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Collecting manufacturing information in a global distributed manufacturing environment

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1. Introduction

The increasing sophistication of computer-aided design (CAD) tools has made it easier and faster to design products made up of more and more complicated and intricate parts. Without sufficient experience or guidance, today's designer runs the risk of developing product designs that are unnecessarily difficult to produce. Moreover, selecting the most appropriate manufacturing technologies and understanding the consequences of these selections are important and necessary aspects of the overall design process that lead to improved function, better appearance, and lower cost for the final product. Making these selections in the conceptual phase where they have the greatest impact on overall development cost and efficacy is critical. From the start, the design team must have pertinent and accurate information about the available manufacturing technologies and the fabrication and production methods of their manufacturing suppliers.

Finland carried out a national development project for technology in the years 2005-2007. Four Finnish universities of technology and eight leading Finnish businesses participated in the project. The primary purpose was to improve efficiency and speed during the early conceptual phases of the design process. The Lappeenranta University of Technology and one of the participating businesses worked with two contract manufacturers to exercise and evaluate an approach for collecting information about the contractors' capabilities and methods. A comprehensive set of survey forms designed to collect this information was given to the contract manufacturers along with an order for the production of a complex sheet metal assembly. The contractors completed the forms during manufacture and returned them upon delivery of the completed product.

Evaluating the returned information for accuracy and value showed the survey approach to be useful and a potentially valuable tool, but pointed out some deficiencies and some possible areas for improvement.

2. Product design challenges in a global manufacturing environment

In product development, design engineers need to satisfy product form and functionality requirements while keeping material and manufacturing costs as low as possible. To accomplish this, the design engineer relies on expertise in the principles of design, engineering, materials, and manufacturing. In today's global distributed manufacturing environment where the manufacturer may be across the world speaking a different language, it is becoming increasingly difficult for the design engineer to keep up. Readily available materials controlled by familiar material standards may be more difficult to acquire and controlled by unfamiliar standards. In addition, manufacturing technologies and methods may vary depending on the location of the contracted manufacturer, and these variances may change as technologies and methods continue to advance.

Decisions made early on in product design establish a large percentage of the overall manufacturing cost of a new product. Decisions made during conceptualization can control materials and manufacturing for the life of the product. Therefore, the design engineer must understand from the beginning the material availabilities and the manufacturing capabilities for each region where the product will be manufactured.

2.1. Understanding the costs of global distributed manufacturing

One appeal of global distributed manufacturing is the potential to reduce manufacturing cost, and often when embarking upon this manufacturing strategy, the focus of attention is labour cost. However, cost of labour is often a small portion of the overall cost of manufacturing [1]. In a distributed manufacturing system, there are many other cost factors. According to Dewhurst [2], these can include taxation, transportation, and quality management. Häkkinen [3] suggests taking into account the following costs; developing the relationship and starting up product manufacturing with each new supplier, the planning and implementation of logistics, production planning, preparing and agreeing to contracts, financial issues and accounting and also quality planning [4]. Ignoring these cost factors seriously under predicts the overall product manufacturing cost.

2.2. Practical design challenges of outsourced manufacturing

The product selected for this study is produced by contracted manufacturers located around the world. To minimize unit and logistics cost, each is close to its local consumption and logistics centers. Previously, this product comprised over 300 parts. To support a new global distributed manufacturing strategy, the client simplified the product design, which is now a sheet metal assembly of 63 individual parts. The design of each part accommodates as many manufacturing methods as possible.

To control basic design integrity, the responsibility for product design over a product's lifetime is often assigned to a single design center. However, with global distributed manufacturing, contracted suppliers may be familiar with different materials, manufacturing technologies, and methods. The different cultural practices of their personnel may result in other unexpected challenges. These differences combine to result in uncertainty for the development team regarding the suitability of their material and manufacturing choices.

