Utilization of a Manufacturability Assessment Methodology and Metric: a Case Study Application

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ABSTRACT

The exact amount of a product's cost that is committed during the design phase is commonly debated, however based on the literature it is generally agreed that 70-85% of the costs are committed during the design phase. This information combined with the Department of Defense (DoD) focus on engineered resilient systems (ERS) has led to the research and development of a Manufacturability Assessment Knowledge based Evaluation (MAKE) methodology. This research is focused on the development of a manufacturability methodology to evaluate and assess alternative product designs in the early life cycle stages. McCall et al outlines the research efforts focused on the creation of the methodology and development and testing of a corresponding software tool. The research has continued forward with enhancements to the MAKE methodology and tool based on case study findings, which is the basis for this paper.

One particular case study involved assessment of an early life cycle design by Speedbox, LLC. Speedbox, founded and owned by a Special Forces veteran, was developed in response to the arduous task of loading and unloading gear for the U.S. Army Special Forces military community. The first generation container, the Voyager-70, stacks and interlocks securely on a 463-L pallet. After receiving customer feedback, the need and specifications for a second generation container, referred to as Endurance, was defined. The initial requirements for the Endurance-40 included a smaller, more compact size envelope, ideal for first responders and outdoorsmen but with similar cargo capacity as the first generation product.

The research team developing the MAKE methodology partnered with the owner of Speedbox and his design team in development of the second generation product. With the goal of moving manufacturability "to the left", i.e. as early in the design phase as possible, involvement with Speedbox was both timely and beneficial in the development of the assessment methodology. By working with Speedbox, the team was able to focus more concentrated efforts on providing manufacturability input into development of a product that was still in the conceptual/early design phase.

As a result, the Speedbox case study provided valuable insight into the research and development activities needed to improve the methodology to better fit with an early lifecycle development phase. Subsequently, a software tool redesign effort took place to improve the outputs available to the user and to streamline the methodology process. This paper will discuss the improvements for the design of the updated version of the MAKE tool and how it can be used for future assessments of DoD products for benefit to the warfighter.

Research Background and Initial Methodology

Design for manufacturability (DfM) typically revolves around the need to design products with the manufacturing environment in mind, resulting in products with low manufacturing cost, high quality, and that meet the customer demands. To this end, there is an abundance of DfM information available to design engineers in the form of guidelines, checklists, data sheets, software programs, etc. (Bralla, 1996; Anderson, 2014; Boothroyd & Dewhurst, 1994). This information is focused on providing design engineers with the best practices, or rules-of-thumb, necessary to design parts and assemblies with a focus on manufacturing. Rather than design engineers basing their decisions on traditional form, fit and function, DfM adds another layer of complexity for trade off analyses associated with the design.

Most of the information available in the DfM community is focused on the analysis of individual parts and assemblies by identifying characteristics of the parts or assemblies that may cause issues during the intended manufacturing process (i.e. machining, casting, welding, assembly, etc.). Typically, other functional areas of manufacturing that may impact cost are not included in the DfM analysis. For example, the labor required for training with new or specialized processes or environmental, health and safety (EHS) concerns that may drive the need for special equipment or training (McCall, et al., 2018).

Prior research has led to the development of a Manufacturability Assessment Knowledge-based Evaluation (MAKE) which is a methodology developed to assess the manufacturability of a product at various stages of a product's life cycle.

MAKE serves to identify areas within multiple manufacturing areas (Quality, EHS, Supply Chain, etc.) that are impacted by characteristics of the design. The concerns identified in the assessment drive the determination of a manufacturability metric than can be used to compare alternatives of a design at any level from the individual components up to the final assembly (McCall, et al., 2018).

Research by McCall et al., (2017) defined the Manufacturability Interaction Matrix (MIM) as “a taxonomy-based system used to classify the key criteria of manufacturability” that “serves as the basis for the assessment and is used to provide a structured process for evaluating parts and assemblies within a given design.” This matrix allows the Subject Matter Expert (SME) to ask the question, “What is the impact of a particular aspect of design on a particular aspect of manufacturing?” Over the course of several case studies and taxonomy improvement iterations, the current version of the MIM, V3.0, was developed (Figure 1). This MIM was used to perform the Speedbox assessment, detailed in the following sections.

