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Taxonomy Based Assessment Methodology: Improving the Manufacturability of a Product Design

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Abstract

Studies have shown that a substantial portion of lifecycle costs are committed during the product design stage. The literature suggests that manufacturability concerns are one of the major drivers of lifecycle costs. This paper explores the development of a first generation Manufacturability Assessment Methodology (MAM) for use during product development. This methodology draws upon a manufacturability taxonomy and a resulting metric, which are original to this research. A case study application of the Manufacturability Assessment Methodology is reviewed and lessons learned from the case study are presented. Guidelines are presented in order to assist the practitioner. Also, future research is outlined.

Keywords
Manufacturability, Assessment, Metric, Lifecycle, Taxonomy

1. Introduction
It is clear from the literature that the design activity plays a major role in establishing lifecycle costs. Anderson (2014) reflects that 80% of product lifecycle costs are "committed" during the product design phase, while 80% of lifecycle costs are "incurred" during the manufacturing phase [1]. Therefore, in order to reduce overall lifecycle costs, it is critical to design products that are manufacturable. The notion of design for manufacturability is a very important topic among practitioners, however little was found in the literature on this topic from an overall systems perspective. It is the objective of this paper to present a novel approach to assessing the manufacturability of a product design. A working definition of manufacturability was adopted by the research team, which states "manufacturability refers to the ease with which a product can be produced."

The Manufacturability Assessment Methodology (MAM) draws upon a taxonomy of manufacturability concerns (i.e. lifecycle cost drivers), which is original to this research. The purpose of this taxonomy is to guide a cross functional team of qualified experts through the assessment process, which is intended to provide a basis so that the assessment is comprehensive and consistent. One of the outcomes of the methodology is the development of a manufacturability metric. The metric reflects the overall manufacturability of the product and pinpoints which features of the design need attention. Finally, the methodology concludes with the development of specific design recommendations which target improved manufacturability of the design.

2. Methodology Development
The methodology was developed assuming a mature product design (i.e. prototype or low rate production). This enabled the team to apply the full scope of the manufacturability criteria. Later efforts will focus on applying the methodology to earlier phases of the product development cycle, where designs have less fidelity, with potentially larger impact on lifecycle costs.

This methodology draws upon an overall assessment framework first published by Walden and Greenwood (2009). The framework involves three overarching phases – Evaluation, Diagnosis, and Prescription. This is termed the E-D-P cycle [2]. The "evaluation" phase establishes, for a given design, a metric that is derived from a taxonomy of manufacturing concerns (e.g., ease of assembly, redundant parts, need for special tools/processing). The "diagnosis" phase deals with the specific details of the design that appear to be driving the manufacturability metric (i.e. cost drivers). The "prescription" phase references a taxonomy of best practices that target improving the design's manufacturability. Once the manufacturability concerns are addressed then the design undergoes another iteration. Continuous improvement in the design's manufacturability can be tracked through the manufacturability metric.

2.1 General Structure of the Methodology

The MAM is based on a judgmental review of the design characterized by key criteria of manufacturability. To ensure a successful evaluation, the assessment must be done by a qualified SME (Subject Matter Expert) with experience and knowledge in the manufacturing industry. The product design must be relatively complete with design documentation (e.g. BOM, design drawings, technical specifications, 3-D CAD, etc.) made available to the SME (i.e. assessor). These guidelines along with the three phases of the E-D-P cycle are used to explain the overall approach of the methodology. The MAM has three main areas of concentration:

- Manufacturability Interaction Matrix (MIM) - A taxonomy of manufacturability potential concerns.
- Assessment Metric Framework (AMF) - Judgmental review of each element of the MIM for each item on the Bill of Material (BOM). This includes rolling up the scores across each level of the BOM.
- Manufacturability Assessment Instrument (MAI) - Assessment software tool uses input from the accessors to calculate the manufacturability scores and provide product design recommendations.

These focus areas establish the structure of the MAM and are discussed in the following sections.

2.2 Development of the Manufacturability Taxonomy

Manufacturing processes are complex and impacted by many factors of a design. As a result, there are potential concerns which have the ability to disrupt the manufacturing operations. In order to assess the manufacturability of the design, it was necessary to develop an organized listing of these potential concerns. The organization of these concerns, or elements, forms the manufacturability taxonomy.

