background, this paper first summarizes the academic literature on robust design, variation prediction, and PCDBs (Section 3). The paper then summarizes the desired state of PCDBs, as described by the survey respondents (Section 4.1). The remainder of the paper focuses on the current state of PCDBs. It was found that ***PCDBs are being successfully used in manufacturing to monitor processes but are not being used to improve design***. (Section 4.2). The survey identified several technical, organizational, and informational barriers to design usage of PCD (Section 4.3):

- Poor population of PCDBs.
- Data pertinent to design not available.
- Lack of management support.
- Lack of usage metrics.
- Lack of incentives for PCD use.
- Lack of PCDB commonality across enterprises.
- Lack of direct design access to PCDBs.
- No linkages to other information systems.
- Poor indexing schemes.
- Poor user interfaces.
- Out-of-date PCD.
- Design's lack of trust and understanding of data.

These barriers are caused by two fundamental problems: failure to communicate between design and manufacturing and a lack of a common, enterprise-wide approach to PCDB usage in the product delivery process. Potential solutions to these barriers are also proposed (Section 4.4) based on the analysis and the respondents' future improvement plans. The key to improving design's usage of PCD is giving designers the ability to get the right data quickly.

A similar analysis of usage and barriers was done for supplier databases (Section 5). Supplier PCDBs[3] have some additional barriers:

- Separate PCDB for supplier data.
- Confidentially of supplier PCD.
- Lack of consistency and availability of supplier PCD.

3 Background

Several articles discuss using process capability data in the product delivery process. For example, Naish (1996) describes the role process engineers play in selecting processes capable of meeting target tolerances. Similarly, Perzyk and Meftah (1998) suggest that designers should have devices to aid in selecting

[2] The quotes in this paper came from the textual responses.

[3] Supplier PCDBs contain PCD for parts from suppliers and may be separate from or together with a company's PCDB for internal parts.

materials and manufacturing processes. Several articles specifically address the problem of using process capability in design for electronic systems (Lucca *et al*. 1995).

A number of articles on robust design, computer integrated manufacturing, tolerance optimization, and variations modeling implicitly state the importance of process capability. The articles published in the *Journal of Mechanical Design*, *Journal of Materials Processing Technology, Journal of Manufacturing Science and Engineering*, *Research in Engineering Design - Theory Applications and Concurrent Engineering*, and *IIE Transactions* between 1994 and 1999 were analyzed. Twenty-eight articles in these five journals assume the existence of PCD and require it as an input to the models and tools described in the articles.

Setting tolerances to match process capability and reflect design intent is the subject of significant literature (Liu *et al*. 1996; Srinivasan *et al*. 1996; Gao *et al*. 1998). A tolerance is defined as the permissible variation of a dimension in engineering drawings or designs (ANSI Y14. 5M 1994). When tolerances are incorrectly set, rework, cost, and/or failure in service increase (Parkinson *et al*. 1993; Chase *et al*. 1996). Tolerances should be optimized to reduce mechanical errors (Lee *et al*. 1993; Lin *et al*. 1997; Zhang and Ben Wang 1998), minimize assembly problems (Ting and Long 1996), and improve product performance (Michelena and Agogino 1994; Wang and Ozsoy 1993).

In addition, a number of articles propose models to predict and optimize end product quality (Parkinson 1995; Chen and Chung 1996; Thornton 1998) Other articles describe methods to optimize product robustness (Parkinson, Sorensen et al. 1993; Andersson 1994).

Several authors have directly addressed some problems with process capability databases. However, most process capability database articles address characterizing the part types and geometries a process can produce, rather than standard deviations and mean shifts. Campbell and Bernie (1996) discuss requirements for a formalized rapid prototyping database. Perzyk and Meftah (1998) describe a process selection system that includes general data on process capabilities. Baldwin and Chung (1995) discuss some methods for managing vast quantities of data using a classification hierarchy.

In summary, much of the research done to improve and predict quality is premised on the existence of process capability data. However, no research discusses how to deliver process capability data to the designers in a form that they can use.

4 Internal Databases

Four topics were covered by the survey: PCDB desired state (Section 4.1), current usage (Section 4.2), usage barriers (Section 4.3), and future solutions (Section 4.4). We separated the results for the supplier databases from the internal part databases because the supplier databases have two unique barriers. The results for supplier databases are covered in Section 5.

4.1 Desired State

PCDBs were originally designed for use by both the manufacturing and design communities. Figure 1 shows the percentage of respondents who indicated that their PCDB was developed for process monitoring, design feedback, inspection, or regulatory requirements. Other development reasons included corporate metrics, dimensional management, and variation simulation analysis.

