The Impact of Self-Serve Applications on Manufacturing Performance

by

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ABSTRACT

This thesis examines the use and impact of self-serve applications in manufacturing environments, while providing a historical review of manufacturing management systems. A survey of Tulip Interfaces, Inc. customers was performed. This survey focuses on manufacturing challenges, how customers typically dealt with these challenges, the impact of the Tulip platform and future opportunities for customers. These surveys were conducted over the phone and in-person using open-ended questions.

Tulip applications are found to increase operator performance and product quality, while improving organizational collaboration as inter-departmental teams implement new technology. Conversely, the perception of the greatest challenge to future adoption of new technologies (such as Tulip) is organizational resistance.

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Title: Sloan Management Review Distinguished Professor of Management
Dedication & Acknowledgements

First, I’d like to thank my thesis advisor, Professor Cusumano for his insight, advice and guidance. Without the support of Natan Linder, the rest of the Tulip team and our fantastic customers, this thesis wouldn’t have been possible. I’d also like to thank Ben Linville-Engler, Jose Raul Ivan Rodriguez, John Rising, Adrien Moreau, Tim Chiang and John Gilmore for their support and feedback. Finally, my deepest appreciation and gratitude to my family, close friends and everyone I’ve met at MIT who has taught and inspired me.
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Introduction

The purpose of this thesis is to understand the impact of self-serve applications on manufacturing operations in light of today’s manufacturing challenges. A key problem facing U.S. manufacturing is that labor force participation in manufacturing is down, while overall productivity is up. This increased production is due to the advancements in, and higher utilization of, automation in production. The current state of automation is designed for simplistic, repeatable tasks, as evidenced by the difficulty of integration of robotics into the factory. Further, since automation is handling the lower cognitive tasks, humans are being asked to handle the higher cognitive load challenges. In the future we expect that the advancement of automation will bring a time when almost any task can be completed through automation, but at what setup cost, flexibility and safety? With fewer humans producing more goods through activities that require higher cognitive load (and with the understanding that human intelligence has not increased in recent history), humans need better training and guidance on the complex operations they are being asked to complete.

This challenge is presented against the historical context of both information technology and manufacturing management systems. We use the concepts of systems of record and systems of engagement to highlight the differences in user experience and overall system functionality to better describe the current state. Enterprise systems have been excellent systems of record but are poor systems of engagement due to neglect of the user experience. Using this as a backdrop, we take a survey of Tulip customers to understand the drivers for
change and the impact that Tulip applications have made to their operations. At the end of the thesis I discuss future opportunities and challenges.

Research Methods

Primary research consists of interviewing Tulip customers from a wide variety of industry verticals: pharmaceutical, consumer goods, aerospace & defense, medical device, luxury goods, machine manufacturers (OEM) and contract manufacturers. These interviews were conducted over the phone and in person and transcribed directly by myself, Justin Burke. In order to preserve confidentiality, no company or employee names are identified in this thesis. This research is combined with a historical review as well as original insights and abstractions of data validity challenges and the management of complexity.

Chapters

Chapter 1 – History of Manufacturing

A brief introduction to the basics of manufacturing and the post-WWII history of manufacturing in the U.S. This also covers the competitive pressures of the preceding decades, relative frequency of organizational trends and a description of lean manufacturing.

Chapter 2 – Technology & Communication

An overview of computing technologies for enterprise, from the original mainframes to today’s cloud computing, including a discussion on the differences between the storage and communication of information. These topics are brought
together with the history of manufacturing to describe the enterprise systems
originally used to manage manufacturing (MRP systems) and a timeline of
communication tools.

Chapter 3 – Manufacturing Management Systems Today

Introduction of the ISA-95 model to understand the various levels of manufacturing
processes and associated control technologies, with a review of how current top-
level systems are often disconnected but the push for AI/ML is creating a demand
for better integrated systems. Finally, a proposed description of why last-mile
software connections are missing from today’s landscape, and what the impact of
this disconnect is on data saliency.

Chapter 4 – Tulip Platform & Customers

Description of the Tulip platform architecture and current customers. The Tulip
platform is made of three major parts: IoT & Connectors (external data sources),
Application Editor & Player (internal data sources), and Analytics (gain insight and
value).

Chapter 5 – Manufacturing Challenges

I surveyed Tulip customers and summarized their current manufacturing
challenges – hiring, training and retaining employees and to consistently produce
at quality. This is discussed against the intersection of labor cost, automation and
investment in advanced manufacturing.

Chapter 6 – The Change from Pre- to Post-Tulip
For many of our customers, the before Tulip the solution involved using paper to train and guide operations while trying to capture data from the shop floor. This chapter describes both the reality of activities and data flow before the use of Tulip, and the change that occurs when using Tulip.

Chapter 7 – Why Customers Pick Tulip

This chapter dives into the primary reasons customers chose Tulip to solve their manufacturing challenges. Key reasons include process visibility and ease of data capture.

Chapter 8 – Impact of Tulip on Manufacturing

I survey Tulip customers to understand the true impact of Tulip on their operations and differentiate between ‘soft’ and ‘hard’ ROI, and ask them to list the most important impact of Tulip. For many, the increase in operator performance was the most important impact.