Figure 1. Version 3.0 MIM

Aspects of Design → / Aspects of Mfg ↓	Material	Product and Manufacturing Information (PMI)	Design Geometry
Process	X	X	X
Quality	X	X	X
Supply Chain	X	X	X
Capital Equipment & Tooling	X	X	X
Labor	X	X	X
EHS & Ergonomics	X	X	X
Capacity and Scalability	X	X	X

Speedbox Case Study: Overview and Background

The Speedbox product is a ruggedized container system developed for the transportation of military gear during rapid deployment of the war fighter. The design involves a robust container that is portable and stackable with the ability to be clustered to fit standard military pallets. Speedbox was designed and developed by a former military special operator who is also the sole owner/manager of Speedbox LLC.

The MAKE research team began working with the Speedbox owner during a critical redesign effort. The first generation unit, the Voyager-70 was designed to fit and interlock securely on a 463-L military pallet. Since its inception, Speedbox has expanded its customer base to include Emergency Response, Fire & Rescue, and the Outdoors Community (hunter/fisherman). As a result of the feedback from existing customers and added requirements from potential customers, the product line underwent development of a 2^{nd} generation product referred to as the Endurance-40. This next generation production is 2/3 the scale of the first, but still has the stackable option and ruggedness to withstand being strapped to pallets and shipped to the forward bases.

A goal of the research team has been to deploy the MAKE methodology as early in the product lifecycle as possible. The timing of the Speedbox redesign effort (between Milestones A and B) allowed the team to get involved early in the development phase of the lifecycle. Additionally, this early involvement provided the details needed for the research team to conduct a meaningful manufacturability assessment prior to finalization of the design and purchase of costly mold tooling.

As previously mentioned, version 3.0 of the MIM was used to perform the Speedbox case study. This case study served several purposes: illustrate that a flexible, reduced MIM is still effective in manufacturability assessments, allow the methodology to be applied to an early lifecycle product, and provide feedback for an assessment software tool redesign effort. In addition to the MIM, best practice templates and SMEs were utilized during the assessment. The Endurance-40 design is based off the previously developed Voyager-70 design, which allowed the research team to perform an assessment on the existing product and apply the recommendations to the design efforts for the new product.

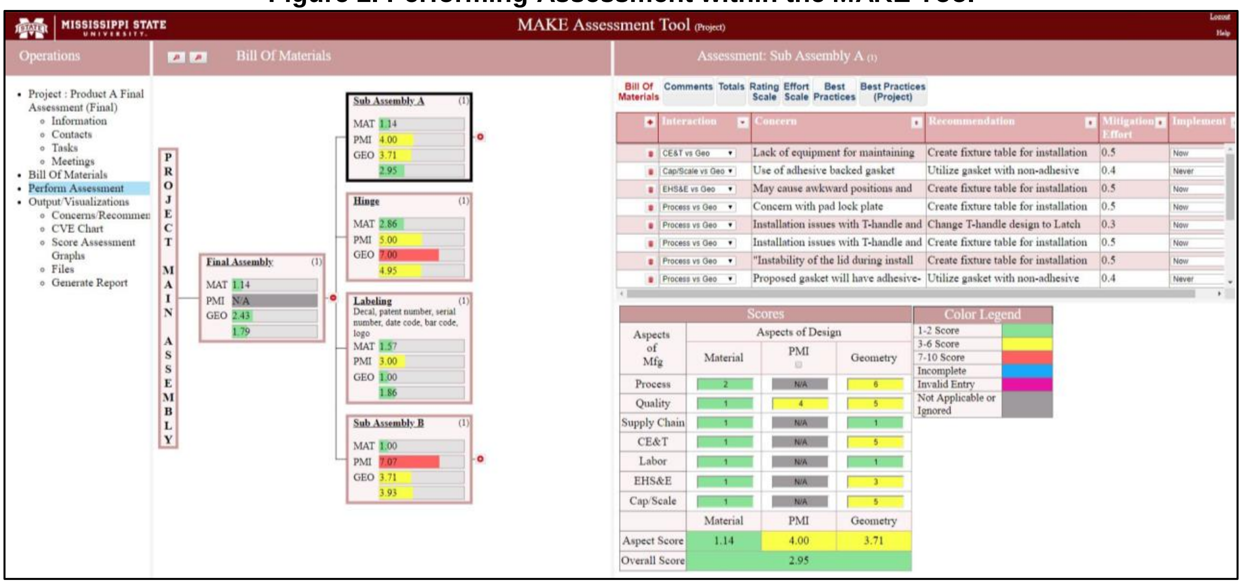
Application of MAKE Software Tool

Wall, Fuller et al. (2018) states that the MAKE software tool is a web-based application with the server-side software written in Python, using the Django framework. It is an organizational tool that allows the SME to evaluate each part, score the interactions from the MIM in Figure 1, and document the concerns and recommendations related to the interaction score. Wall also outlines the initial tool design through screenshots and a detailed walkthrough of the tool’s capabilities. One such capability is the ability to build and export an indented Bill of Materials. In previous case studies, the research team has noted that many small to medium manufacturers don't always have a BOM available. If a BOM does exist, the user can import that directly into the tool to begin the assessment process.