To initiate this effort, the team consisting of industrially experienced members, performed a brainstorming exercise to identify these elements. This activity resulted in the development of an affinity diagram which was created to categorize these elements. During the review of the affinity diagram, the team clearly recognized that interdependencies existed between these major categories. Therefore, a matrix approach to organizing these elements was utilized as opposed to a list that assumed mutual exclusivity. It was determined that the nature of the interdependencies was reflected by answering the following general question: What is the impact of this "aspect of design" on this "aspect of manufacturing"? This led to the initial version of the Manufacturability Interaction Matrix (MIM), shown in Figure 1.

Aspects of Design / Aspects of Mfg	Design	Material	Product Dimensioning	Special Tools	Part Geometry	Special Skills	Ease of Assembly	Reliability	Process Capability	Capacity and Scalability	Ergonomics	Material Handling, Transporting, and Packaging	Strategic Sourcing	Quality testing and equipment	Maintainability
Process	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Supply Chain	X	X			X	X				X	X	X		X	X
Equipment/Tools	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Facility	X			X	X					X	X	X	X	X	X
Labor	X						X		X	X	X	X	X		
Quality	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Cost	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
EHS	X	X		X	X	X	X			X		X	X	X	
Sustainability	X	X		X	X		X				X			X	

Figure 1: Manufacturability Interaction Matrix

These "aspects of design" were defined as the key component or risk area of the product design that has impact on a particular area of manufacturing, "aspects of manufacturing." The intent was for the assessor to evaluate each cell marked with an "X." Based on the MIM in Figure 1, the following are examples of evaluations made by the assessor.

- What is the impact of "part geometry" (aspect of design) on the manufacturing "process" (aspect of manufacturing)?
- What is the impact of "ease of assembly" (aspect of design) on "quality" (aspect of manufacturing)?

2.3 Development of the Assessment Method Framework (AMF)

The Assessment Method Framework (AMF) established the strategy for the assessment process. With the creation of the MIM, the essential aspects of design and their respective, contributing aspects of manufacturing were established. Since the actual impact or importance of each element will vary, a method of "weighting" was required.

One particular analysis method, the Analytical Hierarchy Process (AHP), has been commonly used to decompose complex decision problems. The AHP was introduced to the literature by Saaty [3]. The AHP ratings method [4] was investigated to see if it could be used as an appropriate way to assess the strength of the interrelationships and their relative importance. The interrelationships were defined in the MIM, where their impact was scored and the relative weights were determined so that an overall manufacturability metric was obtained.

This technique is equivalent to performing the traditional AHP with only one alternative available in the hierarchy and generating the required local and global weights. The AHP ratings method utilizes ultimate weights that are obtained from local and global weights of scales. In order to calculate a final manufacturability score, a measure between 0 and 1 or 0% and 100%, the ultimate weight of each scale must first be calculated by taking the ratio of the global weight of the scale to the maximum local weights of all scales that belong to a specific aspect of manufacturing. The sum of universal scores associated with the final selection of scales by the SMEs determines the overall manufacturability score [5].

The normalized scores were defined where 0 represents the least manufacturable item and 100 represents the most manufacturable item. Prior industrial work by a member of the research team utilized the following rating scale as shown in Figure 2. This rating scale was incorporated into the initial version of the methodology and provided a way of prioritizing areas of risk which will be addressed during the prescription phase. The determination of the rating scale remains a subject for further research.

Color	Rating	Description
Red	1-50	High risk, significant issues, stop and evaluate
Yellow	51- 85	Medium risk, some issues (additional build time, extra resources, and special tooling, etc. may be required), proceed with caution
Green	86-100	Low risk, very few issues, proceed

Figure 2: Rating scale

2.4 Extending Manufacturability to a Product Structure

The prior section outlines the approach for analyzing the manufacturability of an individual item within the design. The research then turned to how to extend this scheme across an entire BOM. This involved establishing a structured approach for the evaluation of the product design through a bottom-up assessment of the BOM. The challenge was then to determine how to roll up the individual manufacturability scores so that a total score was obtained for the product. Two basic approaches were evaluated.

1. Establishment of a general "axiom": Product rating, or metric, takes on the rating of the lowest scoring item (part or subassembly) within that BOM.
2. Assume that all parts and subassemblies have equal importance and take an average of all items to reflect the assessment metric.