Preparing a manufacturing documentation package intended for global consumption is another challenging aspect of product development for the global distributed manufacturing strategy. Extra care must be taken to ensure that CAD models and fabrication drawings are complete and sufficiently detailed to convey all the original design intent. Even so, differences in drafting standards from country to country and CAD tools from company to company make a seamless transfer of manufacturing documentation impossible. In many cases, the contract manufacturer must prepare a second manufacturing documentation package compatible with its own systems and personnel to perform effectively. This inevitably results in communication problems and manufacturing errors, especially as the product changes over time.

In addition to the manufacturing documentation package, producing high quality products at the right time without wasting resources depends on a number of other factors. The fabrication drawings prepared by the design center specify material requirements. The contracted manufacturer then procures the materials and ensures they satisfy material specifications. Around the world, a number of materials standards control the production of materials used to fabricated products. Though fundamentally similar, materials produced according to different standards satisfy different requirements. In developing markets, the situation is even more complicated because the material supplier base may change rapidly making it difficult to qualify new suppliers continually.

Once the material procurement issues have been resolved, the manufacturing contractor faces the challenge of properly managing the material stock. How well the contractor manages material does not directly affect the client, but costs associated with poor handling and storage of materials will ultimately influence manufacturing cost. In addition, poor material handling may lead to the manufacture of products with functional or cosmetic defects. These products may ultimately end up in the hands of the end user, which does have a direct negative effect on the client.

Tool condition often significantly affects the quality of fabricated parts. Punching inaccuracies that exceed design tolerances result in parts that cannot be assembled without rework. The challenge of maintaining product quality in the face of variable tool condition is best met by acknowledging the problem and accommodating the consequences of poor tool condition in product design.

Finally, there are practical challenges associated with the manufacturing methods or sequence of operations. Typically considered part of good design practice, factoring manufacturing method into the design becomes more difficult when the manufacturing is carried out in different countries using methods. In some cases, manufacturing relies heavily on manual labor and little automation is available. In others, automation plays a more important role. The product development team must account for either scenario.

2.3. Collecting manufacturing information pertinent to design conceptualization

For this study, the client ordered a number of sheet metal assemblies from two new contract manufacturers located in China. Along with the order, the client requested the contractors to complete and return a comprehensive set of survey forms related to their manufacturing of the assemblies. The forms were designed to gather information about the technologies and methods employed by the contractor to produce the ordered assemblies. They also asked about the contractors' management of the production process, materials, and quality. The primary purpose of the exercises was to evaluate the survey form approach as a method for providing information to the client's product design team.

The survey forms were based on feature classes introduced by Lohtander et al. [5, 6], which classify the shapes and features of sheet metal parts into manufacturing-related features. The features include common sheet metal fabrication operations, such as bending, marking, and threading; and characteristics, such as material type and thickness. This kind of feature-class-based manufacturing information collection was introduced and described previously by Lohtander et al. [7].

The following paragraphs list the menu of operations for each sheet metal fabrication category. The client designed each individual part of the sheet metal assembly for multiple fabrication methods, and each contractor was free to produce the assembly using its own preferred methods. Therefore, the survey forms list a large number of individual operations. This comprehensive listing also helps to develop the survey form approach, which is expected to evolve over time by both adding to or omitting listed features and operations. The original survey forms also provided space to add operations not listed by the menus and other comments.

2.4. Production and materials management information

The survey forms covered two separate aspects of manufacturing; production management and manufacturing methods. The forms covering production management, intended for supervisory personnel, included questions about documentation, materials management, and quality management.

Sheet metal production depends on a detailed and accurately prepared documentation package, which includes items such as CAD models, fabrication drawings, and materials specifications. To properly design and document sheet metal parts, the development team needs detailed information on the documentation needs of the contract manufacturer and on how the documentation package is used. Questions asked by the "production management" forms regarding documentation include the following: Where do the drawings originate? In what form do they reach the employee? Are new drawings prepared for manufacture based on design drawings? How and by whom are the unfolding measurements for the sheet metal parts defined?

