Unit Hours as a Key Performance Indicator

by

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B.S.E. Mechanical Engineering, University of Michigan, 2014

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Abstract

In a complex manufacturing environment, tracking the cause of cost overruns and other issues can be challenging. At one of Boeing's plants, a tool was built to track a key performance indicator based on labor hours. Boeing's measurement of labor hours will capture delays due to part shortages, additional work hours required to complete rework, improper clocking, unbalanced workloads, overtime and any other delays or issues that cause work to take longer than scheduled. The tool also forms the foundation for a visual control system on the factory floor. This web-based tool is designed to improve problem solving at all levels of the organization. Using this tool, the plant's stakeholders can effectively identify and prioritize labor overages before they accumulate, resulting in an improvement in data-driven problem finding and solving.

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Chapter 1

Introduction

As of this writing, management articles and company credos often suggest that teams and individuals make data driven decisions. The reason for this drive is that there is a body of evidence that suggests companies that use data outperform their rivals [1]. Boeing is an aerospace and defense company with over 100 years of history designing, developing, and manufacturing aircraft. In recent years Boeing has adopted corporate-wide guidance to use data in decision making. Can someone make a data driven decision without data? What data do you need to solve a given problem? These questions set the stage for the project and research that will constitute this thesis.

Unit hours are Boeing's measurement of labor time, the time in hours that operators spend working on a given airplane and associated activities. Unit hours are a strong indicator for the overall performance of a manufacturing system. The metric will capture delays due to part shortages, additional work hours required to complete rework, improper clocking, unbalanced workloads, overtime and any other delays or issues that cause work to take longer. The finance organization within Boeing tracks total unit hours on a monthly basis and reports out to manufacturing senior management. These reports of monthly labor costs are scrutinized by both finance and manufacturing senior leadership. Only producing a monthly roll-up, however, is too infrequent for implementing effective data-driven decisions and actions by first line manufacturing management. A lack of timely insight as to what time is being charged

to a given airplane on a given day in a given position leads to an inability to determine data-driven solutions. When this project was scoped, Boeing's "Airplane A" was being built at one of the highest rates of any aircraft in the world. Therefore, Airplane A and its supply chain are a very large undertaking. The problems we are attempting to solve in this context are a small piece of such a large puzzle but with Airplane A's high rate of production, difficulty begins to arise in tracking which jobs are driving incremental labor cost overrun.

The term "job" refers to a specific quantity of work as determined by manufacturing engineering. Jobs can range from a small fraction on an hour to multiple hours and are called Installation Processes (IP) within Boeing. One hypothetical example of a job could be IP-1234567 - Install this, fasten that, etc.

The term "Line Number" refers to an individual airplane by sequence number. So line number 7000 is the 7000th plane in a given sequence. A BEMS identification is an employee's identification number within Boeing's systems. Therefore, at any point in this document, referring to a BEMS means we have broken information down to the individual employee level.

Boeing builds Airplane A at a high rate and volume of multiple airplanes per day. Due to this, many challenges exist which are unique to this aircraft.

This project started with an initial problem statement and expanded into deeper technical and cultural problem solving. The original problem statement was:

1. Unit hours charged by Airplane A Wings exceed the budgeted amount.

The primary problems worked were:

1. Working level personnel lack access to timely and granular unit hour data.

2. Interest in unit hours decreases with decreasing rank in the manufacturing organization.

For additional context, the demands on first line managers within Airplane A Manufacturing to check metrics, from various systems within Boeing, before every 5 A.M. first-shift start are high. Said another way, in order to fulfill all reporting

obligations, team members must access a variety of systems which then turn the daily metric checking into a time consuming task early every morning.

Another truth of the status quo in the Airplane A manufacturing teams is that most, if not all, of the tech tools around novel metrics and the like were designed for very senior management, beyond the general supervisor level. As such, these tools exist, live and die on the whims and interests of senior executives. While these tools may be effective for management to understand what they believe is important to understand, it presents us with an opportunity for cultural change. In driving for more engagement with first line managers the fact that they provided the input, guidance and decision making worked to prove that the tool was for them and by them rather than a top-down directive.

While the problems described above may raise many questions, this document will expand upon these issues throughout.

1.1 Background

Prior to the COVID-19 pandemic, the growth in demand for fuel-efficient commercial airplanes far outstripped the demand for other commercial airliners and was continuing to grow [2]. Therefore, building Airplane A on-time and on-budget is a priority for Boeing and specifically for the Boeing Commercial Airplanes at this point in time. Managing unit hours is one tool of many to support these time and budget goals. The majority of this project was conducted working with Airplane A Wings Manufacturing specifically, so Wings are the focus herein. Wings are used in an airplane to generate lift and thus have a highly engineered geometry and structure. Wings also feature surfaces critical to controlling the speed, roll and yaw of an airplane as well as storing fuel and providing mounting points for the engines [3]. As such, wings feature many complex electronic, mechanical and hydraulic controls as well as critical structural elements. This dictates that Wings are built with a tightly controlled and precision environment and methodology.

The appeal for tracking unit hours in airplane wing manufacturing is related to

visual control as well. A vision for the understanding of unit hours was a tool wherein a first line manager for Boeing could quickly identify if something had gone awry the day before, rather than try and recall if something happened in one or many of the past forty to fifty airplanes that had come through their stations. Quickly identifying issues using a wide reaching key performance indicator thus pays benefits similar to 5S[1] [4].

Despite its advantages, the introduction of a new focus on a metric which is typically in the realm of finance and industrial engineering presents organizational challenges. New initiatives which cannot be traced back to the construction of airplanes run the risk of facing resistance from the manufacturing organization. This is because the manufacturing organization is under pressure every day to make sure that builds are progressing with the highest quality. Individuals who are first line managers and general supervisors require a high degree of prioritization skill in order to filter through a large volume of daily requests and challenges. Thus, the value of tracking unit hours must be proven in order for them to be tracked or used at all.

As a result the effectiveness of a unit hours tool was evaluated via continuous refinement and testing similar to design thinking [5]. This revision and customer interaction proved crucial to tool usefulness and tool adoption.

1.1.1 Wing Manufacturing

Wing manufacturing is physically demanding work at almost every stage of the process. Starting with large aluminum sheets as well as aluminum beams from the supply chain inside and outside of Boeing; the process begins with building the structure of the wing itself. For the sake of an overview, this process largely entails "drilling and filling" at many points throughout the beams and sheets which become ribs/spars and panels, respectively. Drilling and filling is the jargon for drilling holes through mated aluminum parts or subsystems and then filling them with fasteners, typically aluminum rivets and titanium bolts, and fastening them permanently into place. Due

[1]5S (spoken as "five-ess")is part of lean practice and is centered around keeping one's workplace clean. The practices are often translated as sort, set in order, shine, standardize and sustain.

to the high rate of production for Airplane A, much of this structural work is done with the wing horizontal rather than vertical as in some other airplane builds. Horizontal build allows not having scaffolding and requiring workers to climb in order to get to a work piece. This horizontal wing placement also brings the product to the workers and thereby enables more mechanics touching the product at one time, with a large amount of work completed in parallel. However, the horizontal work does require that mechanics do some work overhead, with the wing lifted above.

"Jobs" in this context typically refer to installation plan (IP) numbers which are assigned by the industrial engineering organization. Some jobs are quite large in scope and entail operations and work done across the entire wing, with the design intent being that multiple people will be assigned to the job for every wing that goes through the shop. On the other hand, some jobs are meant for one person to complete quickly in the course of a given wing being built. "Bars" are a collection of jobs that add up to the takt time for each wing. Once the structure of a wing is complete, envision a wing as you would see it on a completed airplane, but lacking the engine, flaps and ailerons. The next step in the process is to do systems installation. These processes install all of the controls that make the wing more than an aluminum box as well as the sealing that allows said box to be filled with fuel. The wingtip and other large assemblies are installed at the final stage of the build before shipping the structure to final assembly.

1.1.2 Airplane A Current State

The original Airplane A predates the modern Toyota Production System (TPS) as well as other innovations in management, manufacturing and industrial engineering. However, Boeing has continuously worked to make the line modern in order to strive for efficiency and profitability.

In the Airplane A manufacturing system, bars are matched up to the takt time and assigned to one or more employees. Furthermore, for each IP, Industrial engineering assigns a length of time called the "bar time" or "chit time" based on time studies and their assessment of the time needed to complete the job. Also, teams are usually

staffed with an "overbar" a skilled employee who can assist on any given job within the team as needed. Furthermore, under first line managers there are team leads who can assist with jobs as well. As a cultural note, there is an oft mentioned legacy of craftsmanship in airplane manufacturing that was talked about on the floor of the shop as well as in various informational interviews. This legacy of craftsmanship seems to be in conflict with standardized work and process stability. This conflict arises because craftsmanship in this context implies individual problem solving approaches, knowledge and skill, within the context of meeting the engineering specifications and compliance requirements. A specific example occurred when we were faced with a problem that delayed the build, many mechanics had each devised individual solutions that they completed if they were assigned the given job when the problem occurred. The solutions were clever and required hard work on the part of each mechanic and team. However, each mechanic solving a recurring problem differently is in direct conflict with standardized work. We will go into more detail on this issue specifically later in the document.

The line is pulsed at the completion of every takt time. If any jobs are not completed once the line is pulsed, said jobs are labelled as 'travelers'. The implications of travelers are further interruption to the value stream as downstream work can not be completed if traveling prior work impedes it.

Available Tools

Boeing had powerful tools available regarding unit hours with different intended audiences and different applications. The systems had fragmented knowledge and application and the intended customers were almost entirely senior managers. Disparate information technology systems in this case led to reduced effectiveness and frustration.

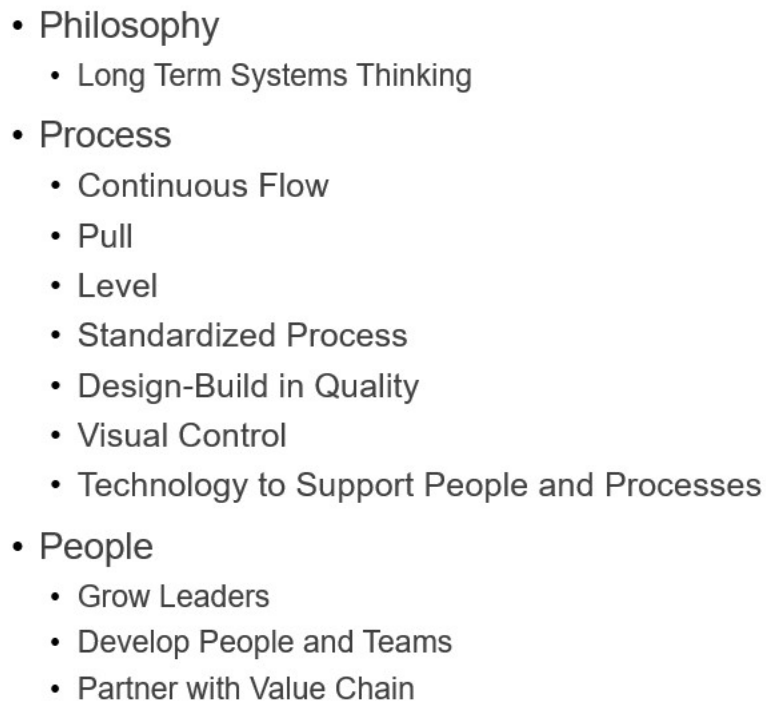

Figure 1-1: The principles of the Toyota Production System adapted from [4].

1.1.3 Comparison to Automotive Production and TPS

The principles of TPS as defined by Liker et. al in The Toyota Way are shown in figure 1-1.