For the initial version of the methodology, the total score was represented by an average score (option 2). However, more research is needed in order to determine the best way to roll-up the scores across the BOM.

The next logical step was to define the format of the manufacturability score, or metric. The format was established for the metric based on a combination of the "total" score and the risk categories. As can be seen from Figure 3, the first element indicates the total manufacturability score for the product (varies from 0-100). The following elements indicate the % of opportunities in the BOM which were classified by the risk categories. In the example shown in Figure 3, the "total score" of 91 represents the "roll-up" score across every item in the bill of material. This total score is followed by the percentages of opportunities in the BOM associated with each of the risk categories. For example, 55% of the opportunities in the BOM were classified as low risk.

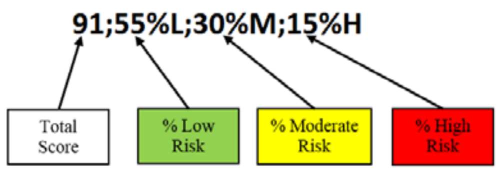

Figure 3: Example Manufacturability Metric

2.5 Manufacturability Assessment Instrument

The interaction matrix combined with the AHP methodology, the Bill of Material based structure of the evaluation, and the scoring approach, all established the blueprint for the metric. However, in order to document and calculate the assessment scores, the Manufacturability Assessment Instrument (MAI) was created to assist the SME in the evaluation of the product design. The tool consists of a graphical representation of the matrix and the global/local weights calculated from AHP. These weights are embedded within the calculations of the instrument, but served to provide the basis for turning the qualitative judgments into numerical scores.

3. Case Study

In order to obtain initial feedback on the validity of the methodology, a case study was conducted. The summary of this case study, discussed in the following sections, reviews this information based on the Evaluation-Diagnosis-Prescription cycle mentioned previously in this paper.

3.1 Evaluation

The case study was performed on a consumer based rotatable TV mount. The product was constructed from a combination of sheet-metal fabricated parts, and other foreign and domesticated sources. The main components included a fabricated frame assembly, a TV bracket assembly, the arm/linear actuator assembly, and a control box. The design consisted of 14 main component parts and 6 assemblies. The resulting judgments for each item in the BOM were entered into the MAI along with critical information that served as rationale for the judgments.

3.2 Diagnosis

The resulting scores for each part and assembly are shown in Figure 4. These scores reflect each individual assessment for the parts and assemblies, but does not reflect the "rolled-up" score. By looking just at these top level scores, one

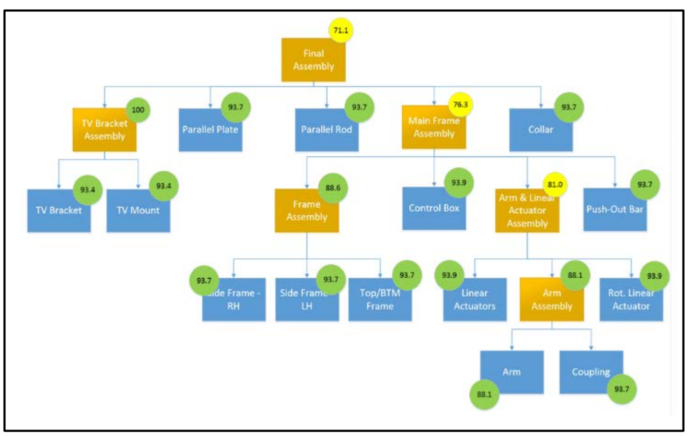

Figure 4: RTVM BOM with scores for each part and assembly

would be led to believe that minimal manufacturability problems exist in the RTVM design, as it provides no indication of the high risk areas. However, when the accessors drilled down into particular items in the BOM, there were indications that high risk areas were imbedded within these scores, as illustrated in Figure 5.

