Improving inventory management to increase profitability

by

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Submitted to the MIT Sloan School of Management and the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degrees of

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Abstract

ShopSabre, a leading designer and manufacturer of computer numerical control (CNC) routers and plasma tables, is experiencing robust growth, with revenues growing an average of 40% each year since 2015. Due to this growth, ShopSabre maintains an average backlog of 130-140 machines and an average lead time regularly exceeding 12 weeks. With each machine bringing in an average of $40,000 in revenue, half of which upon shipment, the backlog can easily account for over $2 million in unreceived revenue.

One cause of the large backlog is a lack of parts and subsequent work stoppages. Apart from a monthly physical inventory, ShopSabre does not have the means to assess inventory on hand at any given time. There are few common systems across sales, purchasing, and production, resulting in occasional miscommunication as well as a lack of data comparing cost of goods sold to revenue on ShopSabre's built-to-order machines.

This research develops a perpetual inventory system across departments by first gaining a deep understanding of existing inventory and processes, then building bills of materials for all ShopSabre products, and finally integrating existing processes into a common inventory system. The research then takes preliminary data from the system to demonstrate possible applications and improvements.

As of the conclusion of on-site research, ShopSabre is fulfilling machine orders with historically low lead times of four to five weeks for routers and seven weeks for plasmas/23s, marking ShopSabre's first year under 10-12-week lead times.

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Thank you to Chris, Steve, Brandon, Curt, Logan, Alex, Brad, Randy, and Ben for patiently answering my never-ending slew of questions and teaching me all the nuances that make up ShopSabre. Thanks to Ken and Mitch for teaching me how to drill, tap, and at a very basic level, assemble a CNC router; my short week on the production floor was invaluable in helping me create bills of materials, understand inventory, and ask the right questions. Thank you to Bob, Deirdre, Cameron, Brooke, and Dave for taking on new tasks in inFlow to make the inventory management system actually work.

I would also like to thank LFM Capital for making this internship possible. Thanks to Steve Cook for regularly carving out time to talk about any topic of my choosing and demonstrating a level of care for my career and future beyond the interests of LFM.

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1 Introduction

1.1 Background

In 2001, Jim Bombardo founded ShopSabre, a leading designer and manufacturer of computer numerical control (CNC) routers and plasma tables used for high-precision machining of wood and metal. ShopSabre prides itself on high quality manufacturing and high customer satisfaction, due in large part to a configure-to-order sales experience and lifetime technical support.

The company has experienced robust growth in recent years, with revenues growing an average of 40% each year since 2015. In late 2019, ShopSabre moved into a larger 50,000 square foot facility, and in 2020, ShopSabre launched its most powerful CNC router, the IS-M series, equipped with an industrial strength Mitsubishi M8 series electronic motion control platform. In late 2020, the company acquired a fourth mill, this one large enough to machine previously outsourced tables and gantries, ultimately reducing costs and increasing profits.

Figure 1.1.1 diagrams a typical ShopSabre CNC router and key components (PRO Series - CNC Router, 2020). The foundation of the machine is the table frame, which is fitted with a rigid tabletop material and an industrial steel gantry. This gantry slides the length of a table via a system of Hiwin rails, ball screws, and bearing blocks. The Z-assembly holds a motorized spindle and moves up, down, and across the gantry to make cuts. The Z-assembly can be fitted with additional tools, such as a JTECH laser engraver or EcoCam tangential knife, which allow for additional machining capabilities. igus® wire carriers facilitate the movement of cables and air lines as the spindle moves along its various axes.