Chapter 9 – Future Opportunities & Challenges

This describes what excites and concerns our customers most as they look ahead to the future in manufacturing. Lack of action by senior management tops the list of concerns, while most companies are excited by the promise of digital supply chain initiatives. For future research, I recommend people research strategies to deal with the impact of group social behavior on an organizations ability to implement new technologies.
Chapter 1 – History of Manufacturing

Every engineered good in the world is manufactured. Goods are defined as having economic utility, or satisfying an economic want. This could be the headphones we listen to, the cars we drive, and the lifesaving medical equipment in the emergency room. Humans, having worked with their hands and tools for centuries, are adept at creating increasingly complex goods. Today manufacturers around the globe range in size from the one man shop to the world’s largest computer hardware manufacturer, Apple, with a market capitalization of $855 billion. Some goods remain relatively unchanged, while others are updated every year with a new style, size or configuration. How these goods are made has changed in recent history, from the advent of the steam engine to today’s 3D Printers; from handcrafted goods to automated assembly lines. While the technology has changed, humans are still the ones in control of manufacturing.

There are many factors that influence the consumer’s willingness to pay for these goods, including quality and performance. These are engineered attributes and how many companies differentiate themselves to capture market share. For manufacturers, there is a perceived minimum level of quality that must be achieved relative to the performance they are providing the consumer. As the quality of goods from abroad arriving in the U.S. increases, U.S. manufacturers must be able to deliver quality and performance efficiently.

A more focused recent historical perspective is necessary to understand where we are today for the management of manufacturing, with its limitations and opportunities.
Recent History of U.S. Manufacturing

Coming out of World War II, the U.S. was uniquely positioned to take advantage of its relatively unscathed infrastructure and robust domestic manufacturing capabilities. The 1950s saw the beginning of a surge in U.S. manufacturing, using assembly line control and production in batches. Companies strove for standardization and repeatable processes to lower cost of production, increase quality and have repeatable performance. Buoyed by a growing middle class, this is often referred to as the Golden Age of the U.S. Economy. (Gold) This Golden Economy was driven by a large increase in consumer spending. Due to the high level of growth, there were no industry-wide attempts to focus on systematic improvement of manufacturing. When the Golden Age came to a halt in the recession of the early 1980s, dynamics began to shift. Companies began to look beyond the assembly line for ways to systematically improve their manufacturing options.

Starting in the 1970s and increasing through the 1980s, there was a focus on ‘Japanese manufacturing’ and ‘competitive strategy’. With the recession hitting, competitive strategy started to be widely discussed, with increased mentions of Japanese manufacturing, continuous improvement and the introduction of the word “Manufacturability”.

![Figure 1 - Keyword References in Literature (Jean-Baptiste Michel*)](image-url)
This is understandable as in the U.S., there was a sense of competitive pressure from manufacturers in Japan especially in regards to automotive manufacturing. These trends tend to peak in the early 1990s, as the term Lean Manufacturing replaces Japanese manufacturing as the latest buzzword. This term is attributed to John Krafcik of MIT (Cusumano) who wrote “Triumph of the Lean Production System”.

Lean Manufacturing

Lean manufacturing is a set of management and organizational practices that originated out of the Toyota Production System and just-in-time manufacturing. Lean manufacturing is categorized by teamwork and work standardization led by teams with best practices & tacit knowledge shared. There are low inventory levels in a lean system, as only the materials needed to make the next item are stored with minimal production buffers and efficient repair areas. Interestingly enough, John originally wanted to refer to lean as a fragile manufacturing systems, compared to a ‘robust’ manufacturing system with buffers. (Krafcik)

The capabilities of these manufacturers were measured in three key areas: Productivity, Quality and Flexibility. The spread of lean manufacturing as a concept has continued to grow to this day, with many experts ready to assist companies begin their ‘lean transformation’. Interestingly enough, lean concepts have been introduced into software development as well, as noted by the rise of the DevOps movement. These concepts resonate with people who want to do the right job, at the right time, at the right quality with only the minimum amount of material and information needed.
Rise of the Computer for Enterprises

While manufacturing was undergoing one revolution in the second half of the 20th century, at the same time the world experienced the introduction and widespread adoption of computing technology. The first mainframes were introduced from the 1950s to the 1970s, primarily used for accounting and inventory ledgers. These computers were maintained by data processing groups within organizations. With the advent of the DEC minicomputer for department usage in the 1970s, computers began to find their way into departments other than the central Data Processing group. By the time the 1980s hit, personal computers (PCs) hit the market and forever changed the way everyone views and uses computing technology. With the need to exchange and update information, by the late 1980s, the client/server architecture was born enabled by the advent of TCP/IP and the internet. This is still considered by many to be the standard for information technology services, with a local client for users and a central server for data storage.

Today, the emphasis is on cloud computing. The significant difference in cloud computing is that manufacturers no longer have to maintain their own server racks with locally installed databases and applications, but instead can rely on Platform- and Software-as-a-Service organizations to provide remote servers, software and services for more economically efficient computing solutions. From the user experience viewpoint this simply appears to be a new version of the same client/server architecture they experienced before.
Humans store an immense amount of information in their brains (difficult to estimate, but some put this above 2500 terabytes), albeit with some errors in retrieval and accuracy. We use this information to infer, make judgements and take actions. Because of the fallible nature of the human brain, we use tools such as pen and paper to record and communicate information to others. With computers and the internet, we now have a way to store immense amounts of information and communicate this information across the globe.

We can now abstract away the how and where computing is done, and focus more on the why of these computing systems. I propose that we think of this in two abstractions: the storage of information and the communication of information. Computers and the internet serve these needs, with computers storing information (with associated processing & analytics of stored information) and the internet providing a backbone for communication of information.