Assemblies						
	Final Assembly	Main Frame Assembly	Arm_Linear Actuator Assy	TV Bracket Assy	Frame Assembly	Arm Assembly
Capacity and Scalability	64.4	85.6	100.0	100.0	64.7	69.7
Design	51.4	70.0	65.8	100.0	87.6	90.1
Ease of Assembly	41.4	53.1	57.8	100.0	100.0	100.0
Ergonomics	100.0	73.4	68.6	100.0	100.0	100.0
Maintainability	41.6	49.6	60.1	100.0	100.0	100.0
Material	100.0	100.0	100.0	100.0	100.0	100.0
MHTPMaterial Handling, Tran	86.3	84.2	100.0	100.0	100.0	91.3
Part Geometry	100.0	100.0	100.0	100.0	90.3	100.0
Process Capability	51.4	58.9	70.3	100.0	100.0	63.4
Product Dimensioning	56.9	47.0	67.8	100.0	44.6	68.0
Quality Testing and Equipmen	53.9	81.3	81.3	100.0	63.0	52.9
Reliability	55.7	71.7	71.7	100.0	100.0	100.0
Special Skills	100.0	100.0	100.0	100.0	100.0	100.0
Special Tools	100.0	100.0	100.0	100.0	100.0	100.0
Strategic Sourcing	100.0	100.0	100.0	100.0	100.0	100.0

Figure 5: Detailed results of the RTVM assembly scores

The results were split into two categories representing the metric for the parts and the metric for the assemblies as shown in Figure 6. Through the communication of these risk areas, the assessment conveyed key areas of manufacturing risk, or cost drivers associated with the product design, specifically with the RTVM assemblies.

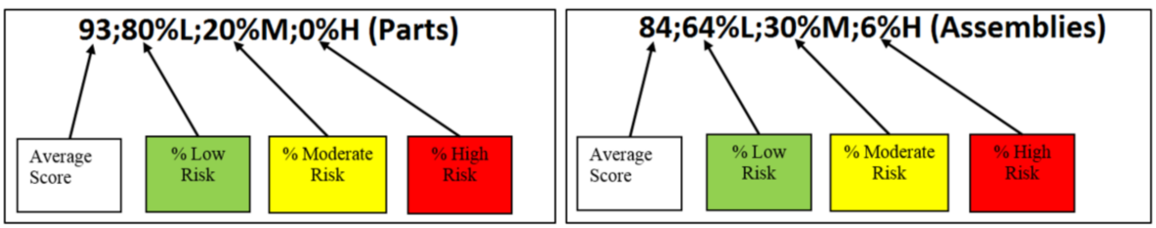

Figure 6: Metric for RTVM case study assessment

3.3 Prescription

The supporting information documented during the assessment, along with the manufacturability best practices, were used to determine prescriptive measures for the areas of risk within the design. The list below includes a few examples of the 32 manufacturability recommendations.

1. Feedback on drawing issues such as thoroughness of the drawing specifications, poor dimensioning, etc.
2. Design changes to eliminate lack of tool access
3. Design changes to eliminate lack of commonality in fasteners

This case study allowed the MAM to show its potential as an assessment tool as it was used effectively to provide scoring and equally important, provide valuable diagnosis and prescriptive feedback to the customer. The team received positive feedback and RTVM has since taken action on 17 of the 32 (53%) recommendations made by the manufacturability assessment team. Per the president of RTVM, “We agreed with all of the recommendations and have or will take action on each of them. These recommendations will push us to make our product better and help ensure our success [6].” Further follow-up is needed in order to understand the validity of the recommendations which will be addressed in future research of the reliability and validity of the MAM.

4. Conclusions

This paper has presented an initial methodology for assessing the manufacturability of product designs. This methodology required the development of a manufacturability taxonomy that was used as a basis for the assessment. The AHP techniques were employed to reflect the relative weights of the taxonomy as they relate to the overall manufacturability of an item within the bill of material. An initial approach was used to develop an overall manufacturability score of an item and then apply it across all levels of the bill of material. The MAM used this approach to identify high risk areas and to develop recommendations which address those risk areas. The methodology was then applied to a case study resulting in positive feedback from the product designer.

The review of this initial phase of the development of the MAM and application of it to the RTVM case study led to several important lessons learned and provided additional direction on future areas of research. These lessons learned and areas of future work will be used to formulate and apply improvements to the existing methodology to create the next version of the MAM. Areas of future research include the following.

- Future work needed to develop a scoring system that better reflects the risk level across the BOM.
- Integration into an overall Tradespace tool to support the broad design activities.
- Development of reliability and validity measures for the assessment methodology.
- Investigation of the applicability of this methodology for less mature designs.
- Enhancement of the MAM and pilot on future case studies.

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