Case study

Interoperability costs in the US automotive supply chain

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Keywords

Motor industry, Supply chain, Design, Costs

Abstract

Concurrent design and engineering in the supply chain are vital to the growing competitiveness of the US automotive industry. However, these innovative design and development processes are hampered if product data cannot be exchanged seamlessly across the supply chain. This paper estimates that imperfect interoperability costs the US automotive industry about $1 billion per year and delays the introduction of new models by at least two months. It also evaluates different methods for alleviating interoperability problems and concludes that emerging technologies and formats offer promising solutions that may lead to significant savings for the industry. Benefits from alleviating interoperability problems can also be realized in other product data exchange-intensive supply chains like shipbuilding and aerospace.

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Introduction

Product data exchange (PDE) has become increasingly important to the US auto industry and to other manufacturing industries. Over time, methods for representing the design of a product have evolved from relying on physical prototypes to using blueprints and then to using digital data. At the same time, a growing reliance on digital simulation and analysis has increased the need for accurate digital characterizations of products to feed these processes. Today, digital product data include not only a representation of the physical properties of the product, but also cost information and other data that allow the integration of the design, manufacturing, and marketing of a product.

Changes in the structure and competitive strategy of the auto industry have also increased the importance of PDE. The decline of the market share of the US domestic auto industry during the 1960s, 1970s, and 1980s led to intensive efforts to identify and eliminate the sources of this decline. Analysts argued that the industry's production techniques were outdated (Womack *et al.*, 1990) and that its market strategies were not in tune with the rapidly changing motor vehicle market (Womack, 1989). As a result, US automakers increased their use of concurrent engineering and other lean manufacturing methods and delegated a greater share of design and development to their suppliers. These changes have decreased the average lead time for a new auto platform from about five years in the mid-1980s (Womack, 1989) to about two to three years today (Jost, 1998; Martin, 1998). US automakers have also made significant progress toward closing the productivity gap with their competitors (*Automotive News*, 1997).

Although concurrent engineering and design outsourcing have improved the competitiveness of the industry, these practices have also magnified the importance of efficient PDE. The responsibility for the design of an automobile and the factory that produces it is now distributed among many companies; thus, product data must be shared

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among a greater number of people and organizations, both concurrently and sequentially. One auto original equipment manufacturer (OEM) estimates that as many as 453,000 PDEs occur each year within the company and among the company and its suppliers. Another OEM estimates that electronic exchange of computer-aided design (CAD) data alone occurs at least 7,000 times per month; that quantity rises as high as 16,000 transfers per month during peaks. This estimate does not include transfers that take place using physical media such as tape and CD-ROM; nor does it include transfers of non-CAD/CAM data.

While it is increasingly recognized that imperfect interoperability is costly to the automobile industry (McEwan, 1995; *Target*, 1994), few attempts have been made to quantify these costs. Fleischer *et al.* (1997) estimated the cost of redundant software due to imperfect interoperability, but to the best of our knowledge no prior study presents a comprehensive analysis of all sources of interoperability costs and their relative importance.

This paper provides the results of a detailed analysis of the costs of interoperability to the US automotive industry. We estimate that imperfect interoperability costs the US automotive industry approximately $1 billion per year and delays the introduction of new models by at least two months. Given the magnitude of these costs, we also present and evaluate several potential methods for alleviating interoperability problems. Neutral format translators like the Standard for Product Data Exchange (STEP) appear to be a promising option for reducing interoperability costs.

Although the quantitative analysis focuses specifically on the automotive supply chain, the information it provides about the relative importance of different sources of interoperability cost offers insight into the potential sources of interoperability problems in other supply chains. Indeed, similar PDE problems are known to exist in industries such as shipbuilding, aerospace, farm machinery, and construction equipment.

Transaction costs and PDE

Transaction cost theory helps explain why efficient PDE is so important to the structure and competitiveness of the automotive industry. While Coase (1960) explained how transaction costs impose inefficiency on market transactions, Williamson (1971) applied Coase's insight to explain firm boundaries and organizational structure. He argued that the "make internally" or "buy in a market exchange" decision depends less on factors such as technological economies and efficient risk bearing, and more on transactional failures and diseconomies of information exchange in the operation of markets for intermediate goods. Governance structures can range from a pure anonymous spot market to a fully integrated firm. The preferred governance structure will depend on the associated transaction costs. These costs in turn depend on the degree to which relationship-specific assets are involved, the amount of uncertainty about the future and about the other party's assets, the complexity of the trading arrangement, and the frequency with which trading occurs (Shelanski and Klein, 1999).