Boeing strives for all principles in TPS but this thesis will start with and largely focus on visual control. TPS is often used in very high volume manufacturing with takt times measured in minutes or fractions therein rather than hours. However, the principles can still be applied.

Automotive production usually runs with parts and subsystems delivered lineside based on kanban based pull systems [4]. In the case of Airplane A, materials management teams work to deliver the day's parts ahead of time based on the daily plan. The materials management system is therefore somewhat of a push system. Furthermore, tools are replaced by operators when the operators determine that the tools are thoroughly worn out; if they make this determination, they then head to a supermarket style tool crib. This contrasts directly with automotive manufacturing where

a worn out tool would be replaced by a lineside support or materials management organization.

As a general heuristic for comparing airplane production as observed in this research to typical automotive production, the wing and airplane manufacturing in question relied much more on the mechanics, electricians and sealers to provide their own support functions. One such example is data entry; often in automotive manufacturing data on tool certification, incoming part batches, and torque values are entered automatically by automated equipment and scanners on the factory floor. In the case of the researched airplane manufacturing, the vast majority of this information in the majority of stations or cells was entered by the mechanics by hand. This data entry entailed walking over to a computer station and digging through the appropriate set of menus and sub-menus to find the appropriate entry field.

Furthermore, typically a large difference between aircraft and car manufacturing that disqualifies much of TPS from being of use is that in car manufacturing the work comes to the worker. Airplane A wing manufacturing provides an excellent test bed for TPS in airplane manufacturing because Airplane A is built at a high rate. Due to the size and rate demands of the product, the wing is brought to the worker with less movement required from operators than in airplane final assembly or larger and lower rate airplanes.

Standardized Work

The Airplane A team was driving increased standardized work while this research was being conducted. Another example of the previously mentioned craftsmanship in airplane building is that many jobs and positions observed relied on expertise from operators who had built many airplanes. Hand-written notes of an individual operator often featured in the work and the mechanic had to make decisions throughout the day in order to complete the work in a timely fashion. This degree of operator freedom and individuality differs from the typical level of standardization seen in a high-volume automotive assembly plant [4].

Data Recording

Another burden for the personnel working on the line was manual data-entry. Mechanics, electricians and sealers often had to record job selection, job completion, torque values and tool certifications in a computer at a computer station. This recording is waste as defined by time spent not working on the product [6]. This differs from modern TPS based production wherein the majority of this data is automated and digitally error-proofed.

1.2 Original Project Purpose

The Airplane A wings senior management team is challenged to reduce the unit hours per airplane in an effort to improve their production system. While senior management created and issued this challenge, that does not ensure that lower levels of the organization were aligned and understood the task. Said another way, even though finance had been challenging the senior management team to reduce unit hours, said challenge had not yet filtered through the ranks.

The unit hours measure includes the standard build process as well as additional rework required throughout the process as charged by the manufacturing team, support processes are accounted for separately. Unit hours can be impacted by improper clocking, unbalanced workloads, overtime, quality issues, or other manufacturing impacts that result in more time required to build a wing. Without accurate and timely recording and display of unit hours, it is difficult to understand which areas require improvement based on the unit hour build-up during the manufacturing process.

1.3 Project Goals

Unit hour usage as a key performance indicator may expose and help uncover strategic process improvements to enable future rate increases. In the early stages of this project we believed that using unit hours to uncover and highlight issues on the manufacturing line, and then using unit hours to measure the improvements therein would

enable increasing the rate of the line and decreasing overtime through improvements in quality.

If, for instance, we used unit hours to find that a large issue delayed production at a given station by one hour, fifty percent of the time; then fixing that issue could lead to decreased average time to complete work in that station. Once the time to complete a problematic job was reduced, eventually the line could be re-balanced and the production rate increased.

Therefore, the project goals were to eventually measure unit hours as an overall operational improvement tool rather than for the sake of the metric itself. Meaning that while there is a goal of improving overall unit hours performance, the primary focus of the research and implementation team is on unit hours' potential to be a powerful production health metric. While the metric is financial in nature, this proposed shift aligns with Boeing's approach to putting safety and quality in its production system ahead of cost and schedule, by capturing data on several of the challenges and opportunities previously mentioned. The metric is powerful in so much as the data would capture many issues and opportunities. This goal is made more meaningful by the context that the manufacturing organization for Airplane A is very large and as such there are many diverse opinions among various teams and divisions as to which numbers and data are worth tracking.

The change management implications of a new metric and tool for the sake of improving one's own performance as well as the performance of one's team are extremely significant. Tracking something that is perceived to be tracked to appease management was a significant roadblock to new implementation. Boeing's leadership culture emphasizes the rotation of senior managers. With the rotational culture, more junior managers and individual contributors often described a "flavor-of-the-month" culture wherein, when a new senior manager came into authority, the daily priorities of the organization shifted.

Hence, implementing a new metric for the sake of the finance or industrial engineering department would likely face tremendous resistance from first line manufacturing management. The metric must therefore exist to tap into the first line

management's intrinsic desire to want to do a better job. Unit hours must be shown to serve its users.

Some readers will find this situation intuitive and a challenge found within any large organization with many individuals and priorities. The research team was led to understand via repeated and consistent anecdotes stating that past senior managers installed in the organization had requested new metrics that served the senior team but not their subordinates. The reader's opinion as to whether or not this is a reasonable request likely varies based on their personal experience. None-the-less this research set out to illustrate to many manufacturing teams that unit hours were different than these past experiences.

1.4 Business Implications

The business implications of a new metric that is intended to enable end users are numerous. First and foremost, a metric which enables oneself and one's team supports the vision for a cultural change to tap into intrinsic motivation. If managers and operators became comfortable with unit hours and how their performance fluctuates after any given shift, they could begin to understand which problems are driving the overage that affected the airplane and organization. As labor is a large cost in most manufacturing systems, reducing labor costs aligns with improving the business [7]. Furthermore, this new intrinsic problem solving need not be from the proverbial "seat of the pants" or a leader's instincts and impulses but rather be data-driven and clearly quantifiable with a tool that makes the information easily available. Understanding and then improving operations is largely the rationale for visual control systems in the context of lean manufacturing [4]. And each case study that was devised and created highlights a different way in-which a first-line manager can reduce the unit-hours wastes in her area.

Thereby, the application of unit hours to improve performance is democratized to the first line manager level and below. This drive to solve problems at lower levels of the organization has the potential to yield many benefits via enabling more personal

and intrinsic motivation as well as freeing up senior personnel to take actions and make decisions appropriate to their station in the firm rather than those of their subordinates.

1.5 Project Approach

First, it is important to learn the problems with the current state (Chapter 2) which we are trying to solve. This research approaches these problems in three areas: Mechanics' Time Entry for Unit Hours Data, The production systems' Status to Established Time Targets and Airplane A manufacturing's Culture of Problem-Solving.

The approach for this project was determined based upon an early understanding from this research that Boeing had many tools relating directly or indirectly to unit hours in her ecosystem. What could and does set this tool apart for unit hour usage is a focus on the needs of manufacturing floor personnel. Many of the existing resources and tools within the company were funded by and designed for executive leadership. While the needs of the firm may be well aligned, the needs of individuals within are often not. Therefore, this research needed to represent first-line managers and mechanics, primarily via their needs and wants to tap into their intrinsic desire to do excellent work and build high-quality airplanes. Intrinsic motivation has been shown to be more powerful than mandates from management [8]. As shown in figure 1-2, the approach was designed from the tools of design thinking in order to make a solution that served it's intended customers as best as possible [5].

The beginning of the described approach involved many conversations and listening on the part of the researcher in order to try to understand what the true needs of the intended audience are. If the vision of unit hours as a key performance indicator is to enable the user to serve themselves, then any pretense as to what will appease management needed to be avoided in initial discussions. This avoidance was to avoid framing the project as a short-term appeasement effort, we instead wished to illustrate the long term potential for one's own uses. Said another way, if users could find their own motivations and specific usages for the metric and associated tool, these

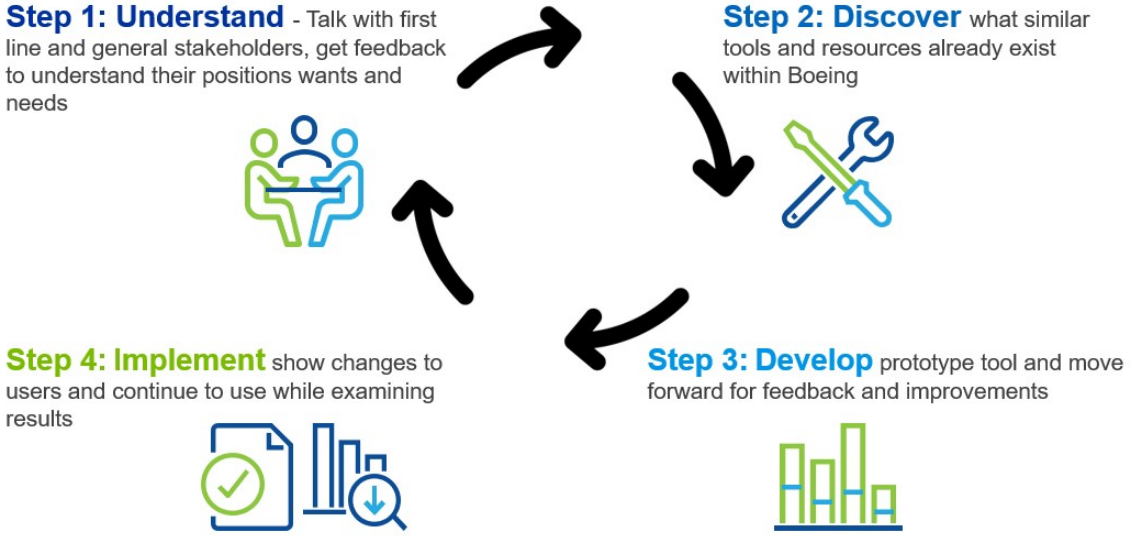

Figure 1-2: Iterative Project Approach Modeled on Design Thinking and Boeing Problem Solving

are more powerful desires for sticking to positive behaviors [8].

The next step in the process was to distill the customer wants into requirements and look through existing Boeing systems to see if they met the needs of the users upon whom this project is centered.

The third step taken was to develop the tool in prototype form and show it to a key group of users to gain further feedback. In later iterations this stage included tactile demonstrations which then revealed intuitive gaps and shortfalls in the tool.

The fourth step taken was to implement that feedback and ensure the robustness of the tool. Then the whole process was repeated throughout the research period.

1.5.1 Methodology and Rationale for Dashboard

Initial investigation into Boeing's available data tools, especially those which were open to the masses and not bound to expensive approval paperwork and headcount requirements[2], revealed that the company had significant infrastructure in place to support tableau dashboards and ingested data from its core servers. As a dashboard

[2]Of course, Boeing has processes in place to formally request new tools through its various IT groups, but these formal requests required budgets and high-level approvals.