Improvements were deemed necessary after utilizing the initial tool in a case study. These improvements included allowing the user to ignore areas not considered applicable, inclusion of scoring guidelines (interaction and mitigation effort) and best practices, the ability to store files within the tool, and enhanced reporting capabilities. Improving the tool in this manner allows for a more effective, organized assessment.

Figure 2 shows the portion of the tool that allows the SME to perform the assessment. Concerns and recommendations are documented in the upper right side. Scores for the interaction, based on the concerns, are entered in the matrix below. As the scores are entered, the bill of materials hierarchy structure in the center is updated with scores for each of the aspects of design and the total score for that particular part. During the Speedbox case study, the Endurance-40 product was still in the design and development stages during the assessment. As such, many of the interactions related to Part and Manufacturing Information (PMI) were not rated due to lack of information. This is typical for a product in early design phases. The methodology and MAKE tool accounts for this by not scoring an interaction that is rated N/A. Furthermore, the software tool allows the SME to ignore all of the interactions related to PMI for an early life cycle product.

Figure 2. Performing Assessment within the MAKE Tool



As the team worked through various case studies, it became apparent how much time was spent reviewing scores and understanding what the scores ultimately mean. In previous improvements to the assessment process, the scoring criteria was improved to be more clear and concise. This improved scoring criteria, along with general manufacturing best practices were included as part of the tool, rather than kept as a separate document. When the user selects either rating scale, effort scale, or best practices in the above figure, the corresponding table will open. This allows the user to have the criteria readily available during scoring discussions. The effort scale relates to the recommendations provided for each concern. The score indicates the effort required to implement that particular recommendation. The best practices are phrased as questions to help guide the discussions and SME thinking.

Typically pictures, data files, and other documents are used as part of the assessment process. The MAKE tool was updated to allow for these files to be uploaded and stored within the database. For organizational purposes, the files are stored within the record for each part. By selecting a particular part on the bill of material structure, the user will get an option for uploading a file. These files are also exportable and therefore shareable among other team members.

Assessment Results

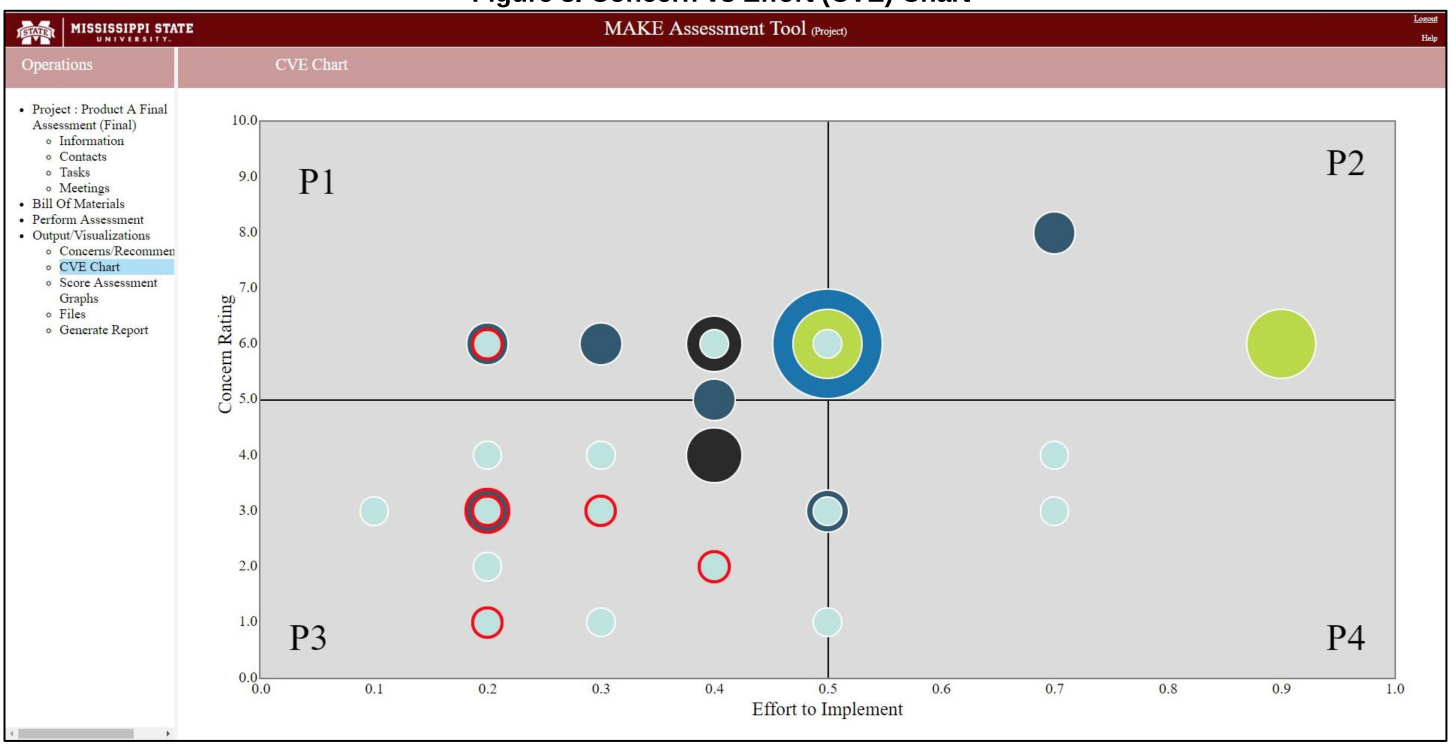
During an assessment, concerns are identified as well as recommendations, which allow the customer to develop their risk mitigation strategy. For the Speedbox assessment, a total of 56 concerns were identified, with 33 unique recommendations. This shows that a single recommendation can mitigate multiple concerns, which is typical in a manufacturing environment with interconnected systems. Within the visualization sections of the tool, a user can see the total number of concerns and recommendations for each part as well as for the entire project.