Storage of information refers to the functions of creation, modification, removal and retrieval. New information is created, old knowledge is updated through modification, incorrect information is removed, all for the purpose of retrieval in the future. When we have structured information in databases and tables, it becomes a simple task to analyze and report on this information. In fact, with the advent of advanced analytics such as machine learning, having tagged and structured data becomes key to deriving future value from this information.

Communication of information refers to the transfer of information from one entity to another. What’s interesting about the communication of information is that by definition this means the information has crossed some sort of boundary (otherwise the information would
not have been communicated). Further, while a third party can often observe the transfer of information, to have the same interpretation of information means both have the same vocabulary and perceive the information in the same way. This is a critical point, because far too often we assume that simply because information has been transferred does not mean it has been received and interpreted incorrectly.

When information sharing systems work well, it’s typically because all involved share either a technical domain or come from the same community and have the same standards for their work and communication. For humans it’s easy to understand why information is often misinterpreted, but even for ‘designed’ technological systems this can fall apart. With the rise of APIs, developers are working at ways of standardizing interfaces to ensure that data interpretation is clear between systems that may be used or designed by groups with different backgrounds.

Bringing it all together

So far we have covered a brief history of U.S. manufacturing, computing history, and a simplified abstraction of information. We need to understand all these topics in order to explain the state we find ourselves in today, with humans using technology to control manufacturing enterprises.

Before the advent of computers, all records were created and updated work by pen & paper. These pieces of paper tracked inventory, kept logs, trained workers and contained instructions for completing work. Previous methods for maintaining inventory levels were based on methods such as reorder point / reorder-quantity. Material Requirements Planning

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(MRP) arose with the advent of computers in the early 1970s and have come to include additional functionality and are referred to today as ERPs. These systems enable managers to better understand and control the flow of materials and operations, but continue to face challenges in terms of the accuracy, completeness and timeliness of the information in these systems.

History of MRP, Predecessor to ERP for Storage of Information

In the 1960s, manufacturing in the U.S. was in its hey-day and companies began to use computers to track inventory and help managers begin to plan for reorder points. This data was stored on magnetic tapes and required intensive labor to update and maintain. By the late 1970s, and with the introduction of random access memory, companies began to use MRP systems for forecasting, scheduling, procurement and shop floor control. These systems expanded their scope in the 1980’s, and by the 1990’s the Gartner group introduced the term Enterprise Resource Planning to better describe the extent to which this software had extended between the various functional silos within a company – accounting, marketing, sales, engineering, planning, operations, and business management. (F. Robert Jacobs)

What’s interesting about the evolution of these systems is that since they arose from the needs of the accounting department to record inventory and plan for future orders, the resulting structure was focused around ledgers. This means that most systems are designed for the storage of the information, but not the interdepartmental discussion and use of this information. Since these tools are centrally configured and deployed, all the business users had to agree to the same user interfaces for their day to day work.
Communication of Information

For communication within these enterprises, the most common methods are face-to-face, email, phone, instant messaging platforms or video conferencing systems. These communications can be between individuals, or within large groups at a meeting or on an email chain. What’s interesting when one considers the above is that we have designed two parallel systems – one for record keeping, and the other for communicating. We ask users to continually switch between systems (context switching) in order to find information, analyze and then act upon this information. Since written letters, we’ve had systems that both communicate and provide us with transcripts or logs of the communication. With the development of email and the internet, these dual-value systems can instantaneously operate across the globe. For almost all the systems we’ve described (ERP/MRP/MES to name a few) none have contextual communication as key to their platform.

What does this mean? If a report is generated in an ERP system, this data is exported or collected in a PDF and sent to a group of people. This group of people now have a new object with which to collectively analyze and discuss between themselves. Now this can be fine for certain use cases, but what if you want to discuss the implications of the report and start modifying parameters in order to gain a better sense of the underlying data and its implications? You now must login back into that system, make the changes, then report out. This represents a fundamental failure of the software systems available to date. As evidenced by the rise of Salesforce (a customer relationship management service) with its integrated note taking, contact storage and emailing capabilities, people value interaction with information in
the native context. Other examples of current systems that value communication and interaction at the source of data include Google Drive and Microsoft SharePoint.
Manufacturers today employ many systems in order to manage their logistics, operations, customer relationship, communications (internal and external) and finances. As noted in the history of MRP and ERP, enterprise resource planning systems form the backbone for many enterprises as they manage the various departments. A common model used to describe the various levels of the manufacturing system is the ANSI/ISA-95 model.

**ISA-95 Model**

Level 0 – Physical process in which materials are modified. The value-add process described at the beginning of this thesis is accomplished in this level of the ISA-95 model.

Level 1 – Sensors and machines manipulating the physical process. Human activity on the physical process also occurs at Level 1, including testing equipment.

Level 2 – Monitoring, supervising or automated control of the process (PLC/SCADA). PLCs are programmable logic controllers, and have formed the backbone of industrial control for decades.

Level 3 – Manufacturing Operations Management (MES). Operations management software has long been a gray area between structured ERP systems and shop-floor level of control with PLCs and SCADA. This level is focused on management of resources, product traceability and management of production.

Level 4 – Business Planning and Logistics (ERP). ERP Systems are used to control inventory, set production targets and track shipments going out the door. Other level 4 systems
include Product Lifecycle Management (PLM), Customer Relationship Management (CRM) and Human Resource Management (HRM).