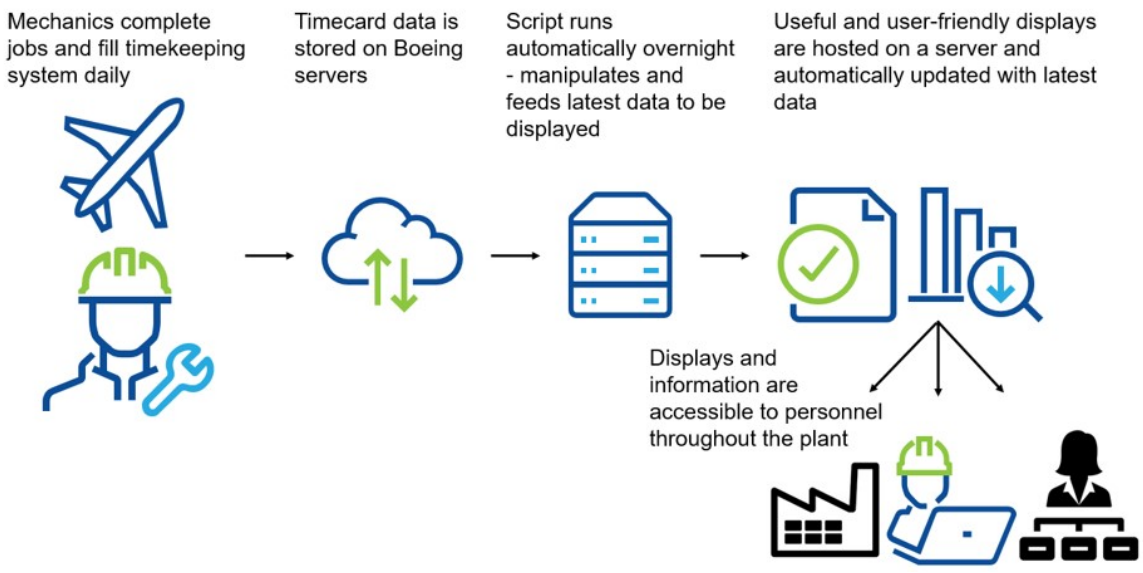

Figure 1-3: The process by which data was accessed and manipulated for this research.

fit well within Boeing's existing infrastructure, the decision was made early in the research period to pursue a dashboard in order to support long-term usage of any tool that was created. The back-end of the dashboard is built based on data from mechanics time-entry. Every day with varying frequency across Airplane A production, mechanics must enter codes defining which jobs they are working on for set periods of time. Chapter 2 will go further in-depth on this process and the associated shortcomings. The job codes, mechanic names, and quantity of labor time used (Unit Hours) are then uploaded to Boeing's servers. The tool created for this research then runs automatically and downloads the data needed to display fields which users determined to be useful. Finally, the "front-end" is a tableau dashboard which displays information in a user-friendly manner and can be accessed throughout the plant on a web-browser. This process is shown in figure 1-3. Furthermore, the decision was made in this process to keep the data as close to the source tables as possible. The rationale therein was to keep the data as close as possible to what was entered by mechanics working on the airplanes. Should a disagreement or a question arise from the data, the researcher believed it would be wise to avoid any code or processing related issues as the root cause but rather to focus on the quality of the inputs to improve the outputs.

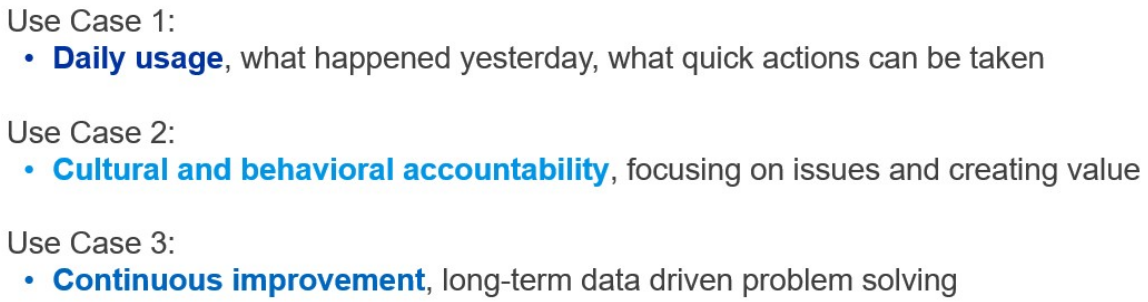

Figure 1-4: The three primary usage cases for solving problems with unit hours.

1.5.2 Methodology and Rationale for Case Studies

Case studies were deemed to be a powerful illustration of a new key performance indicator. This power is necessary because of the inherent abstraction[3] of a new key performance indicator [9]. The case studies bring concrete examples for personnel working close to the product in how the data was used to improve production, not in how the data was used to add a new metric and feed senior management. The case studies that were created are shown in figure 1-4.

Case study one is the primary usage case from this tool as written in the initial proposal. Case study one is based on visual control and notions of statistical process control. The fundamental principle in this instance is looking for irregularities in your positions and then drilling deeper and deeper to search for root cause. Starting with positional data a manager can drill all the way to individual employees completing individual jobs. The first two stages of this case study are shown in figure 1-5 with confidential information hidden.

Case study two is centered around cultural and behavioral accountability, focusing on issues with unit hours behaviors and therein creating value.

Case study three is based on continuous improvement, using long-term data driven problem solving.

Finally the case studies encourage focus on understanding what structural enablers/disablers are in place that lead to low/high amounts of unit hours charged.

[3]Abstract in so much as the project is about introducing data and data usage for overall production health and not just the metric itself.

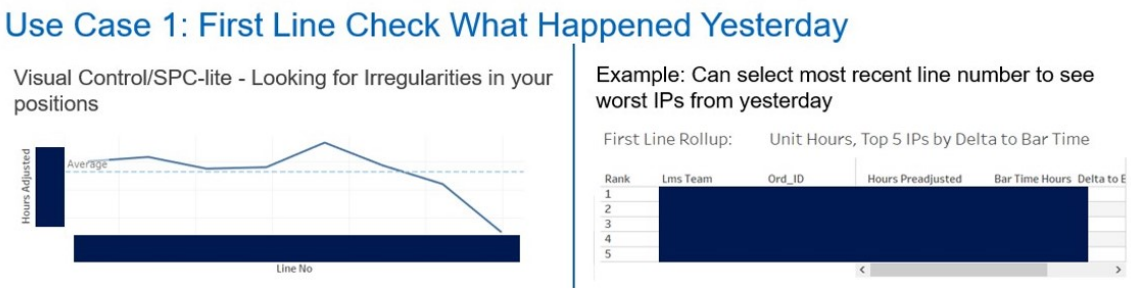

Figure 1-5: First steps of use case one, checking unit hours of recent shifts.

1.6 Literature Review

This section strives to detail a brief summary on past research in the field of lean concepts, specifically visual control in manufacturing, and the resulting effects on process variation in manufacturing. Based on existing work, my research builds upon these concepts and applies them to commercial airplane wing manufacturing.

The Toyota Production System, as described in figure 1-1, and Lean manufacturing principles as listed below are central to Boeing's production system [6].

1. Identify Value
2. Map the Value Stream
3. Create Flow
4. Establish Pull
5. Continuously Improve

In order to strive for these principles, Boeing has a system working towards just in time part delivery in-place as well as a system of team leads within teams whose job as written was to respond like an andon cord and help if the build fell behind. Currently, notification of a job falling behind requires an operator to communicate in person with the supervisor or overbar and describe the situation. Furthermore, the Airplane A team is actively working to drive standardized work across the production line. The team also had ongoing value stream mapping exercises and standardized work implementation.

This thesis seeks to expand Boeing's lean efforts on Airplane A through development, experimentation and implementation of a visual control tool and metrics. Per [6] "metrics are the primary element for changing behavior" via alignment of shop-floor activities to company behavior. Furthermore Feld states that "empowerment at the cell level... leads to improved performance". Which is the stated goal of this research as well [6].

Empowerment is a direct link to the importance of human behavior that underlies a large portion of lean teachings. In fact, Taiichi Ono opens the first chapter of his foundational book on lean management practices by stating that "If you want change, you really have to persuade people first, bringing them around to your way of thinking" [10].

In so much as the direct aim of this thesis is not to research persuasion specifically, it is still important to address. One oft cited work on persuasion is Robert Cialdini's Influence. Wherein he states six key principles used in influencing and persuading others, enumerated below [11].

1. Consistency - People like to be consistent with their self-image.

2. Consensus - Humans are social by nature and often feel that it's important to conform to the norms of a social group.

3. Scarcity - The less of something there is, the more people tend to want it.

4. Authority - Individuals who are authoritative and knowledgeable in their field are more influential and persuasive than they would be otherwise.

5. Reciprocity - Humans don't like to feel that we owe other people, as such we will tend to reciprocate things done for us.

6. Similarity - People are likely to be influenced and persuaded by those that they like.

These principles were relevant to the journey of change management that was a necessary and critical part of this research.

Furthermore, each of these principles served important roles in different times in the change management journey. For instance, consensus and similarity became important elements of gaining more users in later phases of the project as early adopters had started to use the tool and show its beneficial nature.

Chapter 2

Current State Time-Related Issues

In this chapter, we explore the foundational data used in this research and associated project. We find that good inputs are important but not essential for making decisions and using unit hours as a key performance indicator (KPI). This is because the most common erroneous entry methods, as discussed below, often do not affect the core problem statement of aggregate unit hours charged per plane being greater than aggregate unit hours allotted per plane.

2.1 Time Entry for Unit Hours Data

As previously mentioned, all unit hours data is entered by operators, manually on a computer. The system is designed such that operators are told to enter a job or installation-plan at the start of the day. When they mark that job as complete after a quality assurance sign-off, the system automatically calculates the time that was spent on the job.

This automated calculation of time spent on the job is entirely based upon the user input. The list below shows common behaviours used by operational personnel in order to save time and energy in the time entry processes. Each of these techniques has different implications for the accuracy and usage of unit hours data.

1. Batching

2. Omitting

3. Forgetting

Batching, in this context, is far and away the most common time entry method observed during this research which deviated from the expected entry methodology. Batching is when the user enters all jobs that they expect to work on during their shift or cycle at once, rather than entering each individual job in the system when they start said job. So, for instance, say an operator is assigned to hypothetical "A" bar and "A" consists of jobs 1 through 7; at the beginning of a shift or cycle, the operator enters their employee ID into each and every job 1 through 7. This is batching.

After this batching entry occurs, throughout the shift as the jobs are completed they will be noted as complete in the system. So over a hypothetical seven hour period, if an operator starts clocked into jobs 1 through 7 and job number 1 is signed off after an hour, job 1 will be registered as having taken 1 hour/7 jobs-clocked equal to 1/7th of an hour or 8.5 minutes. This is an example but is illustrative of a common time entry practice that leads to high variance within jobs. In order for the data to match the reality of the time elapsed in our example, assuming jobs were not in fact worked in parallel, the operator would need to clock into job 1 at the beginning of the cycle and the job would be marked complete in the system when the sign-offs were complete. The operator could then clock into job 2, rather than all the jobs at once in the beginning. In this ideal case, the job would show in the system as having taken one hour (the amount of time it truly took in our hypothetical). The operator could then go back to the computer and clock into each job sequentially for the rest of the cycle and shift.

Omitting in this context involves jobs which are ancillary or short in nature and duration and which do not have a mandatory and stand-alone quality sign-off. These jobs are often never clocked into at all. Thus when looking at data for individual job performance, some jobs appear to be overachieving and charging very few unit hours when in reality they have many zero entries wherein they were completed but not

Figure 2-1: Common example of forgetting to clock out of a job, giving a cluster of 8-hour clocking charges (entire shift).

charged.

Forgetting is clocking in and forgetting to clock out, which defaults the system to eight hours charged per person. The example in figure 2-1 is a typical example of a cluster of individuals clocked into one job for close to an 8 hour shift.