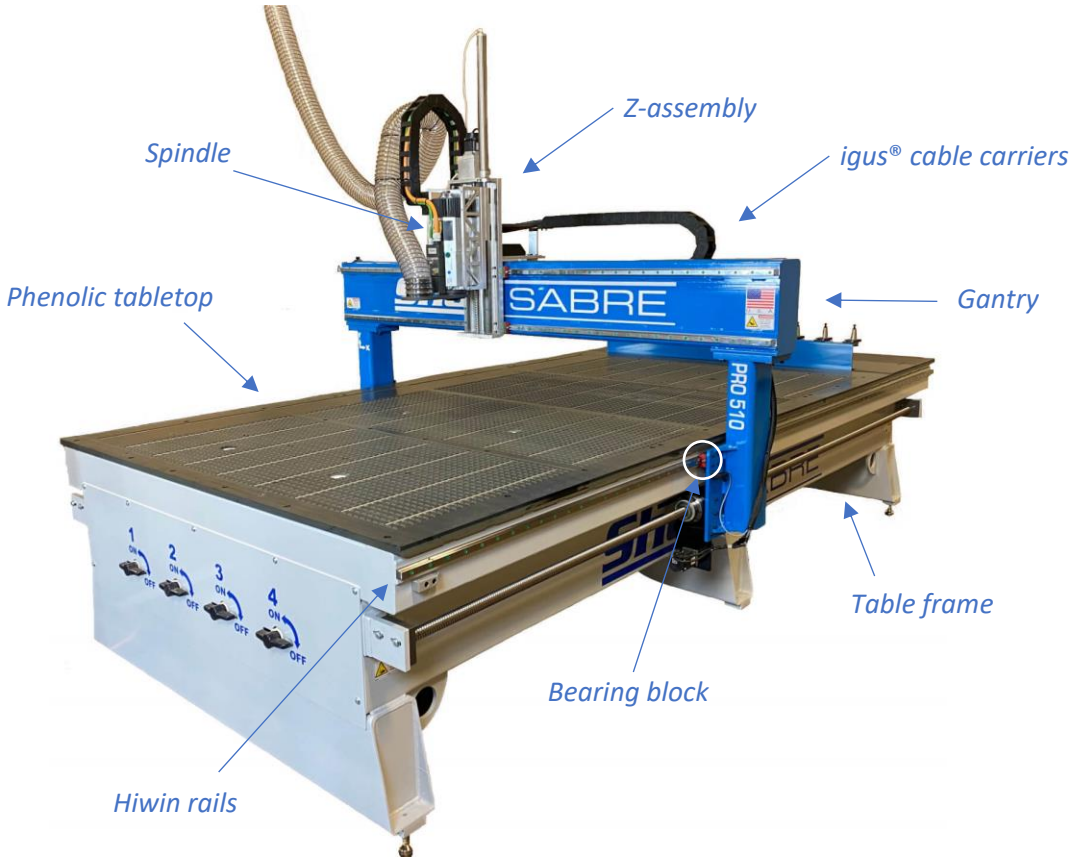

Figure 1.1.1 Key components on a ShopSabre CNC PRO series

Due to a large backlog, lead times for most ShopSabre machines—from customer order to shipment—regularly exceed 12 weeks (see Figure 1.1.2 below). Of those 12 weeks, only four weeks typically constitutes actual build time (welding, milling, painting, and assembly).

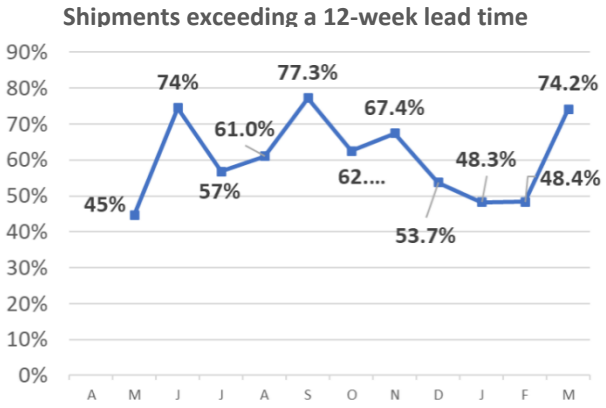

Figure 1.1.2 ShopSabre lead times, April 2019-March 2020.

In 2019, ShopSabre maintained an average backlog of 130-140 machines. In December 2019, this backlog peaked at 258 due to an annual year-end spike in sales caused by businesses taking advantage of the Section 179 tax deduction. With each machine bringing in an average of $40,000 in revenue, half of which customers pay upon shipment, this backlog can easily account for nearly $3 million in unreceived revenue. Figure 1.1.3 shows the monthly backlog in both number of machines and millions of dollars; the dollars of backlog accounts for the total value of the machines, including both received revenue (paid upon order) and unreceived revenue (paid before shipment).

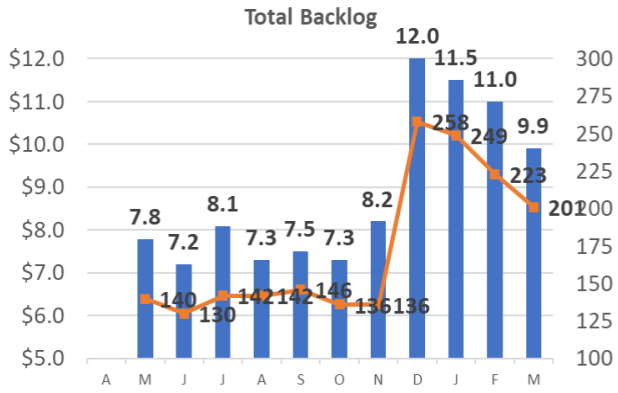

Figure 1.1.3 ShopSabre backlog, April 2019-March 2020.

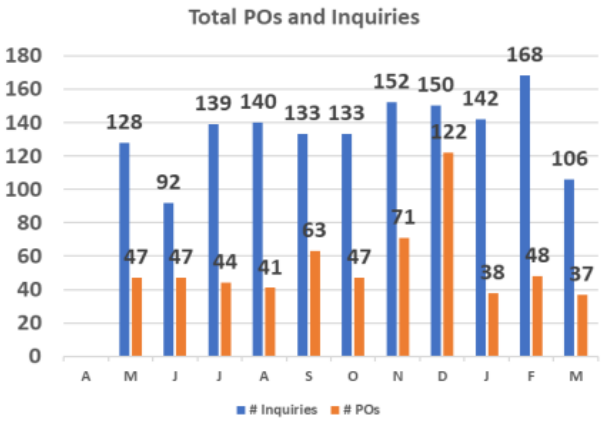

Figure 1.1.4 Sales vs. inquiries, April 2019-March 2020.