Industry restructuring has been a key competitive strategy for the US automotive industry. In response to Japanese competition, US automakers are reducing the time and cost of new product development by adopting the philosophies of core competence and concurrent engineering. They are increasingly focusing on parts and services in which they possess a clear competitive advantage and are outsourcing other work. The adoption of these philosophies has forced significant changes in the relationships between the OEMs and their suppliers. Suppliers have responded to these changes by increasing the flexibility of their role in the supply chain. A single supplier's position in the supply chain may differ depending on the specific part and the customer, and first tier suppliers often work with many OEMs.

Despite the movement toward a more disintegrated supply chain in which suppliers work with multiple companies, buyer-supplier interactions continue to evolve away from an arms-length transaction mode to a relational partner mode (Araujo *et al.*, 1999). This results from the OEMs' recognition that these interactions are key to their overall competitiveness. This is demonstrated by General Motors' corporate supply strategy, which views competitiveness in terms of how well the company uses the resources of suppliers and the impact of these relationships on both productivity and innovation (Araujo *et al.*, 1999).

These changes imply that a key challenge in maximizing the competitiveness of the

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automotive supply chain is to reduce transaction costs while also minimizing the investment required in relationship-specific assets. Currently, the investment required for product data exchange can be very costly, as we will demonstrate. Reducing these costs can lead to further supply chain efficiency as suppliers find it easier to work seamlessly with OEMs without incurring relationship-specific costs that reduce their ability to work for multiple suppliers.

Technical background

Currently, many different computerized engineering, design and analysis, and manufacturing software and hardware systems are used throughout the automotive supply chain. Not only do these systems differ among companies but they can also differ among functions within a company. Each system has its own proprietary data representation. As a result, product data are created and stored in multiple, frequently incompatible formats. Therefore, interoperability problems exist whether files are being transferred between firms or within a firm.

Parties to a data transfer must choose a method for transferring the data from one system to another. The common choices include native format transfer, point-to-point translation, manual reentry of data, and neutral format translation. The choice among the available options depends on a number of factors, including the specific sending and receiving systems, the complexity of the data, and the availability of translators. The decision affects the costs associated with the exchange because different methods for exchanging the file impose different labor and capital requirements as well as different probabilities of error and delay.

The data exchange process is subject to a number of errors. If errors are detected, the parties to the exchange may choose to reattempt the transfer, possibly using alternative settings in the translation software; manually repair the errors; or manually reenter the data that need to be transferred. Some of the more common problems that require repeating the transfer of a solid model or recreating the data include models that arrive with missing, collapsed, or inverted faces; models that do not form closed solids (surfaces and edges do not connect); and models with incorrect feature orientation (Frechette, 1997).

Some problems with file translation and transfer are difficult to detect and may cause problems later in the design and manufacturing process. These errors will most likely be detected later in the production process, either at the prototyping stage, the hard tooling stage, or the production stage. The later in the process these delays are detected, the more costly their consequences.

Even when data transfers are successful, data quality issues can lead to imperfect interoperability. A recent study by the Auto Industry Action Group (AIAG) (1997a) found that these problems are even more difficult to detect than the translation problems described above. The user may not realize that the data are of poor quality until a problem with a downstream software program occurs and leads to the discovery of the problem data. The farther downstream these kinds of problems are detected, the more costly they are in terms of scrapped models, model rework, and project delay.

Sources of interoperability costs

The automotive supply chain incurs several types of costs related to imperfect interoperability. Automakers incur avoidance costs to prevent technical interoperability problems before they occur. Mitigating costs consist of the resources required to address interoperability problems after they have occurred. Delay costs arise from interoperability problems that delay the introduction of a new vehicle. Table I summarizes these sources of interoperability costs, which are discussed in detail below.

Avoidance costs

Avoidance costs include the cost of purchasing, maintaining, and training for redundant CAD/CAM systems for the purpose of native format translation. Many OEMs now require that their suppliers support their preferred CAD/CAM systems so that transfers can be made to and from the supplier in native format. Figure 1 identifies some of the different CAD/CAM platforms currently used by members of the US automobile supply chain. The figure, based on AIAG (1997b), demonstrates that first-tier suppliers that work with several OEM customers and subtier suppliers may have to purchase, learn, and maintain multiple, often redundant platforms or translation software.