These entry methods often do not affect the core problem statement of aggregate unit hours per plane charged being greater than aggregate unit hours per plane allotted. They are worth addressing however as the temptation was for plant personnel and manager-users to attribute any unit hour overage to improper clocking. While this improper clocking invariably plays some role, especially when charging time to an airplane over lunch, for example. The data we reviewed showed improper clocking is a fraction of the total unit hour overage. In aggregate the unit hours exceeded the budget by an order of magnitude due to production health issues. In solving issues with production health, we will also solve issues with unit hours.

Operators are instructed to charge a nominal amount of time per day to setup and meetings as well so those charges will be inaccurate if there is an instance of forgetting to clock. Also, the base time that is entered by mechanics on the day the work is done is recorded on Boeing's servers as "Hours Preadjusted". If the next day or later in the week, an individual goes into their account and makes an adjustment to their time card, then those changes are saved in "Hours Adjusted". Hours Adjusted was used very infrequently by personnel within Boeing and often caused confusion, so it is mostly omitted from the displays discussed in chapter three. This research largely

treats Hours Preadjusted as the primary source of unit hour information.

Issues with clocking confirm the notion that any usage of unit hours will require the skill and judgement of operational personnel rather than a simple numerical readout and diagnosis. This user skill is necessary because of the issues we have discussed above. One could too easily pull up a job and see that the job was over hours and think that is meaningful. That is not necessarily the case however, so one should inspect adjacent jobs in a given bar to further understand the problem and seek out production issues which can be solved. This usage is addressed in more detail in chapter four. If clocking behaviors change via key enablers (such as lineside tablets, etc.) as discussed in chapter six, then a degree of simplicity for the user of unit hours data will come with said changes.

2.2 Status to Established Time Targets

The fundamental problem that drew initial attention to unit hours is that unit hours charged consistently exceed the budgeted amounts. The magnitude of this overage when the line was running at rate was closer to a multiple of the budget than a simple percentage overage of the budget. This overage has many causes, some of which will be discussed later in this document. While this overage may be surprising to some readers, the degree of the overage illustrates that the metric was not widely used prior to this research. Quantity of jobs behind schedule and overtime hours, for example, were tracked much more closely by the organization. However, again, these metrics were tracked for their own sake and not used to find and diagnose other production health issues. Using unit hours more frequently is a new behavior for the organization and gives the opportunity to continuously improve, despite the target being far from the current state.

2.3 Culture of Problem-Solving

The culture of problem solving within Airplane A Wings, within the observations of this research, was very robust and capable. The interaction with this research comes in that many of these problem solving efforts were focused on what could be solved with tactile feeling and instinct from many years of wing building experience, rather than using data. Also, interest in unit hours decreased with decreasing rank in the manufacturing organization. Therefore, resistance to a metric that was intended to help problem solve and then, in-turn, solve the inherent overage of the metric itself, necessitated a more concrete value proposition than just an abstract notion such as "using data is good". Herein case studies created with volunteers very open to change and new ideas became critical to the process.

There are also many stakeholders and support functions within a large manufacturing endeavour such as Airplane A; as shown in table 2.1.

Furthermore, the relationship between first-line managers and their industrial engineering support staff varies widely across the wings organization. One area within wings worked closely with their IE team to request custom data pulls from Boeing's severs for unit hours and many other key metrics. This team was the exception, however, as the majority of Industrial Engineering teams have a full workload with scheduling wings and other value stream mapping exercises. And the ability of IEs to write custom SQL queries is highly variable and dependent upon knowledge brought to the role, rather than on the job training. Therefore, first line managers cannot consistently rely upon Industrial Engineering for unit hours. Thus the tool provides unit hours for guidance and adds context to a larger picture of overall production health.

Functional Area	Responsibilities within Wings Manufacturing
Core Manufacturing	• Responsible for finishing wings at the takt time • First line managers within this organization are primary customers of the unit hours tool from this research • Manages teams of operators and works through day-to-day challenges with active builds
Industrial Engineering	• Sets Unit Hour Budget via Time Studies and Standard Adjustments • Manages the Build Schedule • Leads value stream mapping exercises across the organization
Quality Assurance	• Checks build to print and specification before final unit hours sign-off • Leads some manufacturing problem resolution teams
Materials Management	• Organises, manages and delivers parts and consumables lineside
Manufacturing Engineering	• Designs initial process and major process changes
Finance	• Reviews organization-wide, high level unit hour data with manufacturing senior management

Table 2.1: Airplane A Wing manufacturing functional organizations and descriptions of core contextual roles and responsibilities

Chapter 3

Data Visualization

A large portion of this project was dedicated to giving a visualization that delivered on our stated goals regarding usage of unit hours for the right audience. The first draft of the visualization came very quickly and was based on the structure of the data on Boeing's servers. This first prototype was not well received by example users and thus began an iterative improvement process.

3.1 Data extraction and Server Setup

Boeing's data is stored on servers and is therefore accessible throughout the company with proper approvals and a working knowledge of Structured Query Language - (SQL). The majority of first line managers come from years of experience working as operators on the assembly line and rising through the organization. As a result, SQL and data processing in general are not prerequisites for first line management positions. Industrial Engineers among Wings also varied widely from little to no SQL experience to highly capable of writing complicated queries that were situational and unique. As a result of the structure of Boeing's servers, the dashboard updates daily at nominally four A.M. wherein a user can then see yesterday's results at the beginning of her or his shift.

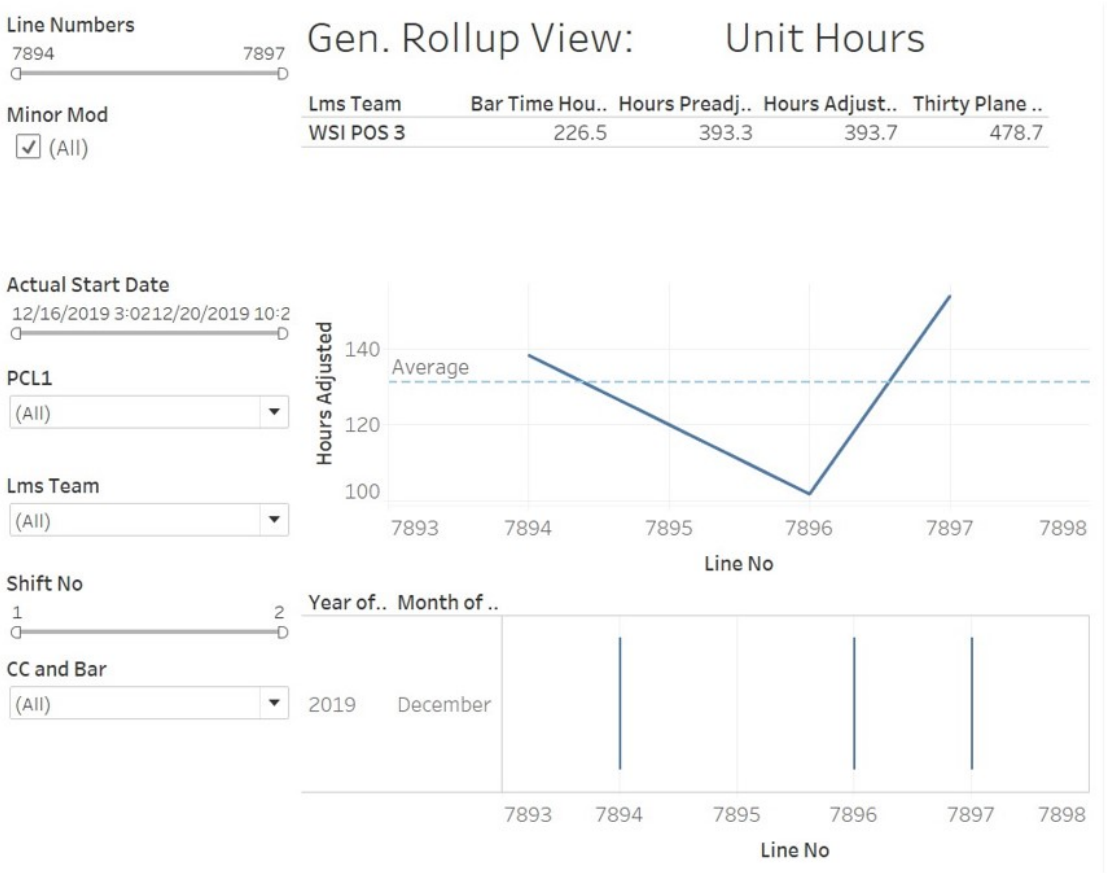

Figure 3-1: The General Supervisor Roll-up View is the First Screen in the Dashboard and the highest level data and information. NOTE: Data in this and all proceeding dashboard-figures are data that are completely fabricated from random number generators and have no relevance to reality.

3.2 Visual Layout, Design, and User Interface

The layout of the dashboard is based on continuous revision with key users who volunteered to be involved in the process. The frequency of revisions was sometimes more than weekly as the research was in the customer facing stages. The final result ended with six tabs within the dashboard. The tabs served different audiences or purposes. The dashboard starts with the highest level views and filters down to the more granular. The first tab in the dashboard is a roll-up view for general supervisors who supervise a group of first line managers as shown in figure 3-1.

The next tab is the first line roll-up which is centered around the first use case and the primary usage for the entire dashboard, wherein a first line manager can

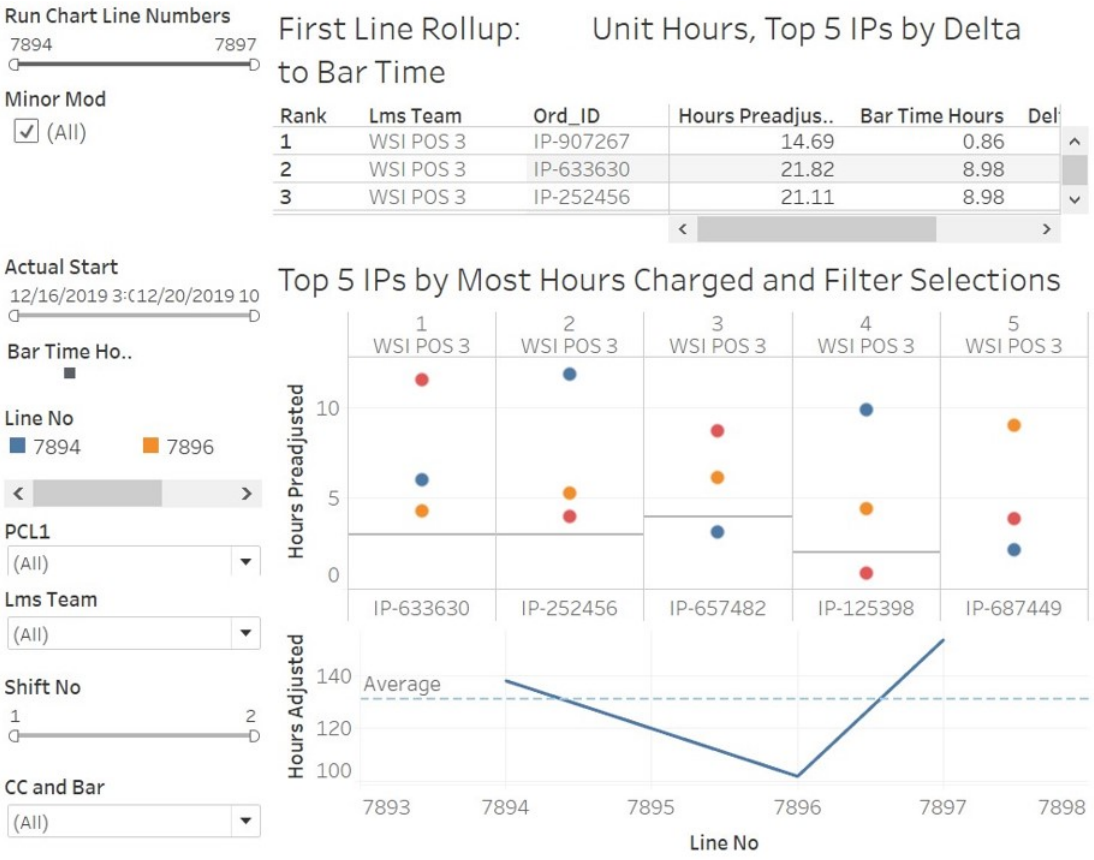

Figure 3-2: The First-Line-Manager Roll-up View is the Second Screen in the Dashboard. The slider bars under the line number legend and under the top grid display indicate that some values are not shown in this static image. NOTE: Data in this and all proceeding dashboard-figures are data that are completely fabricated from random number generators and have no relevance to reality.