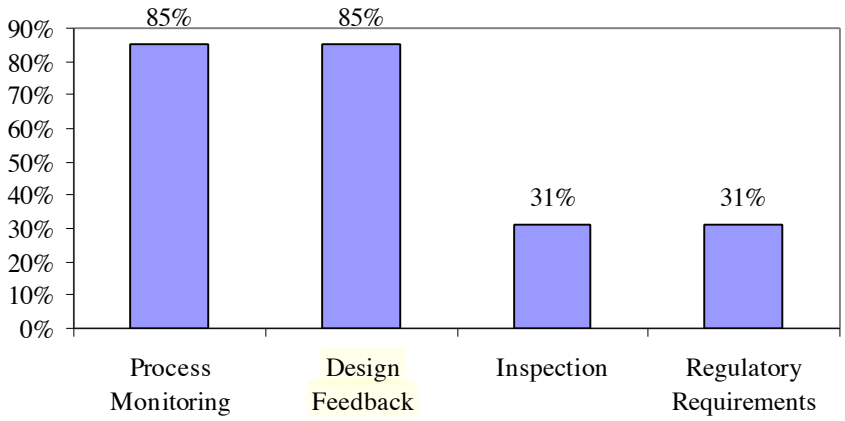

Figure 1: Desired PCDB Usages

Eighty-five percent of the respondents indicated that they would like to use internal PCD for designing new parts with more appropriate tolerances. Respondents also identified several ways PCDBs could be used to improve quality and reduce costs in the design process: identify areas to apply robust design, specify realistic tolerances, and enable design quality verification prior to production. One company would like to "generate an exception report for characteristics that do not meet six sigma." Ideally there would be a "lessons learned database that could be accessed by any site to see best practices and problems encountered by other sites" and "data and knowledge would be transferred to the next generation of a product family for improving time-to-market." Companies would like to use PCD in design to: "design out variation when required", "establish tolerances and key characteristics for a product", "make products more producible", "make designs more robust", "simulate variation", "prioritize process improvements", and "understand the cost impact of parameter values."

The survey results showed that the ideal PCDB is fully populated with up-to-date and accurate data. In addition, it links directly to computer-aided design (CAD) packages and simulation software (i.e., VSA). The ideal database estimates manufacturing costs to enable design trade-off analyses. Ideally, the system would automatically "caution designers when a feature or manufacturing process is being considered that will not meet the established quality level for that particular program." Companies would like to be able to do "cost and cycle time trades vs. performance." Finally, many companies would like to see "a direct link to a drawing program to automatically flag tolerances that do not meet established quality levels."

4.2 Current State

Companies want to use PCD in design to improve product quality and producibility. Most responding companies (93%) have some type of PCDB; however, PCD is used[4] on only ***14%*** (Figure 2) of projects and most companies (88%) use it less than thirty percent of the time.

[4] The usage level refers to the number of critical projects/subsystems where process capability was used to validate the design prior to production.

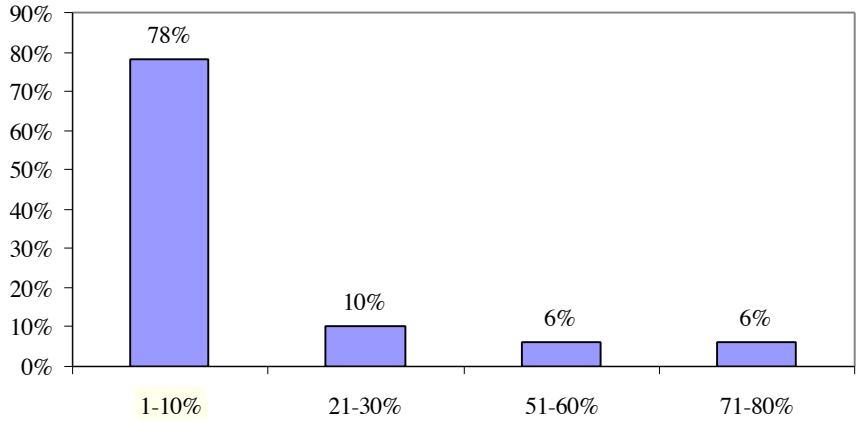

Figure 2: Percentage of Projects Employing PCD

In addition, the PCDBs are still relatively new (Figure 3).

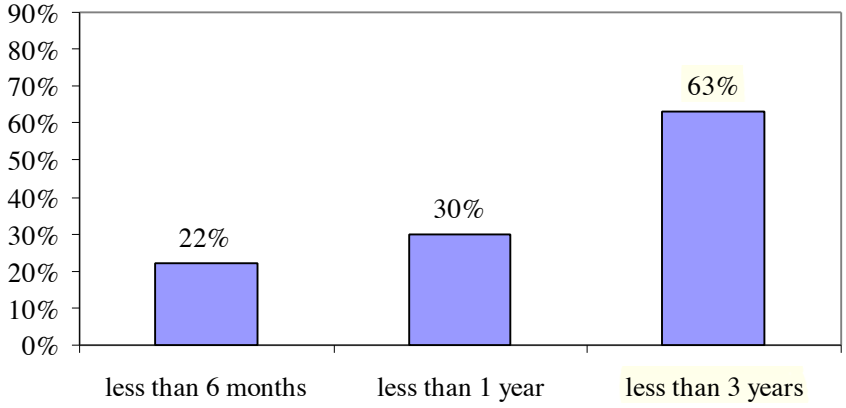

Figure 3: Age of PCDBs

4.3 Design Usage Barriers

Most of the survey was dedicated to identifying barriers to PCD usage by design. The most prominent barriers are poor population of databases, lack of needed data, lack of management support, and limited accessibility to PCDBs. Other obstacles include no linkages between PCDBs and other information systems, lack of usage metrics, poor user interfaces, poor PCDB indexing scheme, design's lack of trust and understanding of data, out-of-date data, no incentives to use PCD, and lack of database commonality across enterprises. The following sections describe each of the barriers. The summary in Section 4.4 describes the interrelations between them.