According to Ollikainen [8], quality defects and production errors are common problems for sheet metal fabricators. How the contractor manages part fabrication quality and the quality of the final product is the focus of the production management forms for quality assurance. Questions asked include: What does quality management for the final product involve, and how is it carried out? What does quality management for subcontracted parts and subassemblies involve, and how is it carried out? How is the quality management system applied?

Material was another item addressed by the production management forms. The study sought to uncover differences between the specified materials and material thicknesses and the materials and thicknesses used by the fabricator. Also examined was pre- and post-fabrication material finish.

Careful handling of raw materials can save costs. Therefore, the survey form questions explored material handling and management. In particular, questions asked about transport of materials to and from material storage and to and from the fabrication equipment. More questions addressed how material was handled during fabrication.

How material stock is stored is an essential factor influencing fabricated part quality. Depending on the country and climate, raw material may be stored in a wide range of conditions. For example, material stock stored in Scandinavian countries must be protected from the elements to avoid corrosion problems. Survey form questions asked how raw materials were stored and in what form. Storage categories included the following: Sheet or roll storage and indoor or outdoor storage.

Tool condition often significantly affects the quality of fabricated parts. Punching inaccuracies that exceed design tolerances result in difficult to assemble parts. These parts need rework, which adds cost. Problems associated with worsening tool condition are best addressed by recognizing the inevitability of tool condition degradation and adjusting the product design accordingly. Survey form items addressing tool condition included: Monitoring the condition of tools. Visual estimate, automated monitoring, randomly or regularly and also itemizing the processes that monitor tool condition.

2.5. Fabrication technologies and operations

The survey forms for "manufacturing methods" gathered information on manufacturing technologies, the fabrication operations, and their sequence. This group of forms covered the fabrication of individual sheet metal parts, addressing the resources and sequence of operations first. Then, the forms sought descriptive information for each operation along with a listing of each associated event, parameter, and auxiliary function.

Cutting and punching are fundamental sheet metal forming processes and of particular interest in this study. There are various ways to cut and punch sheet metal stock. It can be done using laser or water jet cutting equipment or with more traditional cutting and punching presses. The most common methods used today involve CNC laser cutting systems or multitool CNC punch presses. A single fabrication machine may carry out multiple operations, or they may be carried out using multiple pieces of fabrication equipment. Cutting and punching equipment includes the following: A Punching Machine, Presses, A Guillotine Shear, Follow-On Tools, Rolling Coulters, Knife Tools, Laser Cutting, Plasma Cutting, Water Jet Cutting and A Cutting Die.

Bending is another important sheet metal fabrication process. Traditionally, bending operations have been performed using a press brake using positioning marks, which is manpower intensive. More recently, bending is carried out with highly automated panel benders or robotized edging presses. Sheet metal parts are also bent with presses equipped with tools for the purpose. In the case of robotized edging, the part must be designed carefully so the robotized gripper gets a firm grip. Special tooling is needed to make box-like parts accurately. The "bending" forms aimed to identify which bending method was used in edging: edging press, robotized edging press, automatic panel bender, folding machine and traditional presses.

The forming of sheet metal parts comprises many different forming methods or their combinations carried out under compressive stress. Large batch sizes and short manufacturing lead times are characteristic of forming methods. In addition, sheet metal forming provides added strength, a high-quality surface finish, and dimensional accuracy. The "forming" survey forms aimed to determine positioning techniques, machining parameters, and lubrication requirements. Operations surveyed included: deep drawing, stretch forming, rolling and forming with a corner-former.

The aim of the "machining" forms was to determine the machining method and related parameters. In addition, the forms questioned the auxiliary functions related to the work operations. Thread cutting was assigned a form of its own, since it can be done with a number of methods and using a variety of equipment. Sheet metal threads can be added by cutting or rolling to either flanged or unflanged holes. Thread cutting forms examined which of the following machines were used: a machining centre, a milling machine, a turning machine and a drill.

Sheet metal part fabrication often involves grinding. Grinding takes place both before and after the forming operations. Grinding following forming operations may result from imprecise forming or forming with degraded tools. In either case, it is an avoidable operation and expense. On the other hand, grinding can be necessary. For example, grinding if often needed to clean up paint overspray or to spot remove plating because it would be more costly to avoid the overspray or mask the spot beforehand. "Grinding" forms considered the following grinding equipment: circular grinder, face grinder, tool grinder, robot, manually operated grinder and manual grinding.