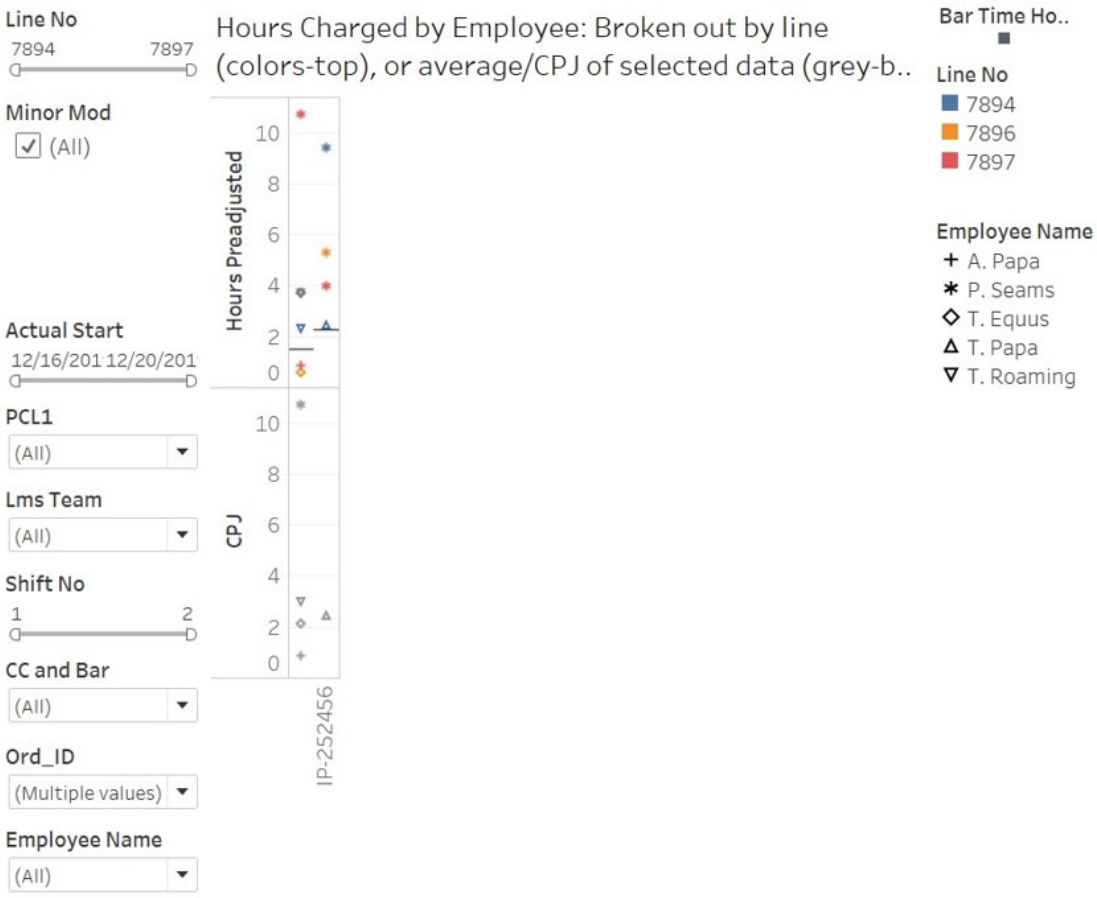

Figure 3-3: The BEMS/Employee Level Roll-up View, shown here with filtering determined by specific situational needs. NOTE: Data and employee names in this and all proceeding dashboard-figures are data that are completely fabricated from random number generators and have no relevance to reality.

check what happened yesterday and see if anything jumps out as anomalous. The top of the view figure 3-2 shows four key unit hours performance numbers by job number as aggregates; the preadjusted hours, the bar-time hours, the delta between the preadjusted hours and the bar time and finally the average of unit hours over the last thirty planes. The thirty-plane average is particularly useful as the bar time often does not provide a useful comparison because the average often exceeds the bar time by 100% or more.

The next tile shows a more visual representation of the same information. It shows a breakdown by line number, job, and position. Furthermore, this view shows the jobs in order of hours accrued over the sorted for time period. This sorting is critical

as a given supervisor will have many dozens of jobs and the intended usage herein is that they can quickly scan for anomalies in hour accrual as part of a daily cadence.

As a for instance, in figure 3-2, we see that the line number in red had the highest charging for job IP-633630 whereas the line number in blue charged a very similar and large quantity for IP-252456. This situation merits more investigation as we would need to dig deeper to understand what drove such a high usage of hours for these different jobs on different builds. Were there part delivery issues, were there travelling jobs that interfered and slowed work, did someone clock into the wrong job, etc.? There are many possibilities and on the next screen we will dig deeper into what the data tells us. In order to investigate, the user can sort to just those two jobs and two line numbers using the left hand side selections.

After doing so we get the figure 3-3 on the next tab in the dashboard. This figure shows that hypothetical employee P. Seams swapped which job she charged over a shift worth of unit hours to. The next step is to have a conversation and understand what is happening with these two jobs. Were there part delivery issues that changed from airplane to airplane? Perhaps there were traveling jobs from a previous station that got in P. Seams' way and different jobs travelled on different line numbers? The conversation is the first step to understand the root cause and working to solve problems.

The BEMS[1] view without the sorting from the previous hypothetical is shown in figure 3-4. In this figure we see that even the small subset of four line numbers of hypothetical data used for this document makes this view very cluttered and crowded. Therefore, sorting in the early displays and then based on the early displays is absolutely necessary for use in this display.

The next tab in the dashboard is the bar view, this tab replicates the data structure from Boeing's servers and therefore presents information with the least amount of filtering. For the advanced user who wants to dig deeper into the data and or field detailed questioning about it, this screen is for you.

[1]A BEMS ID number is a unique identification number assigned to every Boeing employee.

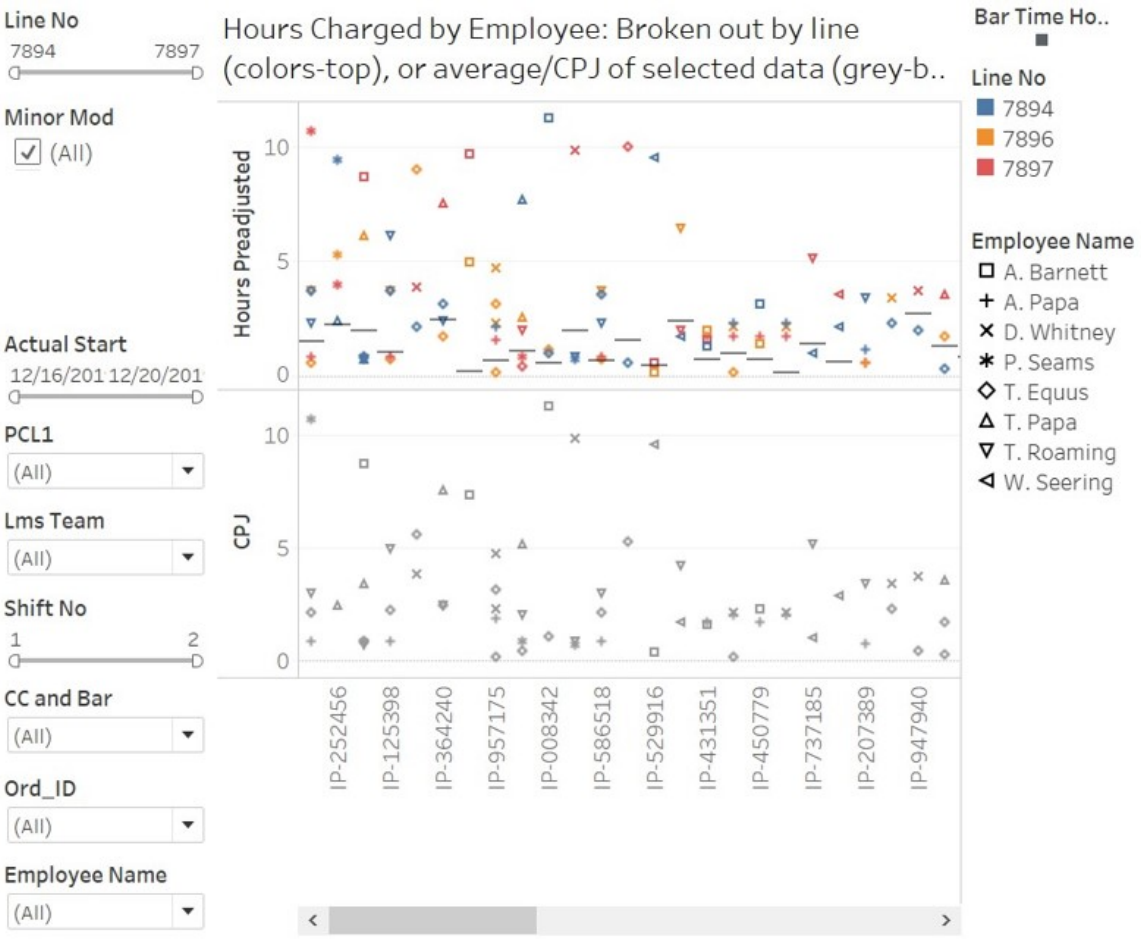

Figure 3-4: The BEMS/Employee Level Roll-up View, shown here without filtering that would be useful to better interpret the results. NOTE: Data and employee names in this and all proceeding dashboard-figures are data that are completely fabricated from random number generators and have no relevance to reality.

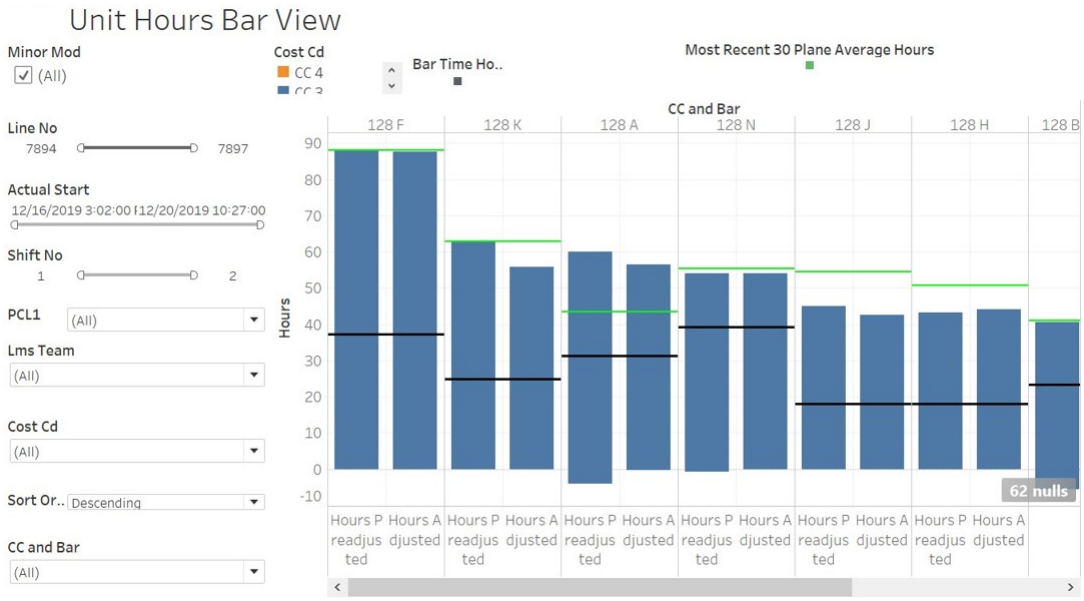

Figure 3-5: The Bar-View shows data as it is structured on Boeing's servers. NOTE: Data and employee names in this and all proceeding dashboard-figures are data that are completely fabricated from random number generators and have no relevance to reality.

