Automating Design for Manufacturability Testing on 3D CAD Models: Exploring the Capabilities of Elysium's Geode API

Balancing Automation and Human Expertise: An Analysis of the Toyota Production System

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Manufacturing has long fostered automation, evolving from early assembly lines to today's advanced robotics and Artificial Intelligence. As technology has grown increasingly capable, companies face the challenge of balancing the increased productivity brought by machinery with the loss of insight carried by experienced workers. The ongoing retirement of the baby boomer generation, which holds significant institutional knowledge, highlights the need for solutions to retain and transfer critical expertise (Burmeister & Deller, 2016). Without intervention, the loss of knowledge could lead to declines in efficiency and product quality for manufacturers.

To address this, my technical project aims to improve the Design for Manufacturability (DFM) process by automating quality checks on 3D digital models. This automation will help ensure consistency, scalability, and the retention of institutional knowledge for design practices that can be defined by explicit rules. This will leave only the more complex, judgement-based cases to human inspectors, easing their workload and streamlining the training of new inspectors. Using an Application Programming Interface (API) by Elysium, this project will convert an aerospace manufacturer's in-house design rules to programmable rules in Python. The aim is to demonstrate the viability of a coded DFM procedure to replace the manufacturer's legacy system. By enabling the development of automated, custom DFM rules, this solution provides a method of preserving design expertise that can evolve with the user's needs.

However, the transition to automated procedures in manufacturing brings social along with technical challenges, particularly in how it reshapes roles and procedures. A company that exemplifies a successful balance of automation with human oversight is Toyota. The Toyota Production System (TPS) achieves this by incorporating continuous improvement, standardized tasks, and collaboration between humans and machines (Spear & Bowen, 1999). My STS project will use Actor-Network Theory (ANT) to analyze TPS, examining how human and machine actors collaborate to maintain productivity and human insight in their production. By examining Toyota's success as a network of interactions rather than isolated components, this analysis aims to reveal crucial insights that could otherwise be missed. Without this perspective, manufacturers risk implementing automation practices that fail to sustain productivity and knowledge retention over time. Because the challenge of incorporating automation in manufacturing is sociotechnical in nature, it requires attending to both its technical and social aspects to accomplish successfully. In what follows, I set out two related research proposals: a technical project proposal for developing an automated solution to conduct DFM tests for a large manufacturer and an STS project proposal for examining the interacting factors that contribute to Toyota's success in automation.

Technical Project Proposal

A global aerospace manufacturer is looking to replace a legacy system for conducting DFM checks. DFM refers to the approach of designing components while actively considering manufacturing feasibility and associated costs. By identifying design issues early, DFM helps prevent delays and reduces rework costs. A NASA study demonstrated that costs escalate significantly when errors are found later in the production process. If an error caught in the requirements phase costs 1 unit to fix, it would cost 3-8 units in the design phase, 7-16 units in manufacturing, and up to 1,500 units during operations (Stecklein et al., 2004). This emphasizes the value of early DFM checks in aerospace and large-scale manufacturing.

Currently, manufacturers use two primary approaches for DFM checks: manual inspections and out-of-the-box (OOTB) automated solutions. Manual checks involve workers visually inspecting proposed models against in-house rules, often relying on intuition developed over years of experience. As the manufacturing industry has digitized, designs have shifted from 2D drawings to 3D CAD models, but the dependence on manual checks has persisted. OOTB solutions, on the other hand, provide automated quality checks with preconfigured rules commonly applied across manufacturing processes. For instance, Elysium's DFX Analyzer will validate CAD models against design rules developed from industry standards and the company's experience with various clients (Elysium, 2021). These tools allow users to adjust parameters, like wall thickness thresholds, to suit general manufacturing needs.

However, both approaches have limitations. Manual checks, whether in-house or outsourced, can be slow, costly, and inconsistent across inspectors. The work is also tedious and repetitive, creating the challenge of employee retention. Additionally, traditional companies often rely on the tacit knowledge of veteran employees, which makes it difficult to scale this expertise across the organization or pass it on to new employees (Johnson et al., 2019). As baby boomers, the second-largest generation in the U.S, reach retirement age, there is growing concern for the knowledge gap they will leave after decades in the workforce (Burmeister & Deller, 2016). OOTB solutions offer scalability and standardization, making them suitable for applying basic rules for large manufacturers. However, they lack the flexibility to accommodate custom DFM rules, forcing companies to rely on manual inspection for unique manufacturing conditions.

Without solutions for retaining the crucial manufacturing knowledge of experienced designers, manufacturers risk inefficiencies and declines in product quality. As software and hardware have evolved to enable faster design iterations and production, DFM processes must improve to avoid becoming a bottleneck. The solution to these challenges lies in Elysium's newly released Geode API. Their extensive experience in CAD data conversion provides them with expertise in handling 3D geometry (Elysium, 2023). Their API allows users to utilize Elysium's geometric analysis with Python code to automate custom DFM checks. This provides manufacturers with the opportunity to work with experienced engineers, designers, and inspectors to convert their hands-on knowledge into definable rules to be programmed. The automation of routine DFM checks can reduce the reliance on manual labor, improve consistency across inspections, and help retain critical knowledge. It will also allow human inspectors to focus on more complex design issues that require judgment, optimizing resource allocation and easing the burden of future inspectors.