Surface treatment gives a product its final look and finish. Sheet metal products generally require preliminary treatment before the actual surface treatment. The "surface treatment" survey forms covered treatment methods and coating parameters, such as target thickness of the coating and color. Preliminary treatment; such as rust and grease removal, cleaning, and phosphating. Actual surface treatment covered issues; such as hot galvanizing, spray painting, plastic coating, and anodizing. After-treatment survey covered asking; such as removal of protective elements, threads, and paint flashes.

2.6. Assembly and packaging

The goal of the assembly and packaging survey forms was mainly to determine the sequence of these operations and the methods used for final assembly. Assembly and packaging operations included: printing/serigraphy on sheet metal parts, packaging of individual parts, subassemblies, equipment of end product, assembly of end product and packaging of end product.

3. Evaluating the collected information

The following paragraphs make general observations about the information provided by the survey forms and discuss the use of the survey form method. Using the forms to compare contract manufacturers was problematic because each approached their forms differently and provided different types of information. In addition, there was some question about the integrity of some of the information given.

3.1. Organizing the data

The data collected was organized into tables for assemblies and tables for parts. These tables present the manufacturing information stage by stage and operation by operation. For each fabricated part, the tables included comments resulting from incoming inspection of the part and comments about the fabrication documentation. The letters A and B identified the two contracted manufacturers.

The survey forms covering manufacturing methods provided an area to list and sequence the fabrication operations. They requested data on the materials used and the dimensions of the raw stock. There were check boxes to identify cutting methods and other relevant information, such as loading and unloading equipment, tool type, and cutting parameters. The forms also inquired about any other auxiliary stages.

Among many other useful items of information, the forms revealed that contractor A fabricated a given part by first cutting the blank and then punching and forming the finished part. Contractor B performed the cutting and punching in one operation using a CNC laser cutter.

3.2. Quality of the responses

Contractor A filled out the documentation survey form for all 63 parts. Contractor B, however, only filled out the forms for 61. Contractor B did not explain why the forms were missing for two of the parts.

Some of the information that Contractor A provided was more difficult to analyze, because instead of strictly completing the form entries, the contractor provided written explanations that were not easily processed. An additional category had to be added for supplementary information or details added by the contractor. Fabrication operations falling into this category included stamping, laser cutting, PEM insertion, washing, oxidation, painting, and riveting. If possible, this information was recategorized based on the engineering judgment of the data processing personnel. In most cases, it was possible to move the data to an appropriate category. For example, parameters for oxidation and painting could be moved to the surface finish category and laser cut punching operations could be recategorized under punching. This inconsistency in filling out the forms resulted in missing data.

Contractor B, on the other hand, did not offer any equivocal elements in their answers, but overall, they were less specific with their answers than contractor A was. For instance, contractor B did not mention punching as a working stage, but had given parameters and other information related to punching.

3.3. Quality of the information

Visual inspection confirmed the accuracy of much of the information contained in the survey forms. For example, by visually identifying nibbled or laser cut features, it was possible to verify the reported sequence of operations. However, it was not possible to confirm all the supplied information. On the material form, the contractors' listed material supplier and initial sheet stock size. Neither was verifiable. On the assembly and packaging form, information from one contractor's report was more complete than from the other's. For example, the second contractor's report did not refer to packaging at all. There were mistakes made by both contractors in filling out the returned forms. Some of the mistakes were obviously copy-paste errors and easily ignored, but others remained uncertainties.

The comparability of the returned survey forms was good in terms of the manufacturing methods and sequence of operations. Data processing personnel could easily determine the primary manufacturing practices and the order of operations for each contractor. On the other hand, there was little detail available. This lack of detail is a clear drawback in the survey form approach. Because they understood and responded to the survey forms differently, using the information to compare contractors was difficult. For example, punching methods were not comparable, because while contractor A itemized all the different punching operations, contractor B did not entirely complete those form sections.