Poor Population of PCDBs. Most databases are not fully populated; an average of ***24%*** of internal parts are contained in databases (Figure 4). Two factors contribute to this: the databases are fairly young (Figure 3) and data has not been entered consistently.

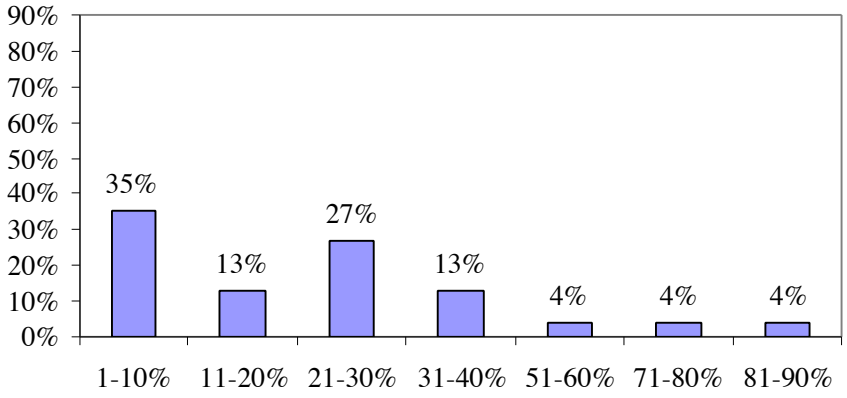

Figure 4: Percentage of Internal Parts in PCDB

The lack of PCD significantly limits design's ability to verify quality. If a designer repeatedly queries the database and the required information is not available, he/she will typically stop utilizing the database.

Data Pertinent to Design Not Available. According to one operations excellence specialist, "data doesn't match what designers are looking for." The data used to monitor process performance and the data needed by design are often not the same. Although manufacturing collects statistical process control (SPC) data (85%), key characteristic data (65%), and part data (62%) only the key characteristic data is typically requested by design. The SPC data is used to control processes and part data is used for inspection and/or process variation monitoring. Manufacturing engineers indicated that they would be willing to collect the data specifically for design; however, designers typically have not been proactive in identifying what types of feature/process/material data they need.

Lack of Management Support. Sixty-one percent of respondents listed lack of resources as an obstacle to design PCDB usage –"it is difficult to get the PCDB prioritized high enough to get it implemented." PCDBs require significant resources including equipment, data maintenance, and training. Because PCD is not being used by design, many companies are now questioning the value of their existing investment – "managers do not have a clear understanding of why PCD is needed, nor do they understand the amount of time and effort that is required to collect and analyze the information." In the last year, many companies have withdrawn support for PCDBs.

Lack of Usage Metrics. The management support problem is aggravated by the lack of good metrics to track database usage. Seventy-eight percent of the respondents do not track frequency or patterns of usage. This is due to a number of problems including lack of resources. One company monitored data usage in the past, but found that people were taking credit for obtaining the data from the PCDBs although they were not using it to improve their designs.

Lack of Incentives for PCD Use. During the design process, management is not requiring or rewarding the use of process capability data. As one manufacturing engineer pointed out "designers are not required to look at PCD as part of their design process." The lack of incentives is a barrier according to forty-four percent of respondents.

Lack of PCDB Commonality Across Enterprises. Over eighty-five percent of the databases are locally developed and maintained (Figure 5). In addition, databases within the same enterprise tend to be incompatible. A wide variety of software packages are used (ACCESS (27%) ORACLE (23%), and QUANTUM (32%)) and the indexing schemes are not compatible. Incompatibility and dispersion of PCD was identified as a major hindrance by fifty-six percent of respondents.

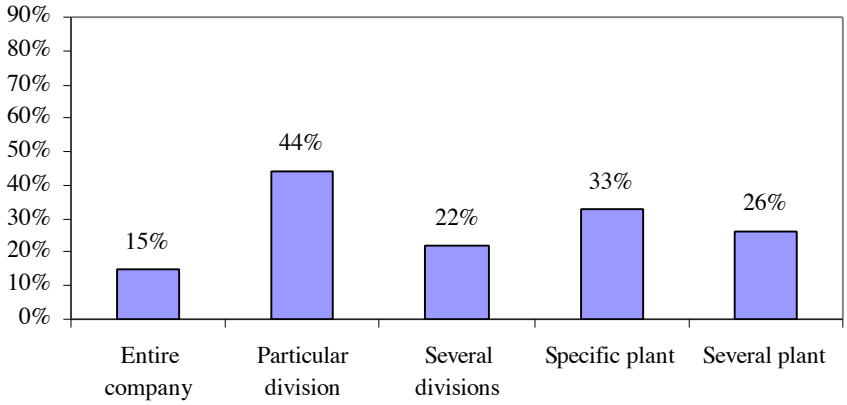

Figure 5: Location of PCD

Lack of Direct Design Access to PCDBs. Forty-six percent of the respondents have PCDB access available to all company employees. The other fifty-four percent limit access to specific groups: process engineers, product delivery teams, quality engineers, operators, design engineers, supervisors, and/or mechanics. A variety of reasons are given for limiting access (Figure 6).