3.3 User testing and observations

The employee-id based screen was the most highly desired and used screen as first line supervisors saw the tool as one which could drive conversations in order to understand given situations. In order to enable employee level data we had to ingest every employee time entry within our given time frame. This resulted in a large data set consisting of roughly sixty million data points, two million rows by thirty columns. One consequence of the size of the data-set is that major changes in the user filtering selections within the dashboard resulted in slow performance.

Chapter 4

Usage and Case-studies

The unit hours dashboard necessitated case studies in order to remove abstraction and drive understanding of the end goal and potential usages for its users. The case studies are not rigid must-dos, but rather they are intended as thought starters and tools for ideas wherein first line managers can use their resourcefulness to expand the power of the metric.

4.1 How-to use the tool

4.1.1 Getting Started

A central usefulness of the tool is that it has all of the given data for every airplane and manufacturing area for the prior year and can be quickly filtered to whatever and whenever a given person is interested in seeing, in order to analyze and diagnose. As an example, if the first line manager of Wings Systems Installation, Position number Three, wished to see their performance for yesterday or a given line number they could quickly do so. Thus, the beginning of using the tool is selecting from the menus on the left side of the screen what one wishes to see. The menus for all tabs are as follows in table 4.1.

[2]The dashboard will largely display the same data throughout tabs based on a user's initial input, however, some tabs within the unit hours dashboard serve different audiences and are therefore sorted and managed differently.

Tab Name	Primary Audience	Selection and Sort Menus
All	All	• Line Number • Minor Model • Start Date • PCL (Area Under a General Supervisor) • Team (One of Multiple Areas Under a First Line Manager) • Shift • Bar
Rollup	General Supervisors	Menus from All
First Line Rollup	First Line Managers	Menus from All
BEMS Rollup	First Line Managers	• Menus from All • Order ID (Installation Plan/Job)
IP View / Bar View / Stats / Pareto	All Users (Includes Industrial Engineering and Finance)	• Menus from All • Order ID • Sort Order (Toggle between ascending and descending hours)

Table 4.1: Table of tab names, primary audiences and menus for the unit hours dashboard[2]

The refinement of available menus was, again, based on the first guess of the researcher and then refined and iterated based upon user feedback. Different users have differing needs in differing situations and that drives differences across tabs. However, efforts were made to avoid adding menus and sorting functions to tabs wherein the results would confuse users.

4.1.2 Case Studies

As mentioned in the opening chapter, there were three case studies on how to use the tool in order to remove layers of abstraction for users. The case studies are as follows:

1. Daily usage - what happened yesterday? what quick actions can be taken?
2. Cultural and behavioral accountability - focusing on issues and creating value
3. Continuous improvement - long-term data driven problem solving

Each case study involved using the dashboard in a different way with different end results in mind.

Daily Usage Case

The first case study, which is centered around daily usage of the dashboard, is the case study which most closely matches the original problem statement as well as the case study which was most time intensive to build and refine.

For context, the demands on first line managers within Airplane A manufacturing to check metrics from various systems within Boeing before every 5 AM first shift starts are high. Said another way, in order to fulfill all report out obligations, team members must access a variety of systems which then turn the daily error checking into a time consuming task early every morning.

Thus, for this critical use case, the highest priority was placed upon the notion that all a supervisor has to do is quickly sort to yesterday and their positions in order to see useful diagnostic information. Figure 4-1 shows the four key steps in the first use case summarized.

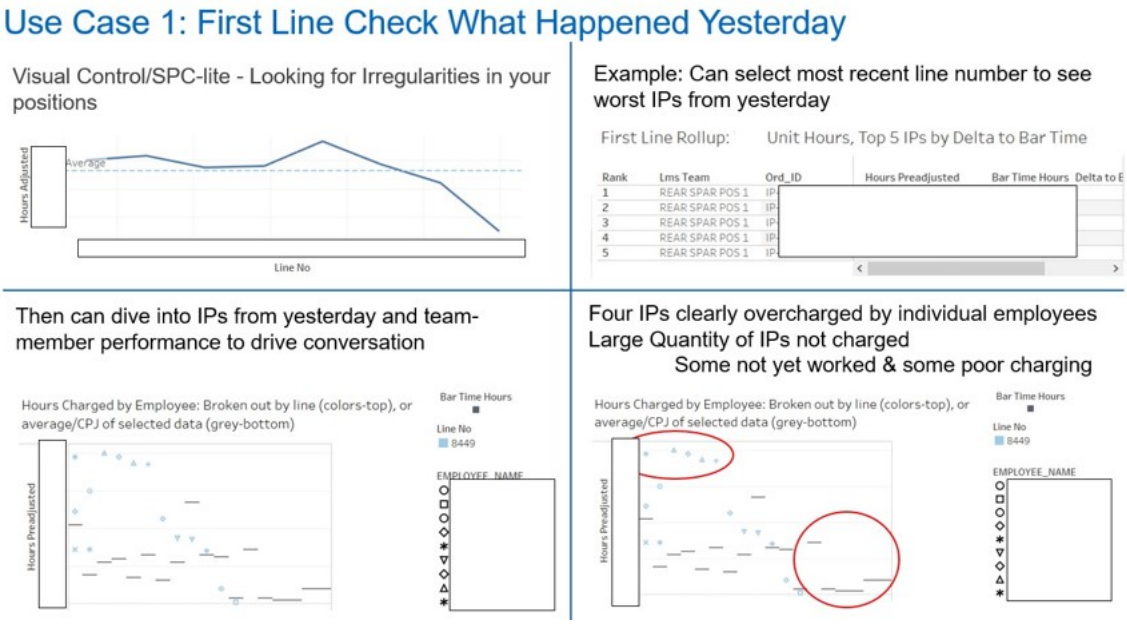

Figure 4-1: Use case one is briefly summarized in four steps. NOTE: All Data is obscured to protect confidential information.

The example in figure 4-1 is based on frequent problems seen around the COVID-19 slowdown at the Airplane A facility, however there are more uses contained within this case. This usage case was the largest driver for the first line rollup dashboard, shown in figure 4-2. We can quickly see in this figure that two different jobs exchange charging the most hours based on different airplanes (different line numbers, shown with different colors). The next step for this information is to look into the BEMS rollup and search for more detail.

The BEMS rollup, sorted for the two IPs wherein we wished to investigate further, is shown in figure 4-3. From this figure we can see that fictional employee P. Seams swapped jobs wherein she charged very high hours across the most recent three line numbers which we are examining. The next step in determining the root cause of this scenario is to have a conversation with the employee to determine the next level of "Whys" and all use cases as written emphasize this point very heavily. This approach stands in contrast to chastising Ms. Seams for her hour charging as that will not enable any problem solving. In contrast, having a conversation with employees in question is the fastest way to get to the Gemba and live the lean principle of Genchi

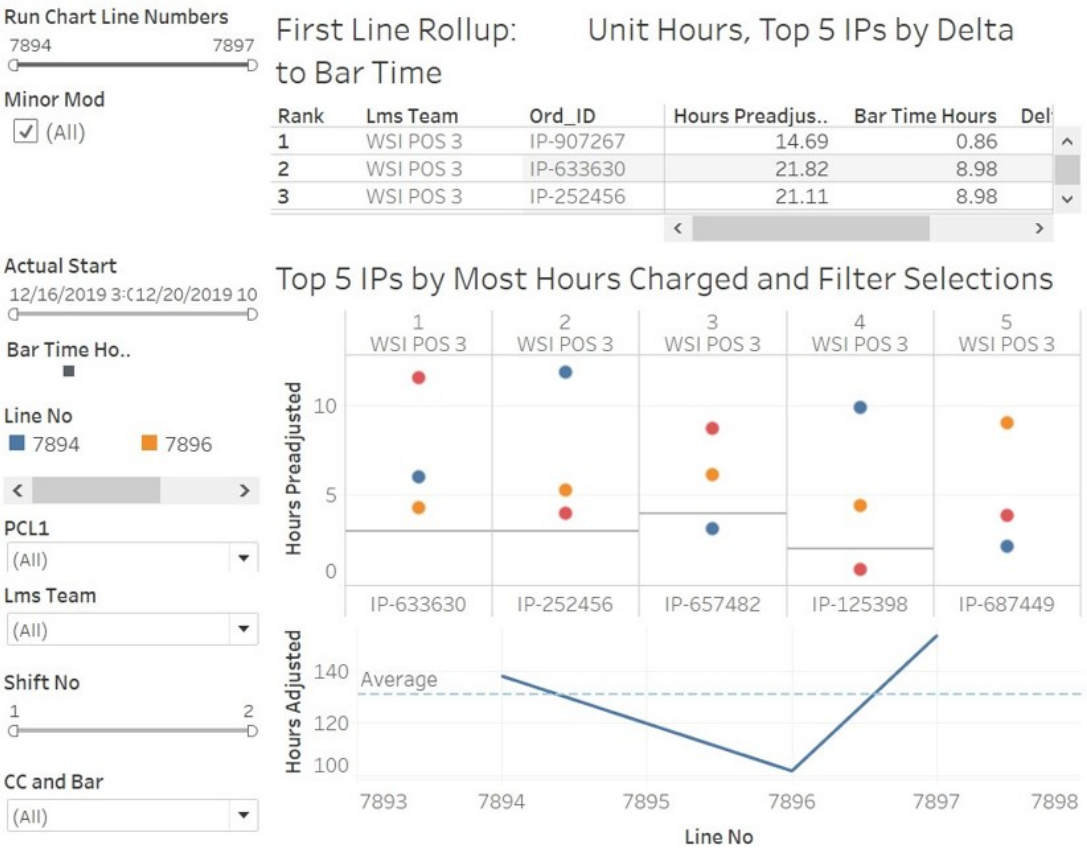

Figure 4-2: The first line roll-up uses basic tools to create a visual indication of any issues. NOTE: The data in this example are entirely fictional and created by random number generator, it's purpose is entirely pedagogical.

Genbutsu wherein the answers or "real-things" are on the line in the "real-location" [4]. For instance, a conversation with Ms. Seams may reveal that one line number was slowed by travelling jobs from a previous station while another was delayed by part non-delivery. Furthermore, it's possible that one time unit hour anomalies as seen in this example may be related to line design, job design or airplane design. These examples are one of many root causes which drive the results that seen here. Again, the operator will be able to best describe what happened if and when a first line manager quickly drives the conversation in a non-judgmental way. A week or a month after the build has completed will likely have faded the issues of the day into forgotten memories.