The goal of this project is to automate the DFM rules of the prospective client, proving that automation with the Geode API can effectively replace their legacy system. The automated solution will be evaluated based on its ability to accurately identify geometric features specified by the DFM rules, extract relevant measurements, and provide clear, actionable feedback on the evaluations of their CAD models. To implement this project, I will analyze the client's rules and models to understand the requirements. I will then review the API's training materials, including use cases, sample code, and documentation, to understand its capabilities. Next, I will develop Python code to automate the DFM checks and apply color-coding and labeling to the CAD models for visual feedback on the designs' compliance with the rules. The solution will be presented to the aerospace manufacturer during a benchmark meeting, highlighting implementation details and the accuracy achieved. The accuracy of the solution will be determined by running the code on the client's CAD models and visually inspecting the results to confirm the correct identification of predefined passing and failing cases. Feedback from the manufacturer during the benchmark meeting will provide additional insight into the solution's usability and practicality. The meeting will help the client decide whether to adopt the solution or pursue additional evaluation steps.

STS Project Proposal

The Toyota Production System (TPS) exemplifies a balanced approach to automation by integrating human oversight and intervention effectively into their automated processes. The two key pillars of TPS, Jidoka (automation with a human touch) and Just-in-Time production, enable Toyota to ensure the high quality and low-cost production of vehicles (Toyota, 2024). In line with the company's philosophy, Toyota implements automation as a complement to human skills rather than a replacement. This is a key factor in ensuring that workers' expertise is not lost even as automated systems emerge.

Existing literature on TPS emphasizes lean manufacturing and a people-centered work culture as key drivers of efficiency and adaptability. Nakane and Hall (2002) explore the emergence of TPS in Japan following World War II, where limited resources fostered a "survival work culture." This environment empowered employees to actively identify and solve problems, making effective use of workers' firsthand observations to improve production processes. Liker and Morgan (2006) examine how Toyota has preserved this culture over time, creating adaptable, standardized processes that make efficient use of human and material resources. While these perspectives highlight TPS's role in enhancing productivity and efficiency, they do not address how the system's networked interactions contribute to sustained knowledge retention. This narrow focus risks missing the complex network at the core of production that allows Toyota to adapt to workforce and technological changes without losing human expertise.

Understanding these interactions is crucial for other manufacturers seeking automation procedures that retain tacit knowledge and will grow alongside evolving industry demands. This analysis argues that the strength of TPS lies in its networked approach, where human expertise is embedded within automated workflows, preserving institutional knowledge and adapting to environmental changes. Using Actor-Network Theory (ANT), this analysis demonstrates that TPS's success is not solely due to specific instances of automation or individual principles, but rather from Toyota's enduring collaboration across its human and machine network that sustains quality and preserves manufacturing expertise.

The ANT framework, developed by scholars like Michel Callon, Bruno Latour, and John Law, views social and technological outcomes as the result of heterogeneous networks composed of human and non-human actors. Network builders construct these networks to address problems or achieve specific goals, defining each actor's role though its interactions within the network (Cressman, 2009). This framework will allow the relationships between the actors to be at the forefront of this analysis. In the context of Toyota, human actors (including production line workers, managers, and senior executives) and non-human actors (such as machinery and work principles) are interdependent and contribute to the company's success, making these relationships crucial to understand.

This research will utilize a combination of primary sources, journal articles, and media articles to analyze the human and technological acting within Toyota's network. Official Toyota publications on TPS principles along with journal articles examining its implementation in industry will emphasize the integration of human insight with automated systems. Media sources on Toyota's strategies will reveal sentiments toward TPS and provide perspectives on why it has succeeded where other automation attempts have failed. ANT literature will provide the basis for identifying actors and dynamics within TPS. With this approach, this study will conduct a qualitative analysis to identify the key factors to successful automation practices as demonstrated by TPS.

Conclusion

The proposed technical and STS projects work together to address the challenge of implementing automation in manufacturing while retaining human expertise. The technical project will deliver a customized, automated DFM solution for an aerospace manufacturer, using Python and Elysium's Geode API. The flexible, scalable solution will digitally preserve design knowledge within the verification process and allow human inspectors to focus on judgement-based cases, therefore easing their responsibilities. The STS project will use Actor-Network Theory to examine the Toyota Production System, revealing how the company has successfully implemented automation processes in large-scale manufacturing. By understanding how Toyota fosters collaboration between humans and machinery, the technical project can draw on these insights for better compatibility with the relevant social, environmental, and technical factors in manufacturing. This will enhance the automated solution, ensuring that it aligns not only with the technical specifications of the client, but the human elements necessary for sustained knowledge retention.

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