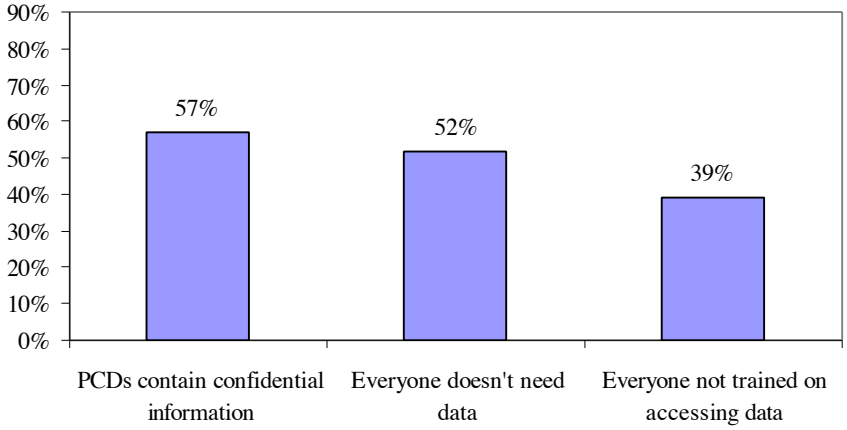

Figure 6: Reasons for Limited Access to PCDBs

Several manufacturing engineers indicated that they don't provide designers with direct access to the PCD because they don't know or trust how a designer will interpret and use the data – "the combination of the database design and the lack of education on process capabilities, lead users of the data to look for the

wrong data and apply it incorrectly to the design." Without direct access, designers must submit PCD requests to the manufacturing engineers. The PCDB owners work with design to determine what data they need and then interrogate the database for them. This process tends to be very time-consuming. One operations excellence specialist notes that "designers don't have time to wait for PCD" and another that "design engineers are behind schedule and don't have time to obtain the data."

Even if designers are granted access to the PCD, data access is awkward. The data is accessed through multiple access methods: shop floor computers (64%), the intranet (60%), network servers (24%), request forms (20%), or weekly and monthly reports. Even when designers have intranet or network access to the PCDB, many do not have the software to access the data. One operations excellence specialist indicated that "access to (PCD) is available but not automatic – you need to know who to ask for it to get it."

No Linkages to Other Information Systems. Another major barrier to effective process capability data usage by design is the lack of linkages to other information/analysis systems –"CAD systems don't interface with PCDB." Figure 7 shows how few links companies have between their databases and other systems. Most of the linkages are pointers from the database to other systems. For example, many databases point to the part drawings but not to the specific feature. None of the companies have systems that enable designers to access PCD from modeling systems such as VSA.

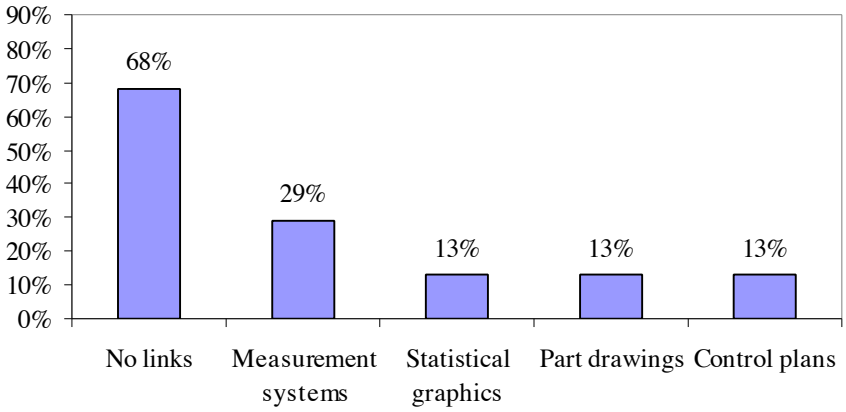

Figure 7: Links to External Systems

Poor Indexing Schemes. Another problem comes from the indexing schemes –"data is not being characterized properly such that it would be useful for the design community even if they wanted to use it." Designers typically want to access data by the feature, material, and process characteristics of the designs they are creating. However, "data is not indexed by query desired" because manufacturing usually indexes data by the part number or key characteristic number. In this case, searching for the appropriate surrogate process capability data requires an understanding of all of the parts in the database. Fifty-six percent of the respondents identified the PCDB structure as a barrier. One said "the database can be easy for the manufacturing function to enter data and use it, but the design function cannot readily use it."

Fortunately, several companies have begun to index their databases based on material, process, and feature characteristics. Fifty-six percent of the respondents said they access the PCDB data by feature type. However, the companies we have visited have multiple indexing systems at the same site and/or have not completed the process of re-indexing legacy data systems – "there is a lack of integration due to fixed mentalities or old paradigms" according to one engineer/scientist specialist.

Poor User Interfaces. Generally the PCD is presented in numerical format and only one set of data can be viewed at a time. In many cases, the user interface requires detailed knowledge of both database query languages and the structure of the specific database. A material and manufacturing process engineer said "there is no user-friendly interface and only those that can write SQL queries can get data." Many respondents also agree that "the PCDB software is not easy to work with."

Design's Lack of Trust and Understanding of Data. In many cases, designers don't trust the process capability data – "engineers don't know about the data, trust the data, or trust the location of the measurements." One senior manager for variability reduction indicated that "manufacturing-collected data may not always be reliable/accurate." First, the databases often don't include a measure of statistical validity including number of data points in a population or gage resolution and repeatability data. Second, special causes of variation are often not indicated. Third, the indexing schemes may not have significant resolution. As a result, the data returned for a certain process code may have significant variability. Fourth, in some cases the date is not included with the data.