Control of Systems

With the discussion of the various levels of the software system, we should consider the implications of trying to integrate level 4 systems such as ERP/PLM/CRM/HRM. These systems are highly engineered and customized, so integration requires extensive work for companies to gain value out of tying all these data sources together. Often this means expensive and long projects for System Integrators and Consultancies. Since these integrations are a) between complex systems and b) complex themselves, the management of these integrated systems has continued to be a problem. Today, there are many ‘data lake’ initiatives, with many in industry focusing on bringing this data together ahead of using tools like AI & machine learning to improve their operations.

Why did we end up here?

When you consider the history of computers and the work we’ve given them to do, it’s natural that these systems would evolve in this manner. Since the days of the minicomputer and individual department usage, these systems are designed for particular communities of users. Communicating information outside the user group was viewed as burdensome, and since these reporting intervals at the beginning were relatively infrequent, the demand to change didn’t really exist. Combine this with the large cost of development of these systems by information technology providers, and the high cost of switching systems, it was easier for

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organizations to stay the course, cobbled together pieces of software and creating new paths of communication between systems only when justified. Otherwise, they didn’t feel the pressure to perform a complete review of their business needs. Even if they had decided to go ground-up with a new system, the current offerings would require lock-in with one vendor, which leaves enterprises in a risky position of having no negotiating position and of needing expensive custom adaptations in the future. That is, of course, assuming this ‘one-system’ exists. Any single system offered by a vendor will have capability gaps relative to what the enterprise needs.

The Last Digital Mile

There are often last-mile digital disconnects within these companies. These centralized management systems are great when all the data was created, updated and analyzed out of the same tool. The primary issue is that in order to create new data, there must be a digital connection to create the data or update the record. In the case of manufacturers with systems that have ISA-95 Level 0-Level 4 integrations, these updates can happen automatically. For all of the manufacturers we interviewed, none had this sort of extensive integration across all of their data sources. Therefore in order for these records to be updated, people have to make manual updates to these systems. In manufacturing companies around the world, the primary method of retrieving data is to create and use paper forms. In the perfect world, these paper forms are then filled out by operators, collected by engineers/Supervisors and brought back to their desks. This data would be immediately transcribed from paper into these digital systems we mentioned above using a computer. Now clearly there are many challenges to this process, the
primary ones being (as shown in Figure 3 below): *Accuracy of Data from Operator, Accuracy of Data Recording, Accuracy of Data Transcription, Completeness of Data, Timeliness of Data.* This is why we’ll note later in this paper that our customers’ 2nd highest concern going forward is data validity, since they know there are confounding factors that continue to cause them problems.

Figure 2 – Standard Data Entry & Errors Model
Chapter 4 – Tulip Platform & Customers

Tulip Interfaces has developed a no-code, self-service manufacturing application platform that integrates with IoT devices and backend databases so that process engineers and managers can create their own intelligent manufacturing applications. Tulip is a spinout of the MIT Media Lab, founded in 2012. The Tulip platform consists of three primary functions: Shop-Floor IoT & Connectors, Application Development, and Analytics.

![Diagram: Shop-Floor IoT & Connectors](image)

Shop-Floor IoT & Connectors

"IoT" is short for the "Internet of Things", a term used to describe any device that is connected to, and communicates via, the internet. Tulip uses the term Shop-Floor IoT to refer to industrial devices that can be connected to the Tulip platform. These IoT devices can be as simple as a barcode scanners, or as complex as a CNC machine. Once connected, these devices can automatically pull in real-time data. Referencing the ISA-95 model, this means data from Level 1 and 2 can tie directly in with the Level 3 for automatic storage of all relevant data. This is powerful as it removes all of the data accuracy challenges we note above in our data entry model, and enables operators to focus on the task at hand rather than worrying about...
remembering and recording information later. Further, since the number and type of devices
can be selected by process and manufacturing engineers, they decide what integrations are
necessary for a given workflow. The Tulip platform also Triggers with an “If This Then That”
structure. These Triggers can be activated by devices outputs to advance the work flow or
activate rework loops in case of poor quality.

Tulip Connectors enables integrations with existing customer backend databases,
typically Level 4 systems such as Enterprise Resource Planning systems. Using these
integrations, customers can automatically update inventory and production records. Using
Connector is a way for companies to add context to their operations, while also instantly
feeding critical information to other systems as its being generated and captured on the shop-
floor.

Manufacturing Applications

Engineers and managers use the Tulip platform to create Tulip applications in minutes
and the instantly deploy them to the shop-floor for use by operators. There are six primary
types of manufacturing applications:

1. Work Instructions
2. Training
3. Audit & Quality
4. Machine Monitoring
5. Job Tracking & Visibility
6. Lean & Process Improvement

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When operators interact with the Tulip application, Tulip can track time, interactions, capture data from operators while simultaneously bringing in real-time data from Shop Floor IoT and Connectors. This enables a powerful feedback loop, shown in Figure 4 - Tulip Manufacturing Data Flow & Activities on page - 38 -

A common Tulip application is for guided assembly work with component traceability. An operator pulls a part from a bin and uses a Tulip-connected barcode scanner to read a serial number. This serial number is automatically transmitted through the Tulip IoT gateway and is passed to a customer-specified backend database via Connectors. If the customer database returns an OK signal, the Tulip platform will instruct the operator to continue the assembly of the part. If the customer database returns a Not-OK signal, the Tulip platform can alert the operator (and management if desired) and then automatically begin a re-work or non-conformance workflow.