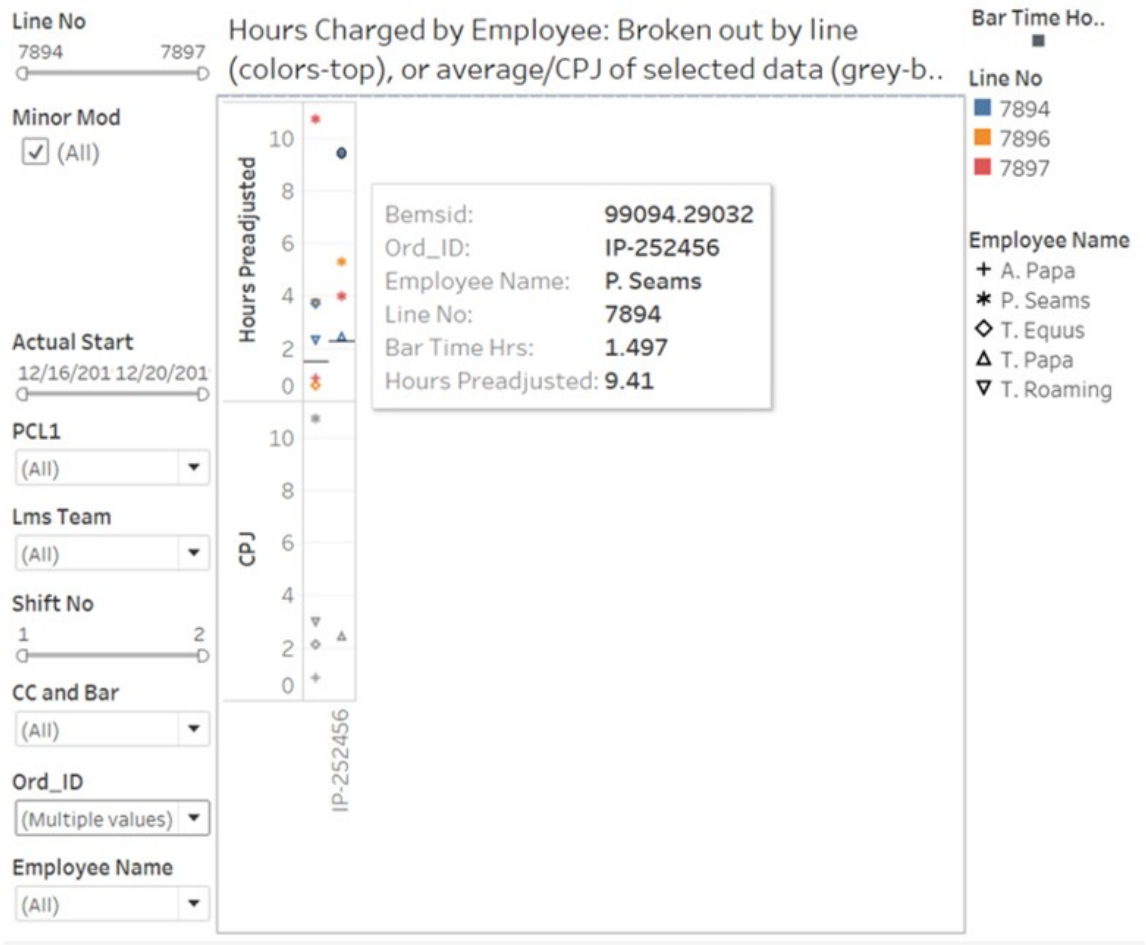

Figure 4-3: Sorting to see the two jobs in question from the first line rollup, we see that fictional employee P. Seams charged high hours to different jobs on different airplanes and this matches our previous observations around job charging from the first line rollup screen.

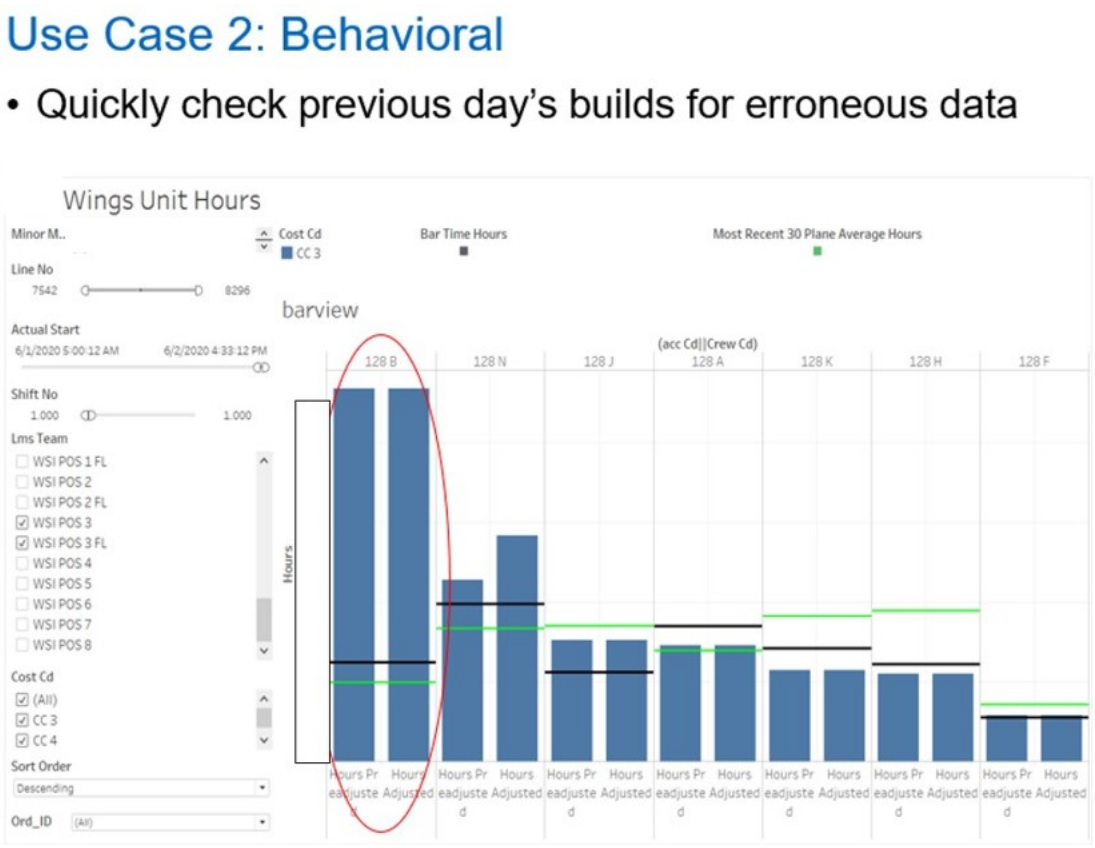

Figure 4-4: In this figure, the highest charging bar on a given day charged a large multiple of it's average charging. NOTE: Axis obscured for confidentiality.

Cultural Accountability

The second usage case can look quite similar to the first using only the data as a diagnostic, the difference comes from the results of open minded conversations with operators. In figure 4-4 we see that the highest charging bar on a given line number exceeded it's average by many multiples. If we hover our mouse over Bar B on this day we can see that the dashboard showed four people clocked into the bar which is higher than usual and one mechanic charged 6.7 hours while not working the bar, which is an incorrect clock.

In this use case the clocking was the case of anomalous data, which is a scenario that clearly exists but is not the main focus of this research. Primarily because fixing clocking will allow one to better diagnose issues in ones station but clocking itself will not reduce the number of hours for the organization or even within a given team.

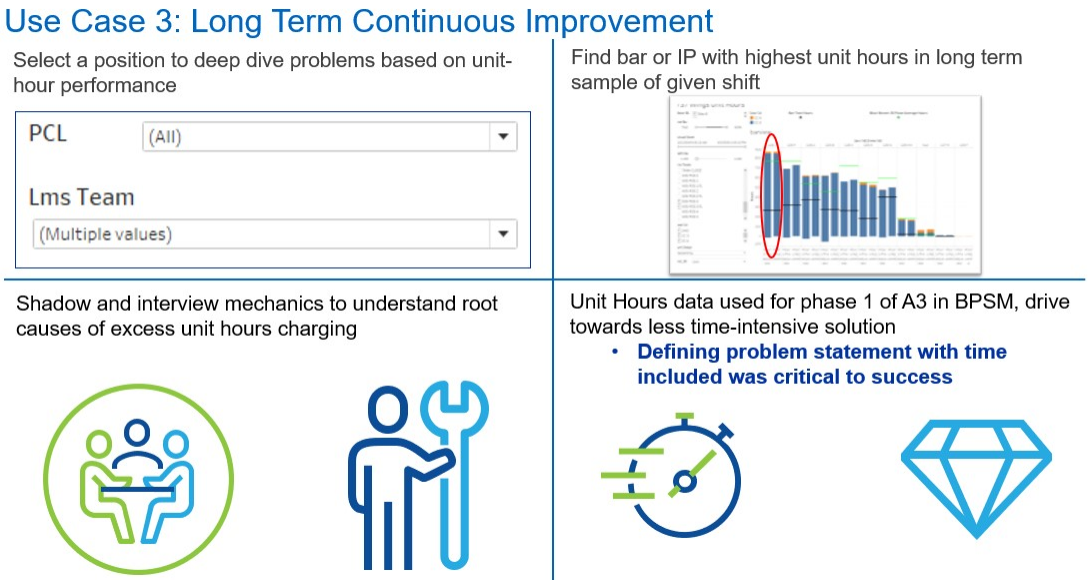

Figure 4-5: The process used to find and solve problems using unit hours during the course of this research. BPSM is the Boeing Problem Solving Model, which is based off of classic Six-Sigma root cause analysis.

Long Term Data Analysis

Even with the occasional erroneous data entry from the previous use case, we were still able to use long term unit hours data to find and solve major issues on the manufacturing line. One hypothesis for why a large data set was able to overcome erroneous data entry lies with the law of large numbers, which states that "as a sample size grows, its mean gets closer to the average of the whole population" [12].

The third usage case asks the user to take a look at large swaths of data to find and diagnose bars and IPs which may have systemic issues leading to consistent unit hour overage.

Within the scope of this research we shadowed a mechanic working a bar that had the highest long term unit hours in a given position wherein the first line manager volunteered to be part of our research. This shadowing revealed that there were re-curring intermittent issues driving the overage in unit hours seen in the data. Namely we found two large problems (more than 30 minutes lost per occurrence) and a multi-tude of smaller deviations from TPS best practices. Shadowing a job where the data told us to go was critical to identifying and later solving these issues. The results of

the problem exploration described herein will be expanded upon in the next section.

4.2 Problem solving using unit hours

As mentioned in the previous section, the unit hours dashboard described herein is a diagnostic tool which points the capable user in the direction of where to look for 5-Whys and other problem solving methods such that they can diagnose and then solve problems, thereby improving the organization's overall performance.

Once we shadowed the worst performing job under a supervisor who had volunteered to take part in our research, we decided to pursue one of the larger problems causing time delays that we had found. On the day of the build, the problem had not occurred and as such the only evidence we were able to collect was the mechanic's telling of events and the time it usually occupied.

The first step therefore was expanding the problem solving team to include other mechanics who had worked the bar and found the same problem as well as the team leader and first line manager.

Other mechanics who had worked this bar confirmed the issue in question, and interestingly, had different workarounds for the issue. These workarounds took the same amount of unit hours as the first one described. One of these workarounds had been accepted in the past as a containment measure, however unit hours would have shown us that it was not, in fact, containing the usage of time, as it was still very time consuming for the operator working the job.