Designers also are often not trained on how to use PCDBs –"the data is not user-friendly to access or to interpret." One senior manager for variability reduction indicated that "design does not always know what to do with the data." Sometimes the designers don't even know that their company is collecting PCD – "designers don't know PCDB exists."

Out-of-Date PCD. There is a time lag between when the data is generated and when it is available; however, design needs access to the most up-to-date data. The time lag results from the data being entered manually. Less than half of the respondents have the PCD entered automatically. One respondent indicated that because of "manual data entry, PCD is updated infrequently."

4.4 Summary

The barriers described in Section 4.3 are highly coupled. To better understand the relationships between the barriers to design usage of PCDBs, a cause and effect diagram was built (Figure 8).

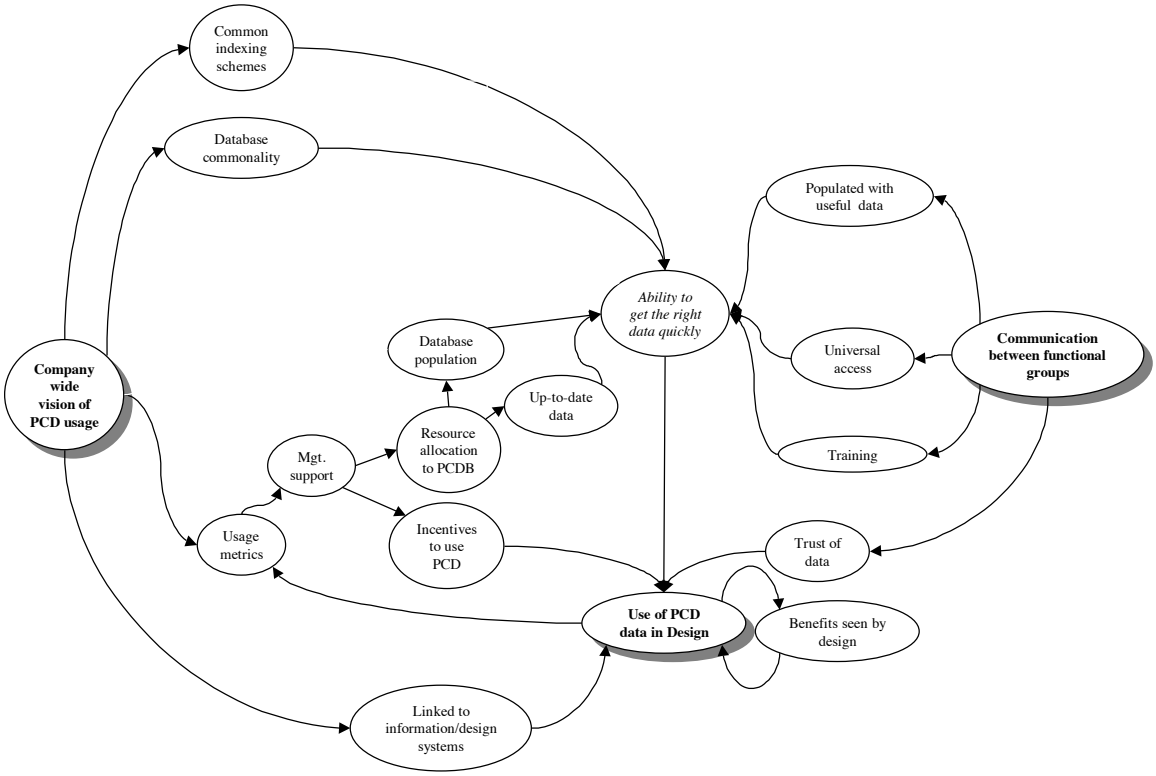

Figure 8: Cause and Effect Diagram for Internal PCD Design Usage Barriers

Design's resistance to using PCD was found to be due to two root causes: a lack of a company-wide vision and plan for process capability database usage and a lack of communication between functional groups such as design and manufacturing.

Company-Wide Vision. A company-wide vision of PCD usage is needed because of the distances between when, where, and who generates and uses the data. During production, manufacturing needs to collect and maintain the correct set of data in a form that design can use and trust. Then, during new product development, design should use this data to validate their designs and to set appropriate tolerances.

It is hoped that using PCD in design will produce visible benefits. However, there are two additional barriers. First, the analysis of process capability, manufacturability, and robustness requires design to invest extra resources when resources and time are most constrained. Second, the benefits of design efforts are not accrued until the design is transferred to production.

A company-wide vision should make four improvements: implement common indexing schemes, develop database commonality, streamline the process by investing in linking PCDBs to other information/design systems, and implement PCDB usage metrics.

Several companies are considering developing one PCDB for their entire company to alleviate the problems of training, access, and data population. This appears to be a good solution; however, transferring legacy systems, ownership, updating duties, and maintenance are major obstacles to such an endeavor. In addition, unless improved indexing schemes are introduced, searching a monolithic database will be very

cumbersome. A better idea, which some companies plan to try, is to "develop a shared server access for all sites so data can be easily accessed from any site."

Better Communication between Design and Manufacturing Functional Groups. Although integrated product teams exist in many companies, manufacturing and design don't communicate enough about PCDBs. Manufacturing engineers have been in charge of setting up and populating the databases; therefore, they have tailored databases for process monitoring. Designers have not been active in this development; therefore, their needs have not been met.