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Table I Sources of interoperability costs

Cost category	Source of cost	Components
Avoidance costs	Multiple CAD/CAM systems	CAD/CAM software licenses
		System maintenance
		System training
	Multiple translators	Translation software licenses
		Software training
	Outsourcing data translation	Third-party suppliers
	Investments in interoperability solutions	In-house interoperability research
		Activities in industry consortia
Mitigating costs	Poor quality CAD/CAM files	Scrapped models, designs, prototypes, parts, dies, etc.
		Manual data reentry
Delay costs	Delays	Car sales forfeited
		Delayed profits
		Delayed consumer benefits

Similarly, members of the automotive supply chain may incur avoidance costs to purchase and maintain point-to-point and neutral format translation software. Point-to-point translators require a pair of translators for each unique pair of software systems – one for each direction. Keeping the translator licenses up to date and ensuring that someone is trained to use them can be very costly to a supplier that works with a number of other companies using many other systems.

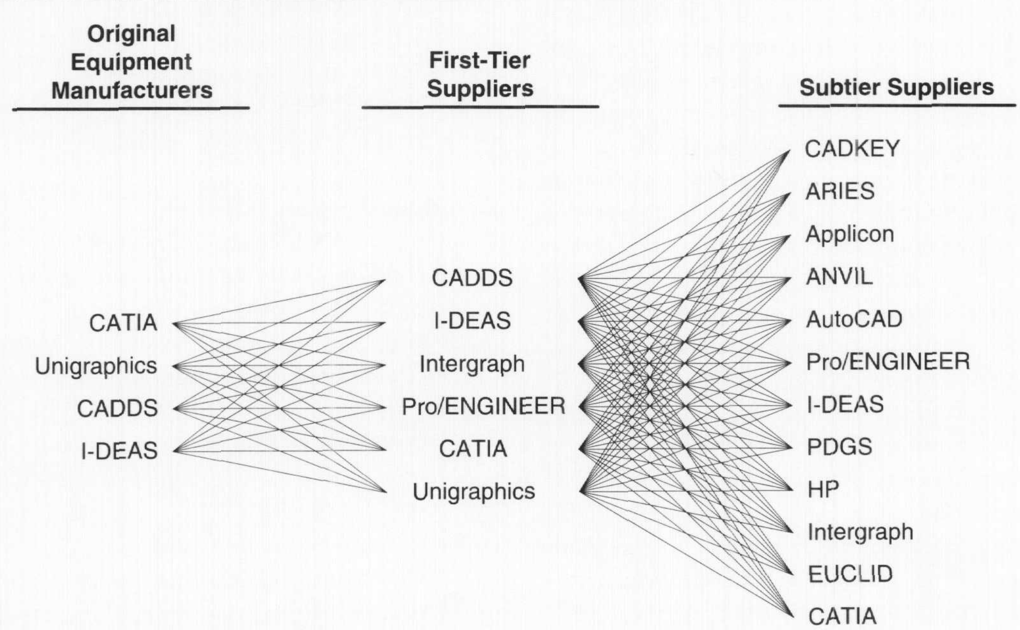
Some companies choose to outsource data translation activities. This approach may be effective for avoiding the cost of purchasing and maintaining software that is used infrequently. However, translation outsourcing may also present problems with quality control. Third parties may not recognize a loss of data and may lack the depth of understanding of the product that is required to make adjustments necessary to solve translation problems. Furthermore, the lack of in-house capabilities may cause a delay in completing a project.

Avoidance costs also include investments in research, training, and other programs aimed at addressing interoperability issues. Individual companies conduct some of this research; an example is General Motors' (GM) investment in the testing of STEP neutral format translators[1]. Other programs, like the AIAG, are jointly funded by industry[2].

Mitigating costs

Problems caused by imperfect interoperability call for mitigating activities. Some data files may have to be manually reentered because no satisfactory method for electronic data exchange is available. Companies working with data files that have been damaged due to imperfect interoperability must invest time and resources in reworking flawed models and

Figure 1 Multiple CAD/CAM systems used in the automobile supply chain



Source: AIAG (1997b)

designs. If data errors are not recognized early on, companies may need to scrap and rework prototypes, dies, or parts.

These mitigating costs may be significant despite companies' investments in avoiding these problems. For example, even native format transfers often cause downstream problems. Different versions of the same software can lead to translation issues, and a lack of standards and procedures for developing product data can limit the usefulness of product model data. An important source of mitigating costs is the unavailability of direct translators for many pairs of software, as well as the limitations of direct translators that do exist.