To decrease the backlog, production must be able to outpace sales and, ideally, be able to scale with an increase in sales (as typically seen each December). However, for the majority of 2019, both sales and

production averaged roughly 50 units per month. Figure 1.1.4 shows monthly sales from 2019 to 2020 relative to the number of customer inquiries each month.

At the end of 2019, the company hired additional staff and began implementing a Kanban system for reordering parts in bulk. These changes enabled ShopSabre to increase production from 50 to 70 units per month, gradually decreasing the backlog from 258 units in December 2019 to 163 units by May 2020.

1.2 Problem statement

As the company grows, ShopSabre aims to increase production from 70 to 100 units per month, and as the backlog decreases, the company expects to attract additional customers requiring shorter lead times, increasing sales and profitability.

However, inventory management at ShopSabre is informal, and information on "what parts should be ordered when" can occasionally fall through the cracks. Inconsistent availability of parts continues to limit productivity and throughput. Insufficient inventory of parts is already causing work stoppages and losses of more than two person-hours per day.

Figure 1.2.1 walks through the nuances of this problem and its contributing factors. This research focuses on a single root cause, parts availability, and considers other contributing factors out of scope.

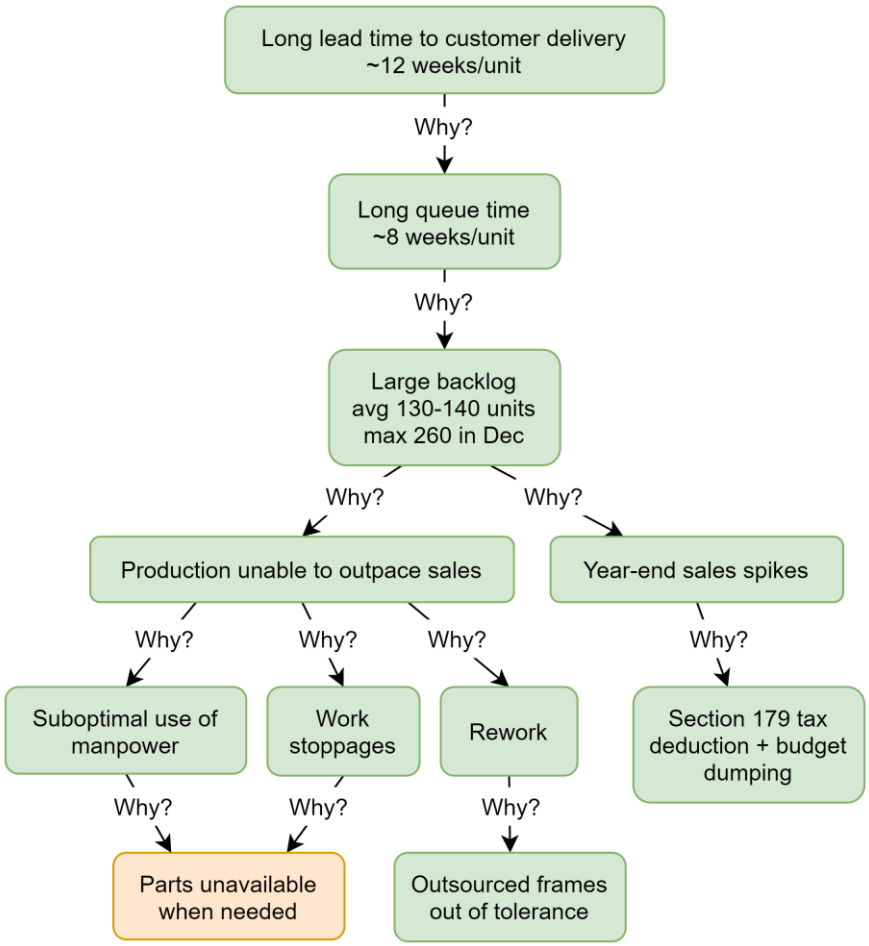

Figure 1.2.1 Problem tree/five whys analysis

The production manager estimates that transitioning the current assembly process to a series of subassembly processes could easily reduce cycle time and double throughput. However, the speed of the new subassembly processes would quickly deplete ShopSabre's parts inventory: ShopSabre would need more parts to keep up with assembly, more mills to keep up with demand for milled parts, and shorter lead times on table frames to keep up with the build queue.

1.3 Hypothesis

The scope of my research focuses on the availability of parts and improving inventory management. I hypothesize that creating a centralized system and process for managing inventory across sales, purchasing, and production will reduce lead times and increase profitability by

- Providing insight into daily inventory on hand (and on order)
- Reducing communication gaps and opportunities for human error
- Ensuring all necessary parts are available for an increase in production
- Reducing time spent on physical inventory counts and manual reordering processes
- Fostering a deeper understanding of cost of goods sold and product margins

Table 1.3.1 summarizes the key metrics for success, including the current state and desired future state.