Better communication between design and manufacturing should make four improvements to design's use of PCD: training, universal access, database populated with the data that design needs, and trust of PCD by designers. One respondent summarizes the need for design to understand PCD: "The design community, in general, does not understand process capability and its use in the product definition process. Incentives and management support will make them want to use the data, but without proper understanding, it will be used incorrectly, which may be a bigger detriment."

5 Supplier Databases

In today's product development organization, a company rarely produces all of the parts and sub-systems in a product. In most cases, upwards of half of the parts in a product are procured from outside suppliers. When designing a system, it is necessary to have access to both internal and supplier process capability data. Historically, parts were designed and then sent out to suppliers for quotes. In this case, contractual obligation and piece part inspection were used to ensure compliance to the tolerance requirements. However, as suppliers become more like partners, it becomes more important to communicate process capability. Supplier PCDBs share some of the same problems as internal PCDBs; however, they also have some unique challenges.

5.1 Current State

Only about half the companies (58%) with internal part PCDBs also maintain supplier PCDBs; nonetheless, several other companies indicated that they plan to develop supplier PCDBs soon. The companies who do not maintain supplier data indicated that it's the supplier's responsibility to maintain capability data and to make it accessible on request. Two reasons were given for developing supplier PCDBs: to design better systems (50%) and to choose between suppliers (58%). Other uses for this information include: evidence of supplier process control, improved supplier processes, supplier certification, histogram qualification, appropriate design change identification, key characteristics, and datum selection. However, as stated above, most development efforts do not make use of process capability data when designing parts; nonetheless, ninety-two percent of the respondents indicated that they would like their supplier PCD to be used by design. Supplier data is usually collected by materiel/procurement groups. These groups require suppliers to report process capability data as part of contract requirements.

5.2 Design Usage Barriers

Design does not use PCD from suppliers for the same reasons they do not use data for internal parts: the databases are poorly populated (an average of ***22%*** of supplier parts are contained in PCDBs), there is a lack of management support for the systems, there is no PCDB commonality, there is a lack of direct design access, and the PCDBs have poor indexing schemes. Several of these common issues are aggravated by supplier specific issues including time lag and confidentially.

Poor Population of Supplier PCDBs. First, in many cases, suppliers don't provide data to customers. Second, suppliers typically provide the data only for the particular part the customer has ordered. The same processes are often used for multiple customers; however, the customer is only given a small percentage of the available data. Eighty-six percent of the respondents have PCD for less than thirty percent of their supplier parts.

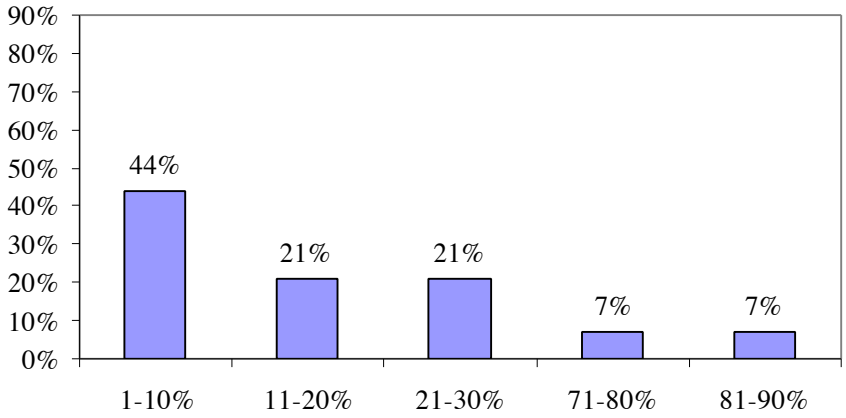

Figure 9: Percentage of Supplier Parts in PCDB

Lack of Management Support for PCDBs. One senior manager for variability reduction said that his/her "supplier management organization doesn't have the resources to manage and track the data." Another said, "implementation is stalled due to other priorities." Many companies feel that "it is the supplier's responsibility to produce and supply their customers with acceptable, defect-free products and service." One company indicated that their purchasing group wouldn't cooperate to develop a supplier PCDB.

Lack of PCD Commonality Across Enterprises. Just over half of the companies/divisions (57%) who maintain supplier data, keep it in a separate database from the internal data. Having two separate databases makes it more difficult for designers and other employees to access the correct information.

Lack of Direct Design Access to Supplier PCD. Only twenty-three percent of the respondents provide universal internal access to supplier data. The reasons limiting PCDB access are shown in Figure 10. Most companies have agreements with their suppliers not to share their data with other suppliers. Most engineers access the supplier PCD through the intranet (36%), shop floor computers (29%), or a request form (14%).

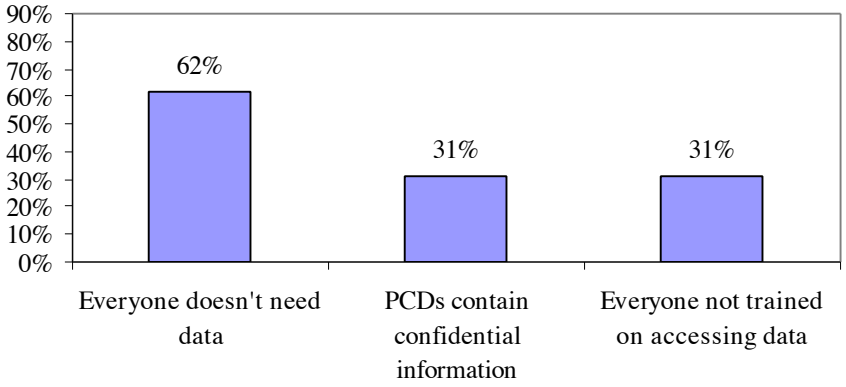

Figure 10: Reasons for Limited Access to Supplier Data

Poor PCDB Indexing Schemes. A wide variety of indexing schemes are used in supplier systems. The data is accessed through part number (79%), key characteristic number (43%), feature number (36%), manufacturing process (29%), feature type (29%), and machine (29%). Other indexing methods include: tooling, suppliers, team, product, and material. The proliferation of indexing schemes is aggravated by the lack of an industry standard.