As previously mentioned, the identified concerns are rated from 1-10. The recommendations are also rated in terms of the effort required to implement said recommendation. The mitigation effort scale runs from 0.1 to 1, with 0.1 being minimal effort and 1 being the maximum effort required to implement the recommendation.

The concern and effort ratings were combined to create a concern vs effort (CVE) chart to provide indication of the benefit vs. effort relationship associated with recommendations. This chart is broken into 4 quadrants, from Priority 1 to 4. Priority 1 would be recommendations that solve high concern items with minimal effort. P2 items are high concern with higher effort. The majority of this case study's recommendations fell in P3, low concern and low effort to implement. Finally, P4 items are those with low concern but high effort to implement. Figure 3 shows the CVE chart for the Speedbox case study.

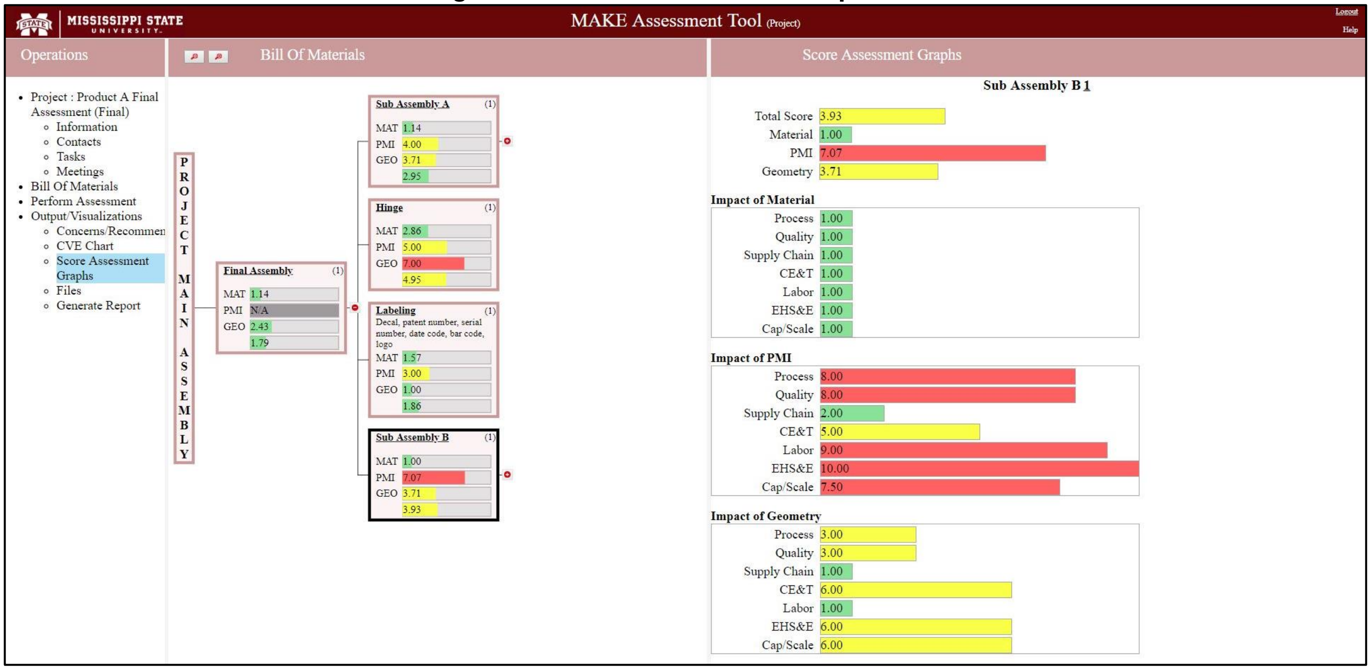
Since a single recommendation may mitigate multiple concerns, the CVE chart needed to indicate this impact. The tool allows the "bubbles" to grow larger as the number of concerns mitigated by that particular recommendation increases. Additionally, multiple concern/recommendation pairs can have the same concern and effort ratings. This is indicated by the red rings surrounding some of the bubbles.