Since the creation and modification of these applications is simple, the people closest to the problems on the shop floor can continuously improve. This makes edge case and exception handling easier than ever, while empowering tacit knowledge gathering.

Analytics with Live Data

The final component of the Tulip platform is a built-in analytics platform. As we’ve been describing manufacturing apps powered by IoT and Connectors, what we’re really telling is the story of data collection in context directly on the shop floor. Once all of this data is collected, it becomes a simple task for engineers and management to quickly ask intelligent questions of the data, or perform correlations to better understand the root cause of a problem. If questions...
arise that require new or additional data, Tulip applications can be easily created and deployed with minimal overhead.

Tulip Customer Characterization

Tulip customers are mostly public corporations (70%), with an average market capitalization $62 billion. The specific industry verticals vary widely: pharmaceutical, consumer & luxury goods, aerospace & defense, medical device, machinery manufacturers (OEM) and contract manufacturers are all surveyed as part of this study. These companies are almost all multi-national, primarily located in the U.S. and E.U. The typical economic buyers of Tulip are manufacturing managers or innovation team leaders. This is in contrast to typical software purchases which are coordinated out of a centralized I.T. organization.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Percentage of Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerospace/Automotive</td>
<td>22%</td>
</tr>
<tr>
<td>Pharmaceutical</td>
<td>17%</td>
</tr>
<tr>
<td>Consumer</td>
<td>22%</td>
</tr>
<tr>
<td>Medical</td>
<td>11%</td>
</tr>
<tr>
<td>Contract</td>
<td>11%</td>
</tr>
<tr>
<td>Equipment</td>
<td>11%</td>
</tr>
<tr>
<td>Heavy Equipment</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 1 – Tulip Customers by Industry
Chapter 5 – Manufacturing Challenges

We asked the Tulip customers to describe their current challenges in manufacturing. We’ve summarized these as challenges related to Labor, Quality, Asset Management, Labor, Market, Innovation, Tracking Productivity and Administrative. Due to the broad nature in which customers responded to this question, we’ve listed abbreviated versions of their responses as well as commentary and general notes.

Labor

For many of our customers, it’s difficult to understand the individual performance of operators on the team. This means that team dynamics and production bottlenecks can be difficult to identify, and can seem to vary at random.

In a recent article in the Wall Street Journal, it’s noted that US manufacturers are noting increased sales, but are having difficulties finding skilled labor. As the US nears full employment, workers are being asked to work overtime at an increased cost to the company and with limited benefit. Overtime can only be sustained for so long before employees suffer burnout or refuse to continue the long hours. (Feintzeig and Weber)

High performance employees can be difficult to utilize efficiently, especially in manufacturing environments where specialized skill sets or permissions are in demand between concurrent projects. There is a need for systems where new hires can easily be trained without concerns about potential decreases in quality. Beyond the initial training, there is a need to ensure that operators continue to follow standard work and don’t miss critical steps.
Making mistakes is easy when assembling complex or variable products. When information is poorly structured or difficult to reference, comprehension is difficult. For manufacturers, it is essential that critical steps are not missed because of poor instructions.

Quality

Performing 5 Why’s or Root Cause Analysis is a challenge for many companies, as the quality they need is either missing or maintained separately by the quality department. Since this data is collected and stored separately, the use of this data is delayed and not compared in context with operations.

Many manual assembly operations are difficult to error proof while simultaneously challenging to automate. This can be for a number of reasons, including product variability, part complexity, or low overall production volume. All of these challenges negate the impact of traditional automation techniques.

This brings up another point with regards to human cognition of complex tasks. This leads to quality issues if we’re asking operators to continually switch between assembling products while also observing and recording data.

Assets

While manufacturers understand the need for preventative maintenance, ensuring the right preventative maintenance tasks are completed so that expensive assets continue to produce can be a challenge. Similar to the separate data maintained by quality departments, maintenance logs and procedures are often kept separately and tracked via paper. This makes
it difficult for operations and maintenance to understand the timing and impact of key maintenance activities on long term reliability and productivity.

For equipment that is maintained or used infrequently, those in maintenance have tacit knowledge of maintaining and operating these machines that can be difficult to capture and share. Therefore it is crucial they have a way to document this information in such a way that will be helpful to others who are just learning how to maintain these systems. Using Tulip provides a way to capture detailed knowledge that otherwise would be difficult to capture with paper based systems. This includes using videos/images to add context and detail to complex tasks.

For machine manufacturers, it is a challenge to understand how their equipment is being used by customers. Many in industry are turning to custom IoT solutions to better understand their equipment usage and work on features such as predictive maintenance. There are concerns regarding the ability for smaller equipment manufacturers to implement and maintain these technology systems, especially when these capabilities are not tangential to their core technical abilities.

Market

Companies are growing quickly and can be hesitant to expand with new facilities. This represents a conservative management style, which can be at odds with investment in new digital technologies. Often times management is asked to evaluate the cost of capacity building versus potential opportunity cost. For these companies, understanding the efficiency and
flexibility of their operations is difficult as they try to gauge the market and prepare to expand operations.

For many consumer goods manufacturers, there are seasonal cycles and shifting consumers trends. This drives marketing and product development to ask for new product introductions (NPI). NPI is especially difficult for high cost of labor countries, as shifting to automation does not solve production pressure due to the product variability and batch sizes. Human labor is excellent at adapting to new situations and changing market conditions, so for some organizations the default response has been to shift production overseas to low cost of labor countries.