Delay costs

Automakers have developed a heavy reliance on concurrent engineering over the last decade. Concurrent engineering has reduced cycle time and accelerated introductions of new designs, allowing companies to respond more quickly to changes in consumer taste and advances in technology. However, companies may relinquish market share and the associated revenues to competing producers if imperfect interoperability delays the introduction of new or redesigned models. Producers can incur significant losses even if market share and revenues are not lost; delays in revenue alone reduce the value of profits because they are discounted.

A delay in the introduction of an improved automobile also imposes costs on consumers. The late introduction of a new product or service can lead to a loss in consumer welfare because consumers cannot benefit from the product's improvements until it becomes available. For example, Hausman (1997) found that consumer welfare declined significantly when federal and state regulations delayed the introduction of new telecommunications services. In the context of this study, the delay of the introduction of a new vehicle may force a consumer to purchase a vehicle that does not provide as much net value (value minus price). This loss in consumer surplus can be attributed to the late arrival of the preferred vehicle.

Interoperability cost estimates for the US automotive supply chain

By quantifying the extent of interoperability costs, the US automotive supply chain can assess the potential return to investments in developing solutions to interoperability problems. Our analysis indicates that imperfect interoperability is very expensive to the US automotive supply chain and that solving these problems may improve the performance of the industry by reducing cost and cycle time.

Methodology

We employed two separate approaches to quantifying the interoperability costs described above. Our first approach, which we call the cost component approach, was to collect company-level data on the different components of interoperability cost listed in Table I. The total interoperability cost for a company was estimated by summing these components of cost. Our second approach, which we call the aggregate cost approach, was to ask key industry executives to estimate the total cost of all components of interoperability costs for their company.

Although each approach is crude, each has its merit. The cost component approach builds a cost estimate from information provided by industry and other sources. Because we asked interviewees to provide only portions of the total estimate, this method put less burden on industry officials to process all of the information needed to provide an overall estimate. However, the aggregate cost approach allows industry officials to consider interoperability cost factors that we may not have considered. It allows them to consider the entire scope of the problem and offer a vision of the automobile industry with perfect interoperability among computer systems and software. This approach may provide a more accurate estimate because its scope may be more complete.

By using both of these methods, we were able to provide not only an estimate of the overall costs of interoperability, but also information about the relative importance of these sources of costs. We were also able to compare the estimates to each other. As indicated below, our estimates of the total interoperability costs in the US automotive supply chain do not differ significantly between these two methods.

To estimate the labor costs associated with interoperability, we assumed that most interoperability tasks would be performed by a Level III Engineer, with an average unloaded hourly wage rate of $25.00 (US Department of Labor, 1996a). Adding a

48 percent benefits rate (US Department of Labor, 1996b) and a 60 percent indirect cost rate brings the per-hour labor cost to $59.20.

Because redundant software systems are usually used for a number of years, we treated these costs as a capital investment and annualized them over their expected useful life. We assumed a 7 percent discount rate as recommended by the Office of Management and Budget (1995) and a useful life of five years for the software as recommended by several industry contacts.

Data sources and extrapolation methodology

To construct the two types of cost estimates described above, we collected primary data from representatives of companies in the automotive supply chain. We supplemented this information with secondary data on the automotive supply chain and its design and development costs. We collected the primary data via telephone interviews with representatives of ten companies in the US automotive supply chain: two of the "big three" OEMs, five suppliers, and three tooling companies[3]. To add qualitative information from a slightly different perspective, we also discussed interoperability issues with one company that manufactures auto-related equipment. The combined 1997 sales of the five supplier respondents was over $38.4 billion, representing about 13 percent of the sales of the "large supplier segment" of the auto industry (*Automotive News*, 1998). The three tooling companies we interviewed together comprise about $79 million in sales, most of which is conducted in the auto industry. Although the tooling industry is difficult to define, we estimate that these three companies comprise about 2 percent of the total tooling business in the auto industry (US Department of Commerce, 1995).

Because we surveyed a small purposive sample of the industry, we cannot claim that the survey results are statistically representative of the entire affected population. Nevertheless, we provide a crude extrapolation from our sample results to the population based on sales information available from secondary data sources. For each industry segment, we developed aggregate estimates by summing the costs provided by the respondents and multiplying those costs by a weighting factor based on the percentage of revenue the sample represented. For example, the total revenues of the tooling suppliers responding to the survey represented about 2 percent of total industry revenue; thus, we multiplied their summed responses by a factor of 50. Although this extrapolation procedure does not provide estimates with definable statistical precision, it does provide a cost-effective and reasonable method for developing an industry estimate.