	Unit of measure	March 2020	Goal (2021)
Productivity	Machines/month	52-56	100
Lead time	Weeks	12	4-6
Backlog	Machines	220	<100
	Millions of dollars	$4.4M	<$2M

Table 1.3.1 Metrics for success

1.4 Research methodology

To test my hypothesis, research will progress through the following stages:

Understand current inventory and processes

- Spend time on the shop floor shadowing various teams through the production process
- Build bills of materials for each ShopSabre product line and relevant accessories in the existing inFlow inventory management system

Develop a centralized system for managing inventory (inFlow)

- Integrate existing sales, production, purchasing, and receiving processes into inFlow, establishing a perpetual inventory system
- Troubleshoot challenges and refine the system to ensure sustainability

Use data from inventory management software to ensure parts available when needed

- Estimate demand on hot components using data from inFlow; use demand to calculate safety stock, reorder points, and reorder quantities

2 Literature review

2.1 Customer value proposition

While there are many ways to increase profitability, the overarching goal of reducing lead times stems from ShopSabre's customer value proposition. In his book *Operations Rules*, Dr. David Simchi-Levi emphasizes that companies cannot "compete successfully on all dimensions of customer value, such as innovation, choice, price, and experience." Rather, a company must focus on a particular value proposition, which will then shape the company's operations strategy (Simchi-Levi, 2010, p. 7).

As mentioned earlier, ShopSabre's value proposition is customer experience: the company prides itself on high customer satisfaction, a personalized sales experience, and lifetime technical support. Simchi-Levi suggests companies that offer customers unbeatably low prices might prioritize efficiency in their operations strategy; however, companies that focus on customer experience must focus more on responsiveness, as described below.

> …a responsive strategy focuses on speed, order fulfillment, service level, and customer satisfaction. Here, the objective is not necessarily to squeeze as much cost out of the supply chain as is humanly possible but rather to eliminate stockouts and satisfy demand by competing on response time and speed to market. Typically, in such a strategy, product variety is high and product lifecycle is short, manufacturing or product assembly is based on realized demand rather than forecast, products may be customized, a buffer inventory of components is emphasized, and sourcing, supplier selection, and transportation strategies all rely on speed rather than only on low cost. (Simchi-Levi, 2010, p. 8)

Many of the aforementioned characteristics are already integral to ShopSabre operations, namely customizable products and product assembly based on realized demand. If ShopSabre is to maximize customer satisfaction, its operations strategy also needs to focus on speed, response time, and order fulfillment. Currently, long lead times are preventing ShopSabre from fully satisfying its main value proposition.

2.2 Push- vs. pull-based supply chain strategies

Beyond customer value proposition, Dr. Simchi-Levi also discusses the effect of product type and other factors on relying on a push or pull supply chain strategy.

A push-based supply chain is one in which "production and distribution decisions are based on long-term forecasts. Typically, the manufacturer bases its demand forecasts on orders received from the retailer's warehouses." In a pull-based supply chain, on the other hand, "production and distribution are demand driven so that they are coordinated with true customer demand rather than forecast demand. In a pure pull system, the firm does not hold any inventory and responds only to specific orders. This is enabled by fast information-flow mechanisms that transfer information about customer demand, e.g., point-of-sale (POS) data, to the various supply chain participants" (Simchi-Levi, 2010, p. 36).

ShopSabre operates using a pull strategy in which customer demand flows regularly from sales representatives to the production floor. Due to the company's consistent backlog, ShopSabre is able to order most components based on actual sales orders, and similarly, the production floor welds and assembles tables based on this realized demand.

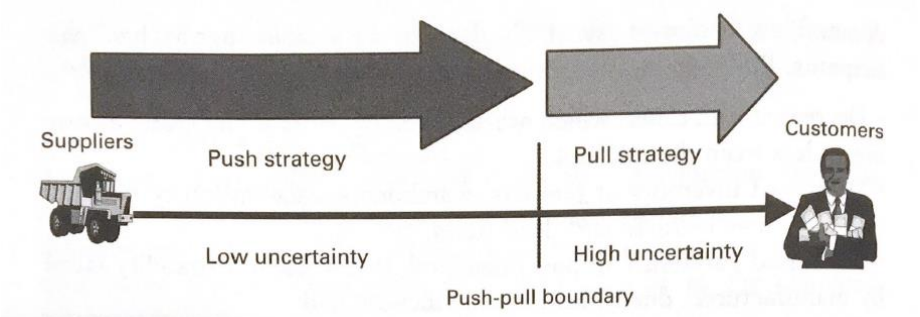

Figure 2.2.1 The push-pull boundary

However, a push-pull boundary, illustrated in Figure 2.2.1 (Simchi-Levi, 2010, p. 38), lies between ShopSabre and its parts vendors: while ShopSabre might be placing orders to vendors based on realized demand, vendors are still relying on demand forecasts to fulfill ShopSabre's orders. As is common in push-based systems, the parts vendors may experience an exaggeration of variability down the supply chain known as the bullwhip effect, depicted in Figure 2.2.2 (Simchi-Levi, 2010, p. 222). As vendors attempt to respond to ShopSabre's orders, which might vary in quantity, frequency, or both, they risk either stockouts and low service levels (causing parts to be unavailable for ShopSabre's production floor) or unnecessarily high inventory costs to prevent stockouts.