Innovation

For companies that are innovation-centric, there are challenges for middle management. These managers are asked to evaluate new technology while not receiving the time or resources allocations to accurately analyze the potential impacts. There are also concerns that by continually chasing technology it is difficult to organize projects that can provide real value. These managers instead would prefer to perform bottom-up assessments on potential key improvement opportunities and then scout for technology that can provide real value.

Other companies view the innovation landscape as a source of existential crisis with disruptive technologies that could destroy their traditional value proposition. These companies prioritize investments in advanced technologies as a way to gain a competitive edge and stay
ahead of the curve. A common sentiment among this group was that all manufacturers should view themselves as a software company first, and a manufacturing company second.

Tracking Productivity

A major challenge is the accurate recording of manufacturing operations data. Because of paper forms and instructions, many companies simply do not have visibility on their true first pass yield or other key pieces of data. There are also concerns that the assumptions they make regarding their production capabilities are incorrect. These manufacturing assumptions are typically based on one-time measurements or time studies. These challenges of typical data entry are depicted in Chapter 3, Figure 2 – Standard Data Entry & Errors Model.

Administrative - Overhead / Support Staff / Regulation

Companies are concerned about bloated back offices of support staff and are looking for solutions that don’t require extensive investment into new departments, but instead want to deploy tools that are intuitive for staff to use. These same customers note they can almost always gain more money for budgets, however they’re looking for whole solution providers due to the historical difficulty of implementation. This means new projects require outside service providers in order to make these projects a reality.

For companies in highly regulated industries, there is a high burden of documentation: creation, maintenance and management. Our customers note that many procedures and documentation results from issues identified during audits. This means that as an organization, they do not holistically review to see what documentation or procedures are truly necessary in
order to efficiently produce safe, quality products. Procedures that are integrated with regulatory compliance simultaneously solve both of these challenges.

General Observations

Due to the high cost of labor relative to the product cost, decreased productivity significantly impacts their profit margins. Many of their manufacturing goals are focused on understanding the efficiency of their current operations and identifying areas for improvement. Unfortunately for most of them, their baseline data is incomplete and incorrect.

Simultaneously, many of these companies are asked to increase production while facing labor constraints. Management is hesitant to make additional capital investments and automation isn’t flexible enough to account for changing product demands. Therefore better utilization of existing labor is incredibly important and (historically) difficult to accomplish.
Chapter 6 – Pre-Tulip Solutions to Manufacturing Challenges

For the challenges we discuss above, for many of our customers the solutions are the same. Engineers either used paper print-outs that were distributed across the plant or had to make largest investments into fixed digital solutions to capture data. Broadly, these manufacturing challenges can be separated into two categories: the guidance of operations and data collection from operations.

Guidance of Operations

From our observations, we noted the preferred method for providing guidance to operators was laminated sets of instructions. These training or instructions documents are typically created in office productivity software and stored in centralized network storage for access by the relevant groups within the company. These instructions may or may not be tied to existing revision control systems, or PDM/PLM software. There are challenges to providing instructions in this way:

1. Ensuring that the instructions on the floor are up to date.
2. Understanding if operators are following the instructions.
3. Getting feedback from operations on the usability of the instructions.

For many, an upgrade to the distributed paper method was for process engineers instead to create PDFs that are then displayed on computers at the relevant work stations. This solves the challenge regarding revision control of instructions, but still leaves gaps regarding the use of instructions and operator feedback on the instructions.
This leads to scenarios where operators do not follow the correct procedure, instead basing activities and assembly operations off of memory and intuition. As respondents noted during the interview, often times we do not consider the operator experience when designing training modules, sharing instructions or creating forms.

Data Collection from Operations

Similar to how managers and engineers provide guidance to operations using paper, or paper-on-glass systems, the same methods were used for data collection. Operators would perform the work, and then record data by hand on paper forms to capture information related to quality, non-conformance, production and inventory adjustments. These forms have to be collected by others and brought back for data entry into ERP or other top level systems. This process is shown in Figure 3 - Typical Manufacturing Data Flow & Activities, below. As we explored in the implication of data saliency in Figure 1 - Keyword References in Literature on page - 24 -, this means that data can be incorrect, incomplete or delayed.

Implications of Current State

For almost all of the groups interviewed, there is a recognition that previous systems were designed from the technical perspective of data or information recording, rather than from a user-centric design perspective incorporating both engagement and recording. This has led to decreased use of these systems, as those who must interact with them view them as a burden to overcome. When people have negative views of the system they’re using, there is a lack of motivation to engage and improve. These systems end up being frustrating to use,
providing little value to operators, with no recognition challenges and no discernible impact or improvement to their daily operations.

For many customers, their complete control loop of typical activities and data collection activities look something like the following.

![Diagram of typical manufacturing data flow and activities]

*Figure 3 - Typical Manufacturing Data Flow & Activities*

There needs to be a better way to create systems of record and engagement that can gather the data, provide feedback to operators, create visibility for management and help the
various groups within the enterprise more effectively coordinate. The following chart shows the same scenario, when using the Tulip platform.

![Tulip Manufacturing Data Flow & Activities](image)

*Figure 4 - Tulip Manufacturing Data Flow & Activities*

When using Tulip, the typical issues associated with these systems disappear and both operators and management can focus on the activities and challenges that matter most.
Chapter 7 – Why Customers Pick Tulip

Visibility

Of the groups surveyed, there was the overwhelming sense that management felt like they didn’t have visibility into what was limiting their operations. Since Tulip could capture sensor, machine and operator feedback instantly and analyze in real-time, management could start asking more intelligent questions about what was impacting their operations.