Figure 3. Concern vs Effort (CVE) Chart



The MAKE methodology is based on the Evaluate, Diagnose, and Prescription (EDP) cycle (Walden, McCall 2016). As part of the diagnose phase, the SME may choose to dive deeper into what is causing the score for a particular part or assembly. Within the tool, the Score Assessment Graphs quickly allow a user to identify opportunities for improvement. For example, by analyzing the graphs in Figure 4, for subassembly B1, we can see that the PMI score of 7.07 is driving the score of overall 3.93. Diving further into the PMI area, we see that Environmental Health and Safety and Ergonomics (EHS&E) has the highest impact on PMI, followed by Labor. These would be potential areas where improvement efforts should be focused.

Figure 4. Score Assessment Graphs



The final step in the assessment process is to report the findings back to the customer. During previous assessments, significant amounts of time were spent creating reports for the customer. With the recent improvements made, a user can select from an executive summary style of report or customize the report based on the intended audience. These reports are exported in PDF format and can include any or all of the graphs, files, or charts created within the tool.

Future Work

Significant improvements have been made to the tool, allowing it to become an integral part of performing a manufacturability assessment. The tool ensures that all pertinent parts are assessed in a streamlined, organized manner. Future areas of improvement include the ability to perform analysis of alternatives within the tool, along with refinement of rollup scoring methods and ability to assign weights to certain parts or aspects.

Ultimately, the current methodology and resulting tool were developed with a focus on Milestone C activities. However, usage of the methodology for the Speedbox assessment has shown there is viable application of MAKE to Milestone B activities as well. Current efforts are underway on how to adapt this methodology to pre-Milestone A, where design fidelity is at a minimum. By doing so, the use of a yet to be defined version of MAKE to assess manufacturability of pre-Milestone A designs becomes more feasible and provides more of an impact in the life cycle costs.

References

Anderson, D.M. (2014). *Design for Manufacturability: How to Use Concurrent Engineering to Rapidly Develop Low-Cost, High-Quality Products for Lean Production*, Boca Raton, FL: CRC Press

Boothroyd, G., Dewhurst, P., & Knight, W. (1994). *Product Design for Manufacture and Assembly.* New York: Marcel Dekker Inc.

Bralla, J.G. (1996). *Design for Excellence*, McGraw-Hill, Inc., New York, NY.

McCall, T., Dalton, L., et al. (2018). "Developments of the Manufacturability Assessment Knowledge-based Evaluation (MAKE) and Application to Case Studies," Technical Report for Engineer Research and Development Center, Vicksburg, MS.

McCall, T., Fuller, S., Dalton, L., Walden, C. (2017). "Manufacturability Assessment Knowledge-based Evaluation (MAKE) and a Pilot Case Study." Proceedings from the *2017 American Society for Engineering Management International Conference.* Huntsville, AL.

Wall, E., Fuller, S., Falls, T. (2018) "Design of the Manufacturability Assessment Knowledge-based Evaluation Tool." Proceedings from the *2018 American Society for Engineering Management International Conference.* Coeur d'Alene, ID.

Walden, C., McCall, T., Gedik, R. (2016) "Taxonomy Based Assessment Methodology: Improving the Manufacturability of a Product Design" Proceedings from the 2016 Industrial and Systems Engineering Research Conference. Orlando, FL.

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