Supplier PCD Not Readily Available. There is a significant time lag between when PCD is generated and when it is accessible. Supplier data is often (64%) entered into the database by quality groups. The manual entry and the variety of formats lengthen the entry time. Another problem is the inconsistency of supplier data. Data arrives in a variety of formats from different suppliers[5]. Fifty percent of the respondents receive data in a handwritten format, thirty-six percent in a process capability program, and forty-three percent as a spreadsheet. Other forms include: formal report submittals, qualification reports, on-site reviews, weekly and monthly reports, and histogram reports. Some companies are considering the possibility of streamlining supplier data so that all suppliers provide data in the same format. One technical advisor for process improvement indicated that "all supplier data must be transferred to a standard format", so all supplier data should be obtained in this format orignially. Nonetheless, one respondent indicated that "the vast majority of sub-tier suppliers have too many different customers that would demand too wide an array of reporting. This would drive suppliers' costs well beyond any perceived value."

Confidentiality of Supplier PCD. Suppliers are hesitant to share process capability with customers and/or designers because of two problems: confidentiality and competitiveness. The first is a risk that other suppliers will be allowed to access the data, even though most companies have "an agreement with each supplier not to share their data with other suppliers." The second problem is caused by the need stated in Section 5.1; fifty-eight percent of the respondents want to use process capability data to choose between suppliers.

[5] Suppliers have multiple customers each of whom have unique process capability data reporting requirements. Customers have many suppliers each of whom may provide the data in a different format.

5.3 Summary

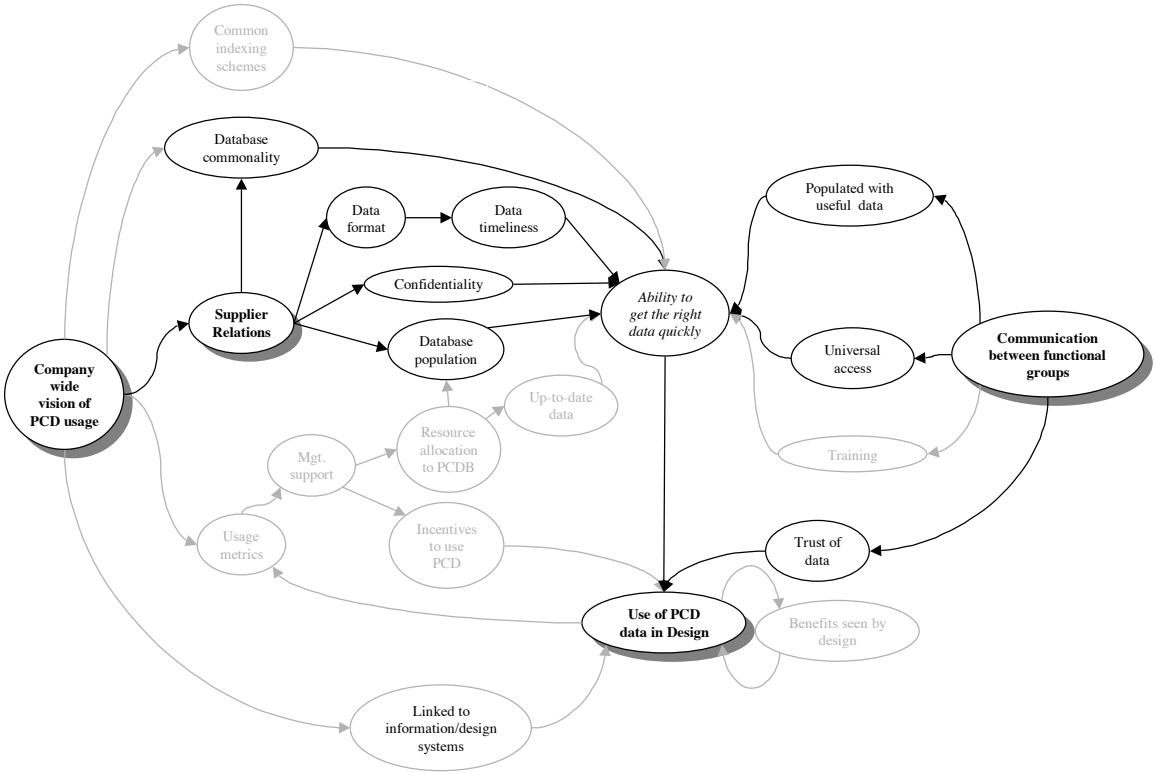

Figure 11: Cause and Effect Diagram for Supplier PCD Design Usage Barriers

Figure 11 shows the cause and effect diagram for the supplier PCD design usage barriers. The causes and effects are superimposed on the previous cause and effect diagram for internal PCDBs (Figure 8). The supplier-specific problems stem from two root causes. First, communication between design and materiel impacts the same issues as for internal PCDBs and also directly impacts the ability to get the right data quickly (due to time lag). Second, supplier relations result in varying data requirements, different formats, and the need for confidentiality agreements. There is also a problem with the lack of commonality between PCDBs for internal and supplier parts.