The ability to record at who (operator) did what (revision controlled procedure) when (date and time) provides detailed visibility. Since Tulip can also track how long it takes for steps within a process to be completed, companies can understand the impact of product changes on manufacturability and be confident that the proper manufacturing steps are followed.

Ease of Development for Data Capture

The second biggest challenge was a lack of time to train or learn new tools. For those surveyed, this included time for training of users on new technology and amount of time required for creating new applications. Tulip’s ease of use in creating new applications was compared to the ease of using an iPhone. Other groups recognize that while they knew what they wanted to analyze, they were unable to do so because of a) how long it took to capture and enter data and b) other solutions were too structured and don’t offer them the necessary flexibility. The combination of a minimal learning curve and time to develop was essential so people could get their tools deployed on the floor quickly.
Another aspect of this ‘ease of data acquisition’ is due to the fact that users of Tulip do not have to submit IT tickets in order to deploy new Tulip applications. This means the manufacturing group controls their own reality for deploying solutions.

Capture Tacit Knowledge for Continuous Improvement

For other customers, the key is the ease of updating work instructions. This enables engineers to better capture and share tacit knowledge, so that organizations are able to continuously improve operations.

Production capacity decreases when highly skilled employees leave or are reassigned, and being able to quickly train new operators is vital. With best practices routinely updated into standard work and training applications, organizations are able to scale out their knowledge while maintaining productivity.

Prevent Errors in Manufacturing

Customers want to reduce mental complexity for their operators, and having the Tulip Triggers functionality (if this, then that) means they can create complex process logic that manages the process complexity for the operators. This, combined with the visual and interactive nature of the platform, means that instructions no longer have to rely on words to describe, but can use images/videos with direct callouts instead.
Improving Interdepartmental Coordination

A surprising, but revealing, reason is that for some customers the choice to implement Tulip was an organizational decision. For them, the implementation of Tulip brought together business units that typically interact at arm’s length with each other. Due to the various power struggles that can exist within companies (between departments or specific people), initiatives are commonly contained to one group, without input from the wider business.
Chapter 8 – Impact of Tulip on Manufacturing

Table 2 - Impact of Tulip

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Percentage of Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase Operator</td>
<td>24%</td>
</tr>
<tr>
<td>Performance</td>
<td></td>
</tr>
<tr>
<td>Cost Savings from</td>
<td>21%</td>
</tr>
<tr>
<td>Quality Improvement</td>
<td></td>
</tr>
<tr>
<td>Increase Process</td>
<td>21%</td>
</tr>
<tr>
<td>Visibility</td>
<td></td>
</tr>
<tr>
<td>Improved Organizational</td>
<td>17%</td>
</tr>
<tr>
<td>Collaboration</td>
<td></td>
</tr>
<tr>
<td>Political Pushback</td>
<td>10%</td>
</tr>
<tr>
<td>Decrease Training Times</td>
<td>7%</td>
</tr>
<tr>
<td>Faster Learning Curve</td>
<td>7%</td>
</tr>
</tbody>
</table>

When surveying our customers, we found there are two groups of responses, split between 'soft' and 'hard' return on investment (ROI). The responses are summarized by what impact customers considered most important in their organization.

The hard ROI comes from increased operator performance, cost savings with better quality, decreased training times and faster learning curves. For managers and directors who face stringent cost justifications on projects, Tulip's fast time to ROI made the purchasing decision an easy one. Customers observed the following:

- Tulip increased individual operator and team performance on the manufacturing line. In some cases, this meant that the company could meet increased demand from the market while efficiently utilizing existing production capacity. Many customers reported at least a 10% increase in production yield.

- Simultaneously, Tulip saved money on quality issues. These savings are attributed to less scrap, less rework and less time spent working on defective goods. Tulip also made quality checks faster, more repeatable and easier to perform. For customers, this means
Tulip ensures high quality while increasing production. One customer reported a reduction in defect rate by 99%.

- Tulip increases the speed at which process engineers can both deploy instructions, and analyze data. For many customers, process engineers spend close to 8 hours a week collecting, transcribing and analyzing data. By using Tulip, customers could gain almost a one full day a week back for their process engineers.

- Tulip decreases the time to train new operators, or to cross-train operators for new skills or on a new product introduction. Customers reported that what used to take weeks to several months in order to get operators fully productive is shortened to at most a week of training. In many cases customers noted a reduction in training time by 92%. This is because Tulip can automatically guide operators through training modules, while supervisors can assess performance and provide targeted feedback. Supervisors are also able to train more operators simultaneously.

These benefits are consequential for the organizations that achieved them and help them create new standards for productivity and efficiency. These benefits are related to the soft ROI outcomes reported by customers. One key soft ROI is the increased process visibility into operations. For many, they had no baseline with which to measure themselves. Through use of Tulip, customers discovered that previously held assumptions about their manufacturing capabilities and processes were incorrect and there were hidden costs on their manufacturing operations.
Additionally, many noted improved organizational collaboration as a result of using Tulip and having to work hand-in-hand between departments like IT, Operations, Quality and H.R. Because of these new collaborations, other projects and ideas started to circulate and the companies could realize the benefit of a more inclusive, innovative culture.