Allowing ShopSabre's parts vendors to receive insight into this demand on a daily or weekly basis would reduce the bullwhip effect, risk of stockouts and reducing the need for high levels of safety stock for both ShopSabre and its vendors. This also reduces lead times from vendors, better positioning them to anticipate ShopSabre's upcoming orders. Creating a centralized information system that aggregates customer demand and demand on the production floor within ShopSabre is the first step toward making this information available to vendors.

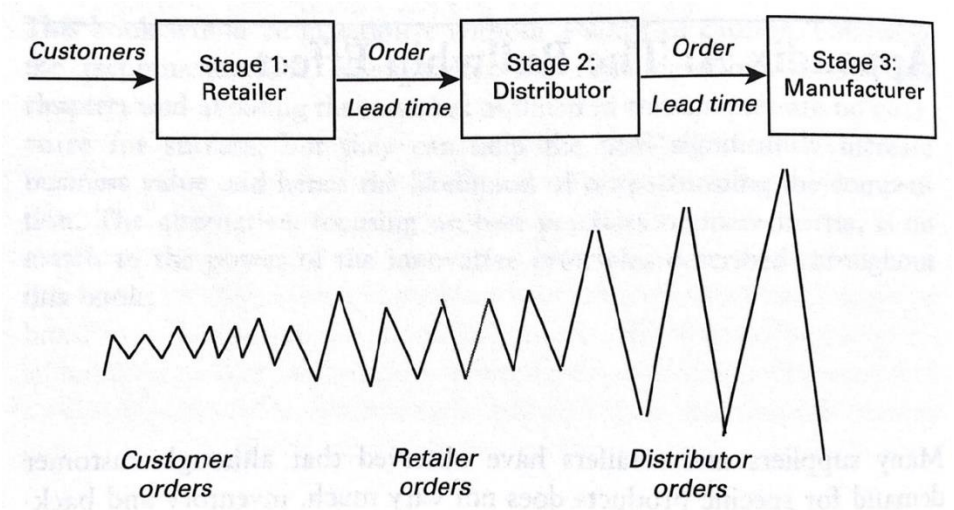

Figure 2.2.2 Demand variability and the bullwhip effect

2.3 Investing in information technology

In terms of both business process and information technology (IT), ShopSabre falls under what Dr. Simchi-Levi's terms a Level I organization. "Companies at level I are characterized by the proliferation of

many independent processes. Companies are organized functionally with no or a low degree of integration…Firms at level I have batch processes, independent systems, and redundant data across the organization. The focus is on spreadsheet and manual manipulation of data for decision making" (Simchi-Levi, 2010, p. 113).

IT investments are likely to reap significant rewards even in simply creating a common source of data across a small—but growing—company like ShopSabre. Dr. Simchi-Levi cites the compelling case of General Motors who, by linking its various divisions through IT investments, reduced response time for a customized vehicle from 60 days to less than 20 days while also cutting supply chain inventory in half (Simchi-Levi, 2010, p. 108).

In a study of 75 different supply chains, Heinrich and Simchi-Levi highlight how companies with mature business processes perform better than level I companies like ShopSabre and, more notably, mature companies that invest in IT infrastructure perform still better, with lower inventory carrying costs and higher on-time delivery performance (Heinrich & Simchi-Levi, 2005).