The forms covering production management included questions about documentation, materials management, and quality management. This information did not provide enough detail to judge it on a part-by-part basis. The contractors' responses were more general and were not part specific. The most important data gained from the management forms concerned material and the size of the raw material stock.

4. Discussion of the survey approach and recommendations for improvement

In general, the information received back from the contract manufacturers related specifically to manufacturing operations and did not provide a lot of information on manufacturing technology. The manufacturing steps taken by each were different, however both approaches seemed reasonable and produced similar results; an acceptable finished assembly for essentially the same cost.

While clearly still being developed, the survey form approach appears to be a useful tool to keep the design and development team up to date regarding the available manufacturing technologies and methods. Both contractors completed the survey forms and provided most of the requested information. There were, nevertheless, some errors in the information given. Regardless, the responses were relevant overall and allowed data analysis personnel to draw conclusions about the targeted manufacturing-related issues.

The results of this study cannot be applied generally to all situations. Each client-supplier relationship differs and these differences will affect the survey approach. In this case, the relationship between the client and the contract manufacturers was new and offered significant future business for the contractors. The contractors were likely eager to establish the relationship and therefore more cooperative about thoroughly completing the survey forms. In general, this may not be a problem, because the client's design and development team has a greater need for information about a new supplier and does not really need as much information from the more familiar established suppliers.

The results of this study will serve as a basis for further development of the survey form method. It will make it easier to understand what needs to be added and what can be left out. The exercise clearly showed the survey forms should be more user-friendly for the contractor. In addition, the forms need revision to assure they gather data that is more easily processed by the data analysis team. Some parts of the survey did not provide any useful information. Future surveys may omit these items. Finally, there may be value in customizing the survey forms for each application to ensure the information requested is relevant to the expected specific manufacturing technologies and methods.

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M. Lohtander, I. Varis

GAMYBOS INFORMACIJOS RINKIMAS GLOBALIAI PASISKIRSČIUSIOJE ERDVĖJE

R e z i u m ė

Suomija 2005-2007 metais parengė nacionalinės gamybos plėtros projektą. Juo siekta padidinti konceptualaus projektavimo efektyvumą ir greitį ankstyvoje proceso fazėje. Labai svarbu žinoti galimų gamintojų galimybes ir gaminio projektavimo metodus. Optimizuojant gaminio paskirtį, išvaizdą ir kainą, projektuotojui būtina susipažinti su galimomis gamybos technologijomis ir nuo pat pradžių panaudoti jas savo projektuose. Patikimam ir nepertraukiamam gaminio tiekimui užtikrinti projektai turi būti konkurencingi su galimais gamybos ir našumo metodais. Šio tyrimo užsakovas reikalauja iš dviejų kontrakto vykdytojų sukomplektuoti lakštinio metalo rinkinį ir pateikti jį gamybai tinkama forma. Šio tyrimo tikslas įgyti daugiau žinių apie rangovo galimybes bei metodus.

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COLLECTING MANUFACTURING INFORMATION IN A GLOBAL DISTRIBUTED MANUFACTURING ENVIRONMENT

S u m m a r y

Turbochargers Finland carried out a national development project for technology in the years 2005-2007. The aim of the project was to improve efficiency and speed during the early conceptual phases of the design process. An understanding of the capabilities and methods used by the available manufacturers is important when developing product designs. To optimize product function, appearance, and cost; designers must be aware of the available manufacturing technologies and incorporate them from the start into their concepts. To ensure reliable and sustainable product delivery, concepts must be compatible with available fabrication and production methods. For this study, a client ordered a complex sheet metal assembly from two of its contract manufacturers and requested they complete and return a comprehensive set of survey forms related to its manufacturing. The effectiveness and value of this survey approach to increasing knowledge of the contractors' capabilities and methods is the subject of this paper.

Keywords: Sheet metal, manufacturing, manufacturing processes of sheet metal products.

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