Results

Our analysis indicates that imperfect interoperability imposes about $1 billion of costs each year on the members of the US automotive supply chain. Our two methods for estimating interoperability costs – the cost component approach and the aggregate cost approach – led to very similar estimates. Using the cost component approach, we estimated total interoperability costs in the US automotive supply chain as $1.05 billion; using the aggregate cost approach, our estimate was $1.02 billion.

Because the cost component approach provides a greater level of detail, we focus our discussion below on the results from that method. Table II summarizes the results of our analysis using the cost component approach. The majority of the annual costs are attributable to mitigating costs – the cost of correcting problems caused by imperfect interoperability.

A significant finding highlighted in Table II is the difference between the burdens that interoperability problems impose on each segment of the industry in terms of the percentage of total segment revenue. While these costs comprise less than one-tenth of 1 percent of revenues for both the OEMs and the first tier suppliers, they represent a much higher cost burden for the tooling suppliers. The primary source of these costs is mitigating costs. We explore the causes and implications of these costs below.

Avoidance costs

We estimate that the automotive supply chain spends about $53 million per year on avoidance costs; these costs represent about 5 percent of total interoperability costs. As indicated in Table II, the avoidance cost burden for OEMs is low. This is primarily because they favor a specific CAD/CAM system and require their suppliers to share product data in their preferred format. GM requires Unigraphics, Chrysler requires CATIA, and Ford requires I-DEAS. Hence,

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Table II Summary of annual interoperability costs: cost component approach

	Costs by industry segment				
Source of cost	OEMs	Suppliers	Tooling	Total	Percent of total
Avoidance costs	2,302	35,656	14,841	52,799	5
Mitigating costs	247,773	204,094	455,778	907,645	86
Subtotal	250,075	238,750	470,619	960,444	91
Percent segment revenue[a] (%)	0.075	0.083	11.914	0.513	
Delay costs				90,000	9
Total costs				1,050,444	100

Notes:
All figures are in thousands of US dollars unless otherwise stated
[a] See Brunnermeier and Martin (1999) for details of revenue estimates for the OEM (pp. 2-15), supplier (pp.2-18) and tooling segments (pp.2-20)
[b] We could not determine the distribution of costs for this category

the cost of maintaining multiple CAD/CAM systems falls mainly on the suppliers.

Table III details these avoidance costs by type. Redundant software costs the industry over $30 million per year, split roughly equally between suppliers of automotive parts and assemblies and suppliers of tooling. Some larger suppliers indicated that they had several redundant CAD/CAM systems because they supply several OEMs. In addition, all the suppliers use at least one neutral format software (IGES, DXF, or STEP), and many also use point-to-point translation software. For these redundant systems, costs include not only the one-time purchase price, but also annual license fees, personnel training, and system administration.

Some firms outsource their PDE to third parties, while others have internal departments that operate in this capacity for their internal clients. We included both types of "outsourcing" in this cost category, which we estimate at about $18 million per year. Supplier respondents indicated that they may increase their reliance on third-party translation in the future, particularly as more qualified data translation services become available. However, an OEM expressed concern that third-party translations may cause delays and lead to inferior quality compared to in-house translations.

The OEMs and most of the large suppliers also incur consortia membership fees, labor time devoted to consortia activities, and travel expenses, totaling about $3.6 million per year. In addition, some OEMs have in-house research programs, such as the GM STEP Translator Center, to examine interoperability problems. While the cost of these programs clearly falls into the category of avoidance costs, we were not able to obtain an estimate of the GM STEP Translator Center's budget, nor were we able to obtain an estimate of the other OEMs' internal research activities. Thus, our estimate of avoidance cost is an underestimate that does not include the cost of internal research activities.

Mitigating costs

By far the largest portion of interoperability costs is due to the need to repair or replace unusable data files. The OEMs together spend approximately $248 million per year correcting or recreating unusable data. One OEM noted that downstream engineering departments spend as much as 50 percent of their time dealing with poor translations or

Table III Source of annual avoidance costs

	Costs by industry segment (US$ × 1,000)			
Source of cost	OEMs	Suppliers	Tooling	Total
Redundant software	0	8,918	3,107	12,025
Licenses				
Maintenance	0	4,524	2,821	7,345
Training	0	3,278	8,914	12,192
Redundant software costs	0	16,720	14,842	31,562
Data translation outsourcing	2,042	15,594	0	17,636
Investments in interoperability solutions	260	3,341	0	3,601
Total avoidance costs	2,302	35,655	14,842	52,799