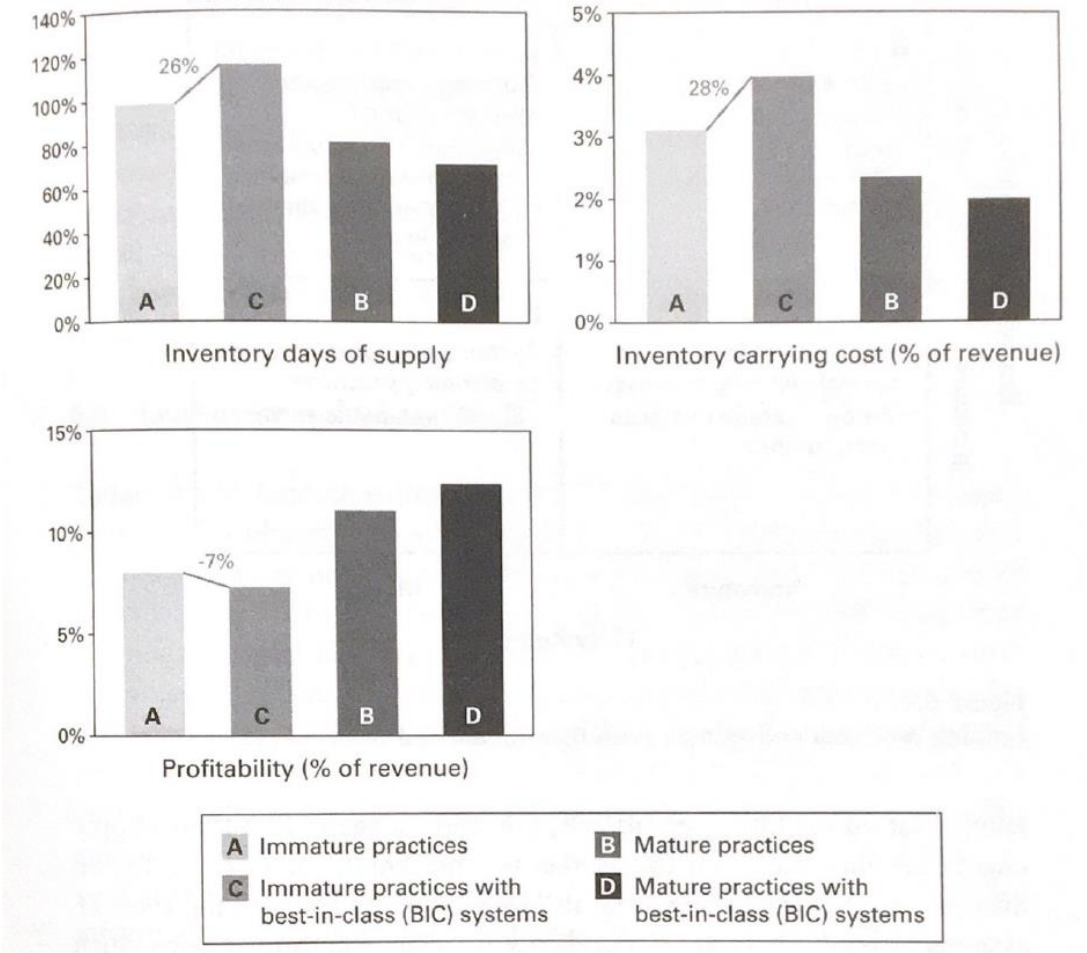

Figure 2.3.1 The effect of investment in IT infrastructure (Simchi-Levi, 2010, p. 117)

The study also warns against the dangers of investing in IT without the appropriate business processes. As alluded to above, inventory carrying costs generally trend down and profitability generally trends up with business process maturity and IT investment. However, as illustrated in Figure 2.3.1, the study also

found that “companies with best-in-class systems (the top 20 percent of IT-mature companies) that are process immature have higher days of supply, higher inventory carrying costs, and lower profits than process-immature companies that did not invest in IT infrastructure.” In other words, companies with “mature IT systems but immature business processes” actually “perform even worse than those with immature systems and immature processes” (Simchi-Levi, 2010, pp. 115-118).

Dr. Simchi-Levi explains that while best-in-class systems are costly investments, they only provide information, and in order for that information to be effective, a company needs corresponding business processes to utilize the information appropriately.

2.4 Calculating safety stock, reorder points, and reorder quantities

In ShopSabre’s case, the company needs to use the data generated by a common, perpetual inventory system to formalize and even automate its reordering process. Once sufficient data on demand and lead times is available, ShopSabre can create a more quantitative policy for determining reorder points and quantities using the following simple formulas:

$$reorder\ point = cycle\ stock + safety\ stock$$

$$cycle\ stock = daily\ consumption\ x\ lead\ time$$

Cycle stock is simply the inventory consumed over the course of time between ordering and receiving. Safety stock, a buffer to account for unanticipated events such as excess demand or delayed shipments, can be slightly more complex to determine.

Small companies like ShopSabre might use an informal safety stock calculation, basing safety stock on future weeks supply and aiming to have a certain number of weeks of inventory on hand at all times. However, in his article “Demystifying Inventory Optimization,” Dr. Sean Willems suggests companies can achieve a significant improvement in service level with minimal increases to inventory holding costs simply by moving to a more scientific safety stock calculation grounded in analytics (Willems, 2020). This safety stock calculation is as follows:

$$Safety\ stock\ required = z\sqrt{\mu_L\sigma_D^2 + \mu_D^2\sigma_L^2}$$

z = constant determined by level of service desired
μ_L = average lead time
σ_L = standard deviation of lead time
μ_D = average demand
σ_D = standard deviation of demand

The service level used to calculate safety stock indicates the probability that an item is in stock. For ShopSabre’s purposes, the service level is the probability that the production floor will have a component available as needed. A desired service of level of 95, for example, aims for a given component to be available when needed on 95 out of 100 days. Figure 2.4.1 (Crack the Code, 2020) shows the appropriate Z-score for the desired service level.

Desired cycle service level	Z-score
84	1
85	1.04
90	1.28
95	1.65
97	1.88
98	2.05
99	2.33
99.9	3.09

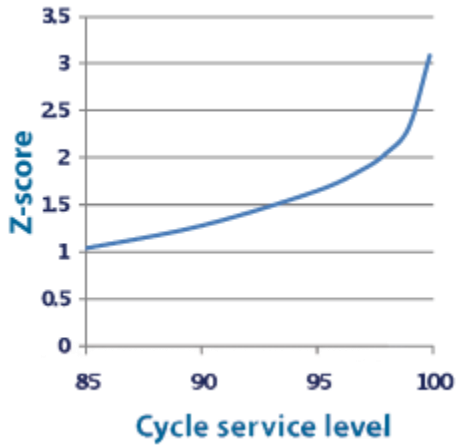

Figure 2.4.1 Relationship between desired service level and Z-score

For ShopSabre, the recommended service level varies by component. Key components that can cause major work stoppages may require higher service levels, while less critical components that can be found at local hardware store if needed might require lower service levels. Current service levels and recommendations for improvement are discussed in more detail in Chapter 5.