On the flip side, a few customers noted that they faced increased political pushback from within the organization as a result of implementing Tulip. This is unsurprising for those reading this who come from large organizations, where bureaucracy and power dynamics often trump teamwork and collaboration.
Chapter 9 – Future Opportunities & Challenges

Now understanding the impact of Tulip on our customers operations, we focus on the present and future challenges and opportunities faced by our customers. Their responses are summarized to the right. As shown by the tight spread in frequency, there are only a few key concerns that stand out from the rest.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Relative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of Action by Management</td>
<td>16%</td>
</tr>
<tr>
<td>Data Validity</td>
<td>14%</td>
</tr>
<tr>
<td>Hiring or Contracting Additional</td>
<td>11%</td>
</tr>
<tr>
<td>Technical Resources</td>
<td></td>
</tr>
<tr>
<td>Cultural Acceptance of Changes</td>
<td>11%</td>
</tr>
<tr>
<td>Automated Data Collection</td>
<td>8%</td>
</tr>
<tr>
<td>Labor Efficiency</td>
<td>8%</td>
</tr>
<tr>
<td>Availability of Skilled Labor</td>
<td>8%</td>
</tr>
<tr>
<td>Scaling New Systems</td>
<td>5%</td>
</tr>
<tr>
<td>Technology 'Hardening'</td>
<td>5%</td>
</tr>
<tr>
<td>Design Thinking/Skills</td>
<td>5%</td>
</tr>
<tr>
<td>Backwards Compatibility</td>
<td>3%</td>
</tr>
<tr>
<td>Disruption Failing to Produce Goals</td>
<td>3%</td>
</tr>
<tr>
<td>Regulatory Burden</td>
<td>3%</td>
</tr>
</tbody>
</table>

What are manufacturers concerned about?

The most commonly expressed concern is that management will fail to take action on new initiatives. This result is not surprising, as corporate inertia can often be a limiting factor to implementing new technologies in any enterprise. One can imagine that for unproved systems this sentiment makes sense, but for the customers interviewed in this thesis the return on investment was already proved out. This speaks to the lack of action in the face of fact-based reasoning change. Often this goes against the gut intuition demonstrated by many leaders. This hits upon the same power dynamic we noted before, where human behaviors are intertwined with their historical power positions. New systems of interaction challenge and disrupt previous ways of managing organizations.

Justin Burke
Next were concerns around data validity, but not automated data collection. This is especially interesting when one considers the historical emphasis on systems of record in order to measure and improve operations. At the beginning of this research, I assumed that most companies would be focused on automated data collection rather than the data validity of existing systems. This speaks to the real, practical issues of valid data collection. Often times this is the particular challenge they were solving with Tulip, however the concerns of data validity extended to parts of the organization that are not already using Tulip. As companies begin to evaluate the use of A.I. or machine learning, it’s apparent that the limiting factor isn’t the company’s desire to implement new technologies. Instead, it is the limit of their ability to first enact the change through action, and second, trust the data they’re previously collected.

Scaling out new technology due to challenges of hiring enough technical resources or implementing new organizational structures is also high on the list. This requires groups to work together in ways they haven’t before, while also adding new capabilities. When one considers the power dynamics at work in the organization, this could prove to be a significant barrier to value creation unless management provides the leadership to take it over the finish line.

Digital Transformation Initiatives

Considering that many Tulip customers have innovation initiatives, I was curious as to what other technologies or capabilities they would invest in for future competitive advantages. The two primary trends are 1) automation and 2) supply chain visibility.
Automation

Automation investments are expected from advanced manufacturers, with a focus around flexible automation initiatives rather than rigid capabilities that cannot change with new product introduction. My expectation is that as the functional level of flexible robotics increases, easily reprogrammable robotics may finally provide the expected ROI for manufacturers. Easily reprogrammable means guiding the robot through the correct sequence of actions via direct manipulation instead of computer simulation and programming. Further, machine builders may begin lowering costs or looking for common data platforms so they can create modular turn-key solutions, rather than the fixed solutions that are typically deployed today.

Supply Chain

Customers are looking for data transparency, data validity, and data timeliness in their digital supply chain initiatives. This data can then be used to improve relationships with vendors. Blockchain enthusiasts will excitedly point to the impact their technology can have with shared, distributed, immutable ledgers as a way to provide this transparency. I argue that companies are not ready for their data (even if encrypted) to be publicly available. I expect that many companies will begin implementing digital supply chain projects with key vendors. These one-to-one, or one-to-many supply chain links can provide immense valuable for planning purposes, as delays or production challenges can be visible and accounted for.
Artificial Intelligence

I expected the topic of artificial intelligence to be widely discussed by customers, but with one exception none of our customers brought up the topic of artificial intelligence or machine learning. Through conversations conducted outside the scope of my surveys, the leadership of many companies indicate they find the technology interesting. However these same groups noted that while the benefits of these technologies for better predictive maintenance programs would be helpful, the apparent costs seem too high and of limited value, compared to their primary challenges of data validity and labor shortages. As demonstrated by advancements in artificial intelligence in restricted domain sets, there is a lot of promise to this technology. However, too many view A.I. from the perspective of a technology looking for a problem, rather than a problem looking for a solution. I argue for that A.I. to be impactful, we must first think about what questions are difficult and worth answering, and then evaluate technologies in order to solve these challenges.

Future Research

A key area for future research is the intersection of innovation, technology infusion and organizational behavior on enterprise dynamics. Humans (generally) do not like change, so when change is forced upon them they try to find a way to maintain the status quo. For innovative technologies to truly come to bear, we must address the human challenge.
Bibliography