Companies have many plans to improve their supplier PCDBs. The first is to increase the reporting requirements. In addition, companies plan to integrate their supplier and internal databases. Some companies plan to enable electronic transfer of supplier data directly into their database. One company plans to "allow suppliers access to data that they submitted, associated data from internal parts that mate with their parts, and assembly measurements."

6 Conclusion

Initially, PCDBs were developed for both process monitoring and design feedback. However, the goal of design feedback is not being achieved because of three reasons (Figure 12). First is a lack of communication between design, manufacturing, and materiel. Second and third are a lack of trust between

suppliers and customers and a lack of a company-wide vision about how to utilize process capability data in the product delivery process.

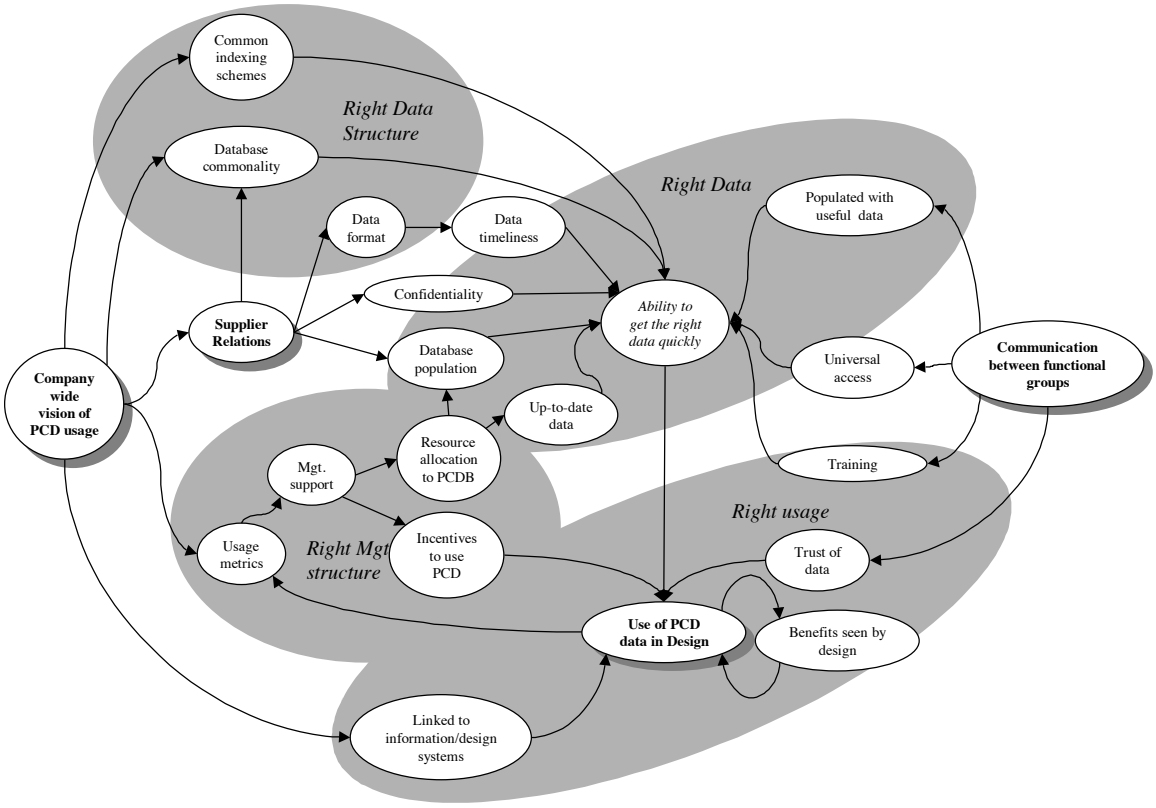

Figure 12: Combined Cause and Effect Diagram for Internal and Supplier PCD Design Usage Barriers

In order to utilize the current PCDBs for design feedback, several fundamental changes must be made. First, the incentives and processes to use the data must be implemented. Without this, even the best database will not be used. Second, a company-wide strategy for the database structure must be developed. This will facilitate training and alleviate accessibility issues. Third, communication between functional groups to identify what data should be collected and how it should be presented and interpreted must be improved. Figure 12 shows that the barriers to PCD usage by design can be split into four main needs. The PCDB must have the right structure, the right data, the right usage, and the right management structure.

Our research in this topic is being continued through a case study with Boeing. We are looking at improving the statistical validity of PCD and the format in which the data is displayed. We will also look at determining optimal alternative data to use when the feature of interest is unpopulated. Finally, we will examine how data should be presented when a designer only knows some of the details of the design (i.e., the designer know the feature and material but doesn't know which process to use).

A variety of other interesting research topics result from this analysis. First, a better system of process capability indexing is required. Second, research on better user interfaces for PCDBs is needed. Third, research is required to determine how to link existing process capability databases with existing CAD and

analysis software. Fourth, companies have expressed an interest in including cost estimates in the PCDBs to enable process trade-off analyses.

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