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poor quality CAD/CAM data files. Another OEM noted that, on the average, rework requires an average of 4.9 hours per data exchange. With over 450,000 PDEs per year, this rework is extremely expensive for this company in terms of engineering labor time. Suppliers and tooling companies also incur significant mitigating costs. Suppliers incur over $204 million per year for reworking data files. The need to manually reenter data is especially troublesome for the tooling companies. They report that a large proportion of their jobs require rework or reentry of some kind. These costs amount to over $455 million for all tooling suppliers – significantly higher than the costs reported by the suppliers and a much larger percentage of the industry's total annual revenue.

Our interviews with the tooling suppliers indicate two reasons for these high costs. First, tooling suppliers typically have one primary CAD system into which they must transfer all incoming data (although some large tooling suppliers do maintain a seat on the customer's system to receive the data in the first place). The second reason, which is probably more significant, is that tooling suppliers must make significant changes to the product data to make it useful for their purposes. That is, the data as delivered do not meet the needs of the tooling design, so they have to be reworked to be useful.

Delay costs

We collected information on two types of delay costs:

(1) lost profits due to a decline in market share; and
(2) decline in the net present value (NPV) of the lost profits due to the delay of revenues.

We asked the OEMs and the suppliers to estimate the amount by which development time for their products would fall if interoperability problems did not exist. Although the answers differed among the respondents, the average for the suppliers weighted by their revenue shares was about four months (from an average 36-month development time), and the OEMs estimated a reduced development time of about two months. Using the more conservative estimate provided by the OEMs, we assumed that, without interoperability problems, new automobile models would be available two months earlier if no interoperability problems occurred.

Most respondents indicated that they experienced no significant potential loss in market share due to delays caused by interoperability costs, or that they were not able to quantify this impact. However, producers incur losses simply due to delaying the profits from the introduction of new models. Clark *et al.* (1987) estimated that the discounted present value of the profits from the introduction of a new vehicle could fall by as much as $1 million for each day of delay in product introduction. Martin (1998) verified this estimate via interviews with industry officials. Furthermore, IRN, Inc. (1997) estimates that the three OEMs introduce about one and one-half new models per year (12 new models in eight years) on average. Therefore, we estimate that a two-month delay in the introduction of new models implies a $90 million annual cost for the delay of the introduction of these vehicles because of imperfect interoperability. We were not able to assign these costs by sector, however.

Discussion

We estimate that imperfect interoperability costs the US automotive supply chain about $1 billion per year. We consider this a conservative estimate. The project's scope and resource constraints and data limitations prevented us from quantifying several additional sources of interoperability costs. These include the following:

- *Post-manufacturing interoperability costs.* We considered only the interoperability costs involved in designing and manufacturing automobiles. Interoperability problems also occur during other phases of the product life cycle, including marketing, after-market product support, and cost analysis.
- *Interoperability costs of small suppliers.* This study quantified interoperability costs to the OEMs, large suppliers, and tooling suppliers. However, smaller suppliers may also incur costs.
- *In-house investments in interoperability solutions.* We were unable to quantify all of the industry's investments in developing interoperability solutions. These investments may be substantial. For example, GM's investment in its STEP Translator Center is not included in our estimates.
- *Costs to consumers resulting from delays.* Interoperability problems delay the introduction of new and redesigned

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autos. Our estimates do not include consumers' welfare losses resulting from delays in the availability of new and improved products.

- *Loss of market share resulting from delays.* We hypothesized that the US auto industry could suffer a loss of market share resulting from interoperability delays, which could lead to a loss of profits to the industry. We were not able to quantify these lost profits; however, they probably are minimal.

Methods for reducing interoperability costs

Our study indicates that the automotive supply chain spends about $1 billion per year trying to prevent or correct interoperability problems. In response to this need, the auto industry has investigated a number of potential interoperability solutions. Below, we discuss the merits of some of these potential solutions.

Single system standardization

Standardization on a single system may seem like the simplest way to ensure compatible data because an exchange of product data in native format requires no translation. However, even within a single company, enforcing this standardization can be difficult because different parts of the organization have different needs, and a single system may not meet all of these needs. Furthermore, even when a single system is mandated, using different versions of the software may create translation problems.