The root cause of the issue was eventually found to be related to design differences between the left and right wing, due to slightly different functional requirements and validation in the area in question. Therefore the team acknowledged that a design change from the engineering team was unlikely to be a fruitful avenue for the team to pursue. As such, we continued collaborative gemba walks and ideation until we found a solution which was roughly 10x faster than the workarounds, did not require any changes from engineering and was within the product design specification from engineering and the process designed by manufacturing engineering.

Therefore, this case study and real problem identified and driven to solution proved the effectiveness of unit hours to not only find problems but also validate solutions which truly solve the root cause.

4.3 Daily cadence for First-Line Managers

While long term problem solving was proven to be effective using data from when Airplane A was being built at a very high rate, the primary focus of the tool is the power of quickly understanding and solving problems in order to try and drive excellence as an intrinsic habit rather than a large project worked by external researchers or consultants.

4.3.1 Mandatory Cost-Tracking as Part of a Six Metric Daily Cadence

As part of the drive to make unit hours part of a consistent habit forming exercise, the idea is under consideration to make unit hours the metric for all first line managers daily cadence. If implemented and followed through, the potential to spot more process slow downs as the build rate ramps up in 2021 and beyond is high.

Chapter 5

Business Implications

The business implications of improving unit hours performance are three-fold. First, labor is a high percentage of cost in any manufacturing environment and therefore reducing that cost will be meaningful. Second, reducing labor hours will enable greater efficiencies and lean changes to take hold as the day-to-day fires of labor shortage will be mitigated with each problem solved. And finally, in the long term, labor hours can serve as a catalyst for further data driven decision making and driving a culture of data-driven ownership and problem solving at every level of the organization.

5.1 Labor Hours as a key to cost

Labor is expensive, according to the MIT living wage calculator, the living wage in the Seattle-Tacoma metropolitan area for one adult with one child is roughly thirty dollars per hour in January 2021 [13]. At 2080 hours per year, that amounts to $61,069 before taxes. As there is a high degree of skill and craftsmanship involved in airplane manufacturing, the pay of many Boeing mechanics exceeds the living wage for the metropolitan area. Therefore, saving labor time on a significant amount of airplanes saves the business money.

5.2 Cultural Change

The modern business environment has been characterized by Pink et. al. as shifting away from traditional hierarchies and towards intrinsic motivation as a key to success and unlocking more from personnel and therefore organizations as well [8]. Airplane A is Boeing's highest volume commercial airplane and as a result, anecdotally from personnel on the manufacturing teams, the organization has been pushed to adopt more principles of lean and TPS than other commercial aircraft which are built at slower rates. The Airplane A manufacturing team, therefore, is a logical testing ground for Boeing Commercial Airplanes to push towards a culture of intrinsically motivated problem solving. One phrase that was said often in relation to this project and research is "enable everyone to run their area like their business". While I must acknowledge that this reads like a slogan and does not come with any particular academic or scientific precision, the point remains that this slogan captures what would amount to a cultural change. The status quo being that some processes and habits of the organization do not enable a spirit of individual initiative, entrepreneurship and problem solving.

Another truth of the status quo in the Airplane A manufacturing team is that most if not all of the tech tools around novel metrics and the like were designed for executive leadership, beyond the general supervisor level, and as such, the tools exist, live and die on changing priorities and focus areas of the current senior leaders. While these tools may be effective for management to understand what they believe is important to understand, it presents us with another opportunity for cultural change. During the development and testing of the tool, the prioritization of first line manager ideas and feedback into the final product was crucial for increasing adoption of the tool and building the foundation of unit hours becoming a powerful daily metric to drive continuous improvement.

5.2.1 Tackling Novel Problems

Dealing with Cross-Functional Teams

The majority of first line managers in the Airplane A organization are promoted because they are exceptional and smart operators (mechanics, electricians, sealers, etc.). This method of promotion and organization building is effective and pragmatic. This method does, however, expose individuals to organizations and politics with whom they are not used to dealing once they are promoted to management. This novelty in personnel and vested interests left individuals in unfamiliar territory multiple times during this research and was implied through past documentation from cross-functional teams. While theoretically guidance on these political machinations could come from general supervisors and be passed down to first line managers, in reality such an approach is not always effective. Therefore, additional training or information in the incentives and interests of other stakeholders inside and outside of the company may prove to be beneficial at enhancing manufacturing's ability to get problems solved when external groups are involved.

Data-driven decision making

According to Lloyd, all business decisions involve some degree of tradeoffs and uncertainty [1]. With this in mind, the push for data driven decisions in order to mitigate these challenges as best as possible is extremely relevant to the modern business environment. While the worthiness of using data to make decisions is established, the technical and organizational complexities remain to be addressed.

As we have previously established, the data itself is not yet at a place wherein unit hours data alone is of the quality and reliability in order to make a decision without a high degree of gemba contextualization and understanding. Said another way, the metric does not yet serve as a decision making metric, but rather a diagnostic tool to drive conversations and targeted investigations.

Chapter 6

Next Steps, Opportunities and Recommendations

At the terminus of this research there was a completed tool, displaying unit hours as previously described, loaded on Boeing's servers and accessible via internet browser throughout Boeing's facilities. While this is an important first step, there are many further opportunities to be explored. Final conclusions and recommended next steps for Airplane A will be elaborated upon herein.

6.1 Long-term dashboard support

At the beginning of this research I made an architectural decision to structure the data in a way that was similar to the structure used by a new data science team that owns and maintains many dashboards within Boeing Commercial Aircraft. This structural decision was made in order to ensure the long term feasibility of the tool. This decision turned out to be worthwhile as the team was able to take the tool over at the end of the research period and has agreed to maintain it until it is replaced. All automated data links for the tool were completed and the dashboard was formally handed off and published soon after the research period ended. In the long term there are also works within Boeing to replicate tools from other divisions in the company which contain a more consolidated approach to all metrics, rather than needing diverse

sources for diverse metrics and analyses. This consolidation would remove one of the most frequent user complaints heard throughout this process.

6.2 Recommendations

Emphasize Standardized Work, Increase IP Maintenance and Support from Manufacturing Engineering - The measurement and tracking of unit hours during the research period revealed that many mechanics do the same job different ways based upon their preferences and experiences. This notion is antithetical to standard work and the drive for standard work will likely push closer to consistent unit hour performance and reveal issues around long term problem solving using data. Furthermore, more standardized work combined with increased IP support from manufacturing engineering will enable the teams to work together to change IPs if they are not conducive to doing work quickly and efficiently or if IPs obfuscate the unit hours data due to shared work and overlapping work tasks. These changes will enable more unit hours based problem solving and resulting line efficiencies.

Implement Automated Infrastructure (e.g. Scanners) and Digital Tooling (e.g. Electric Fastening Systems) - Automation of part checking as well as tooling certification and quality assurance will enable faster production. The status quo of mechanic based manual entry requires time spent away from the product and therefore away from value added work.

Invest in Line-Support Functions - Some of the early experimentation with unit hours revealed that part miss- and non-delivery among other support-based challenges can lead to unit hour delays. Furthermore, many parts within Airplane A are based on either push (rather than lean-pull) based systems or a system wherein the mechanics must retrieve parts themselves rather than have them delivered.

Leader-Led Focus on Data and Key Metrics - While many of the stated goals of this project related to tapping into intrinsic motivation of more junior personnel, the relevance of the influence of management cannot be ignored. If management made consistent and disciplined pushes for a core set of key metrics, the organization could

move in unison towards their adoption.

Discipline and Consistency in Asks to Subordinates, More Personal Approach - Similar to the previous recommendation, churn in management personnel, mentality and requests was a frequent complaint of more junior management. Additional requests that frequently change on top of day-to-day responsibilities have led to some observed feelings of disillusionment and sense of "flavor-of-the-month" culture that would be wisely avoided.

Enhanced Training and Championing of Data Driven Problem Solving - As previously mentioned in this document, many personnel do not have prior experience working with data. As such, implementing training and advocating on the how and the why of data driven problem solving will likely help advance the implied goal of pushing for a data-driven culture.

Develop and Sell New Tools, Practices and Standards within the Organization - Boeing's Airplane A manufacturing organization is large and complex. As such, edicts and tools from other parts of the company may not be effective or well-received within this organization. The challenges of Airplane A's high rate of production are unique within Boeing Commercial Airplanes and this inhibits adoption of products that are otherwise useful. Selling and advocacy of new tools and techniques within an organization may appear overly cumbersome or wasteful, but are actually consistent by-products of the environment. Boeing has internal-sales organizations for other, more widespread data tools.

Continue to Consolidate Information Sources - While this document has established that there are challenges to consolidated sources of data, the rewards for solving said problems are ease of use for the end customers which are primarily junior managers. By lightening their workload in quantity of systems and number of procedures to remember, the employees will have more time to explore the data and find and solve problems.

Use Unit Hours Tool for Continuous Improvement and Error Checking - As a final recommendation, using the unit hours tool created for this research as a first step towards moving the organization into solving more problems with data will push

the organization towards a more data-driven and self-driven culture.

6.2.1 Ideal Future State based on TPS

Per figure 1-1, TPS calls upon several core principles in order to minimize waste and maximize productivity. In this context we have primarily discussed visual control, supporting people and processes and developing people and teams with a minor focus on standardizing processes and pull. Therefore an ideal future state for the Airplane A production line, following these principles, is one which is automated with technology that minimizes mechanic movement from the airplane. As well as a state wherein people are highly supported and developed. That support may be manifest in more pull based part delivery or training in data usage and IT systems to ease data entry across levels of the organization. Furthermore, standardized work will be essential to delivering consistent results and more meaningful data once the clear shortcomings in unit hours have been diagnosed and solved.

6.3 Conclusion

In conclusion, this research has found the usefulness of unit hours as a key performance indicator.

En route to this conclusion, we started in chapter one with examining the current state of Airplane A Wing manufacturing and the territory in which it existed before the pandemic; wherein it was an airplane built at a high rate. This rate creates unique challenges and opportunities to incorporate principles from the Toyota Production System in the quest for higher efficiencies. We also saw that the project largely centered around the use of visual control to understand where the largest problems and areas for improvement exist within the production system.

In chapter two we explored various issues with unit hours and labor time for Airplane A. Namely that time entry is complicated and somewhat error prone, which therefore necessitates a good deal of judgement in usage. We also see that unit hours are a somewhat new approach to problem solving in an organization that, writ large,

has not used key performance indicators as abstract trackers of overall production health, rather than as self serving metrics.

In chapter three we explored the main deliverable of the research, a tool for data visualization. This tool was created to be bespoke for Airplane A and largely based upon feedback of an under-served target customer - first line managers in the Wings organization. The tool was continuously refined by user testing and usage observations.

In chapter four we explored our efforts to remove abstraction from the process of using a new key performance indicator. Those efforts were to create case studies wherein we used the data to find then explore and finally solve problems on the assembly line.

In chapter five we explored the implications of successful usage of our new key performance indicator. Namely, that labor hours are themselves a large part of costs and that unit hours are a fertile KPI to start moving the organization towards more problem solving with data and abstract thought.

Finally, here in chapter six we summarized a series of findings and recommendations to continue the efforts of this research.

The unit hours tool created as part of this research makes available very detailed and targeted information for first line managers who were under-served by tools within Boeing Commercial Airplanes. By providing data in a highly granular and user-oriented format, the dashboard enables the organization to explore the usage of previously unused data to find and solve problems. The tool is built to be visually intuitive and easy to use, with targeted uses for key customers rather than one-size-fits-all for every organization. Developing a widely accessible web-based tool improved scope and scale. This tool allows users to investigate and solve problems with a high degree of autonomy or, said another way, run their area like their business.

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