That said, even for key components, ShopSabre may only opt for a service level of 95 in lieu of higher, more rigorous service levels given that the "customer" in this calculation is ShopSabre's internal production floor rather than a paying customer. While a missing component will delay production, it will not result in a lost sale as in the classic use of service level to optimize inventory.

3 Understanding current inventory and processes

Developing a company-wide inventory system and using the data therein to formalize replenishment processes first requires an understanding of how ShopSabre operates and what constitutes ShopSabre's inventory, all of which revolves around fulfilling customer orders.

3.1 Order fulfillment

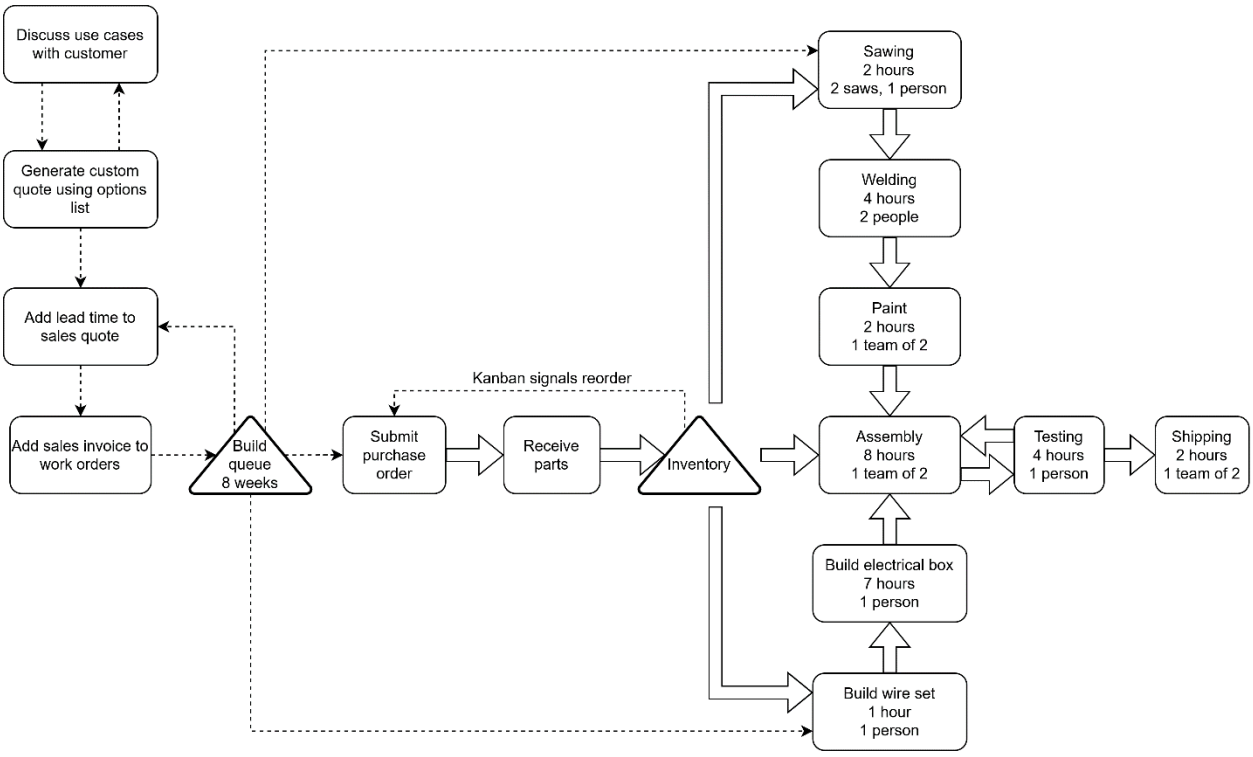

Figure 3.1.1 An overview of ShopSabre's order fulfillment process

ShopSabre's order fulfillment process, shown in Figure 3.1.1, begins with a discussion between the customer and a member of the sales team. The sales team guides the customer through the key decisions necessary to choose an appropriate machine and accessories that meet their needs. From there, sales creates a custom quote, pulling from an Excel-based bank of options and iterating with the customer as needed.

Once a customer finalizes their order, the sales team estimates lead times based on the current build queue and invoices the customer. The sales representative creates an invoice in a similar format to the quote, also in Excel. Customers regularly compliment ShopSabre on the detail included in its invoices, which break down the most important components and add-ons included in the purchase. An example of this level of detail is shown in a Figure 3.1.2.