Enforcing a single-system standard across the members of the US supply chain can be even more difficult and costly. It restricts the company's collaborators to users of the same technology. Alternatively, the company with greater market power can force potential collaborators to adopt its system of choice. The three major US automobile manufacturers require their first-tier suppliers to maintain specific systems for the purpose of sharing product data. Many suppliers work with more than one major customer, each of whom requires a different system. In addition, many of these suppliers have customers outside the auto industry. This situation creates significant extra cost because, as documented in this study and by AIAG (1997b), maintaining these multiple systems concurrently causes:

- less than optimal use of the systems in place, because some systems are only used a small percentage of the time (e.g. used only to transmit data to a specific customer);
- decreased proficiency of CAD users in each of the multiple systems maintained and a resulting decrease in the flexibility with which the engineering staff can be used;
- increased cost for maintaining and administering the multiple systems and increased system administration problems and system down time;
- increased training costs because CAD users must be trained on multiple systems;
- increased number of data transfers among multiple systems used concurrently for the same design project, along with the attendant accuracy problems and costs;
- increased costs of product data management, which becomes increasingly expensive because changes must be tracked through multiple design systems; and
- increased costs of maintaining quality and procedure standards for CAD data, which reduces the quality of the CAD data entering systems.

These costs may be especially burdensome to small companies that produce small volumes because some of the costs of purchasing, maintaining, and gaining expertise in these systems are fixed, rather than variable, costs. Small companies cannot spread the costs of investment in these systems across a large enough volume to make it cost-effective (*Target*, 1994). Thus, these requirements can function as barriers to market entry.

Point-to-point translation

A second approach to sharing data among applications is to develop and use a conversion program that transforms data from the form used by one system to the form used by another system. For some well-defined data translation tasks, these translators work fairly well. However, the drawbacks of this approach include:

- the need for a pair of translators for every combination of systems that require translation (Frechette, 1997);
- the need to update each translator when either of the two systems' software is updated; and
- the lack of availability of translators for all software and all tasks.

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In addition, a high degree of vendor cooperation is necessary to develop direct translators. Sawant and Nazemetz (1998) point out that such cooperation is limited because the development of viable translators requires disclosing proprietary information about the software. Vendors are understandably reluctant to share such information with competitors.

A variation of the point-to-point translation method is a method known as "native-to-native." This method, currently being offered as an Internet-based service by Translation Technologies, Inc. (TTI), provides a conversion that has all of the original geometry and geometric features of the original drawing, recreated in a specified target software application. The files are completely tested for accuracy before being completed. Unlike most point-to-point translators, the TTI technology does not require a different pair of translators for each combination of systems that require translation, and updating the translations methodologies for new software versions is relatively simple (TTI, 2001). The final translation is fully modifiable just as though the file was originally created in the target software (*Computer Graphics World*, 2001). TTI offers translations to and from Pro/E and CATIA and will soon add service for SDRC I-DEAS Unigraphics, SolidWorks, and Autodesk.

Neutral format translation

Another approach to sharing data among multiple systems is to develop a common neutral format for exchanging the data. Implementing the neutral format requires a pair of translators (read and write) between each application and the neutral format. Such translators are often called "half translators." With a neutral format, only two translators are required for each software system. These two translators allow a user to exchange data with any other software system. This approach reduces the cost of translation with multiple systems and simplifies the maintenance of translators as each system evolves. Vendors are also more willing to develop half translators because they do not require the disclosure of proprietary code. A vendor can build a pair of half translators for his product without interacting with his competitor (Sawant and Nazemetz, 1998).

Two alternative neutral format solutions are used most often to exchange CAD data in the auto industry: Initial Graphics Exchange Specification (IGES) and Drawing Exchange Format (DXF). IGES, which is a US national standard, is supported by most CAD/CAM systems. DXF is a proprietary format defined by AutoDesk, the makers of AutoCAD. It is almost universally used for exchanging CAD/CAM data on personal computer-based systems and is used extensively by subtier and tooling suppliers.

Although IGES and DXF have been very successful in some limited applications, they have a number of weaknesses. IGES and DXF are limited because they were designed mainly to communicate design data, but many other types of data that support manufacturing, marketing, technical areas, cost analysis, and configuration management are required. Since IGES is an American National Standards Institute (ANSI) standard, interpretation outside the USA is also problematic, further limiting its usefulness. The US Product Data Association (US Pro) is currently developing an IGES 6.0 release. The company has indicated that this will be the last IGES upgrade and that it will focus future development efforts on STEP with only maintenance upgrades to IGES (Sawant and Nazemetz, 1998).

STEP, an alternative neutral format, is emerging as a potential solution to the interoperability problems in the automotive and other industries. The International Organization for Standards (ISO) adopted STEP as ISO 10303 to achieve the benefits of an internationally accepted neutral format exchange standard. Rather than translating data from one software system into another, STEP provides a complete computer-interpretable product data format. STEP allows users to integrate business and technical system data and covers all aspects of the business cycle, from design to analysis, manufacturing, sales, and service.

STEP goes beyond currently available neutral format translators in several ways. First, it includes more of the types of data required to develop, analyze, manufacture, document, and support many types of products. Second, rather than operating only on the elements common to two systems, STEP provides a base model that incorporates a superset of existing systems and extensions to support special application needs. Furthermore, because STEP is being developed by the ISO, it will enable US

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companies to interact with suppliers and customers abroad.

Recent tests have demonstrated STEP's technical advantages over other data translation methods. STEP has performed better in most cases than IGES, despite the fact that IGES was implemented at least ten years earlier than STEP (Strub, 1998; PDES, Inc., 1998). The AutoSTEP pilot project has documented a steady improvement in performance of STEP translators over time (Fleischer, 1997), indicating STEP's potential for improving data exchanges as its implementation moves forward and the commercially available STEP translators improve. AutoSTEP participants have transferred over 100 production part models between supply chain partners using STEP as the neutral format. Of these models, 83 percent translated as valid solid models, and the project has been very successful at identifying and addressing translator errors (Frechette, 1997).

Conclusion

Electronic PDE has become increasingly important in a number of industries. Concurrent engineering and lean manufacturing are now common practices, and many industries rely on digital simulation and analysis. At the same time, the evolution of business-to-business (B2B) exchanges is enabling more companies to drive product design down the supply chain. Adrian (2000) argues that business partners that fail to link collaborative business processes in the design and supply chain will not survive. In this environment, the cost of imperfect interoperability mounts as the number and complexity of data exchanges increases. Benefits from improving interoperability can be realized not only in the automotive industry, but also in other PDE-intensive supply chains like shipbuilding and aerospace.

In the auto industry, design outsourcing and concurrent engineering are a critical component of competitive strategy. By allowing each member of the supply chain to focus on key competency, the industry is reducing the cost and time required to develop new products. Today, the US automobile industry spends \$2 to \$3 billion on developing a new automobile or truck design (Greenwald, 1998; Jost, 1998). With as many as 12 major platform redesigns and eight minor redesigns per year (IRN, Inc., 1997), even a small percentage decrease in the cost of designing an automobile and its factory can lead to significant savings.

Interoperability costs inhibit the full implementation of the industry's competitive strategy. The \$1 billion the industry spends each year addressing interoperability problems impedes improvement of the efficiency of the concurrent design process. OEM requirements for single-system standardization impose relationship-specific capital costs on suppliers, creating a barrier to entry that limits competition among suppliers. Thus, reducing interoperability costs can improve supply chain efficiency not only by reducing costs, but also by encouraging competition.

Tooling suppliers represent perhaps the greatest potential for reducing interoperability costs in the US auto industry. Our research indicates that tooling suppliers incur much greater cost in proportion to the size of their revenues than do the other components of the supply chain. This industry consists of many small companies whose operations are sometimes not well integrated into the rest of the supply chain. These small companies often use one primary CAD system into which they must transfer all incoming data, and quite often must make significant changes to the product data before they can proceed with tooling design. Improving interoperability between the tooling suppliers and the rest of the supply chain could be a key strategy in further improving the concurrent design process.

Although past efforts to develop a solution to imperfect interoperability have been largely unsuccessful, translation technology is quickly improving. The auto industry and other industries recognize the importance of improved interoperability to future competitiveness, and they are investing in developing solutions. New methods for native-to-native translation are addressing some of the problems associated with point-to-point translators. STEP, a neutral format being developed by the ISO, also has a number of technical advantages over other translation methods. However, even STEP will not solve all interoperability problems like those stemming from CAD system numerical accuracy mismatch and poor data quality. These issues are not directly related to data translation, however, and must be solved in other ways.

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Notes

1 GM established its STEP Translation Center in 1995 to evaluate STEP implementation. The center was disbanded in 1999 after its objectives had largely been met.
2 For example, AIAG, with the support of NIST and the Department of Defense, implemented the AutoSTEP pilot project to introduce STEP to the auto industry.
3 The identity of individual survey respondents has been masked for confidentiality reasons.

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