The sales representative then copies the machine specifications from the invoice to a similar template with prices removed. This becomes a work order for the production floor. The parts department will add copies of both the invoice and work order to the build queue. The build queue exists in three forms:

- A binder of invoices with the parts department
- Two binders of work orders on the production floor

- A spreadsheet created by the parts department, shared with the production floor

1.00	**ShopSabre IS-408 Industrial Router System (55" x 100"Cut Area)** Please Wire for: 3 Phase Operation
1.00	Fully Assembled Precision Milled Over Sized Steel Tube Frame, Over Sized Tube Steel Gantry, Tube Steel Gantry Uprights, Industrial Designed
1.00	Limit Switches on X,Y,Z Axis with Auto Squaring and Boundary Alarms
1.00	Emergency Stop Switch
1.00	X, Dual Drive Y, and Z Axis Driven with Industrial Precision Anti-Backlash Ball Screw Drives.
1.00	Industrial 25MM Precision Linear Guide Rails & Bearings on All Axis - Y Axis Hidden Design - All Mating Surfaces Machined for Precision
1.00	Digtial A/C Brushless Servo Motors with Amplifiers on X, Dual Y, and Z Axis - Closed Loop with Z Axis Brake - Twin 1 Kilowatt Servos on Y Axis
1.00	ShopSabre WINCNC Industrial Controller Hardware & Software
1.00	ShopSabre Computer System - Full Size Desktop System with Solid State Hard Drive , 8GB Memory, 19" Flat Screen Monitor, Keyboard, Mouse
1.00	Vectric Vcarve Pro CAD/CAM Software
1.00	ShopSabre Rolling Enclosed Steel Fan Cooled Machine Operator Control Stand
1.00	ShopSabre Wireless Hand-Held Controller Pendant with Jog Wheel
1.00	USB Wireless for Computer Internet/Network Connectivity
1.00	Phenolic Table Top for 408 Size
1.00	T-Slot Installed Every 8" on Center in Standard Table Top with Clamp Kit for 408 Size
1.00	10HP Becker VTLF 2.250 Non-SK Vacuum System with 4 Zone Vacuum Manifold - Requires 3 Phase 208/230/460 Volt 27.3 / 25.8 /12.9 - Motor Starter Optional - 168 SCFM @ 24" HG *** Add $2,000 for Single Phase**
1.00	Industrial Pop-Up Table Reference Pins (3 on Left Side 2 along Front)
1.00	Tool Measure Switch - Measures Tooling Height without Changing Z Height for Fast Tool Change & Increased Accuracy
1.00	Material Height Touch Pad - Electronic Z Setter
1.00	8KW 10HP HSD Auto Tool Changer Package - 10 Position (24,000RPM)
1.00	Tool Changer Package Includes: 10 Qty - ER32 Collets, Cones, Tool Forks. Tool Rack Mounted to Machine, Collet Wrenches, and Chuck Holder. Auto Spindle On/Off Auto Spindle RPM, Super Z Technology includes Air Balancer for Z Axis
1.00	Quick Release Dust Skirt - 4" Outlet for Connecting to Dust Collector
1.00	Upgrade to Dust Dock Dust Skirt with Containment Design
1.00	Add 2.5" Spoil Board Cutter
1.00	**Advanced Bit Kit for Wood -** (2) 1/4" x 7/8" DE DC FINISHER, 1/2" x 1 1/4" DE DC FINISHER, (2) 3/8" x 7/8" DE MORT XP VIPER, (2) 3/8" x 7/8" DE MORT XP VIPER P1/4" x 7/8" DE MORTISE VIPER, 5MM X 70MM RH CT BRAD POINT, 8MM X 70MM RH CT BRAD POINT

Figure 3.1.2 Machine specifications from a sample sales order

The accounting department uses ShopSabre's current sales order format, which includes prices for added options, and enters values line by line into QuickBooks Online. Before sending the sales order to the customer, ShopSabre's customer liaison removes line item pricing, adds a lump sum price to the sales order, highlights the balance due, and changes the date.

3.2 Purchasing and receiving

On any given week, ShopSabre aims to have three weeks of parts on hand with the fourth week on order. The parts department's process for reordering relies on regular review of the build queue and a partially established Kanban system.

The parts department uses the aforementioned binder of invoices to order high-dollar components based on realized demand. Each week, the team orders specific parts required for the next 20-25 machines in queue. If there are enough machines in the queue, parts may place two orders in a single week. When lead times are short (e.g., five weeks), the parts department orders parts for all outstanding

machine builds. When sales and the backlog increase significantly, parts only orders up to twelve weeks out in the build queue.

The purchasing team creates purchase orders in inFlow, the parts cage receives components on the shop floor, and checked packing slips are hand carried to accounting to attach to purchase orders and invoices. For key components that can cause work stoppages, the parts manager marks any components received as fulfilled in inFlow. Since the data in inFlow is generally unused, there is no real imperative to mark components as received, and purchase orders for less critical components are typically left unfulfilled.

For low-dollar components ordered in bulk, ShopSabre relies on a perpetual Kanban system, featuring either two bins of components or a single bin with a central divider. One bin (or section of a bin) is the "front" and the other the "back," and the front bin bears an index card with part information. When the front bin is empty, the card is hand-carried to the purchasing department, someone reorders the part, and the purchaser carries the card back to the relevant inventory manager to hold until the ordered part arrives.

One problem with the current system is, in reality, the "front" and "back" bins are often side-by-side on the shelf (see Figure 3.2.1), and staff will occasionally take parts from the "back" bin, causing lower inventory levels than indicated by the Kanban.

Figure 3.2.1 Front and back Kanban bins

While procurement completes the majority of purchase orders through inFlow, the team occasionally purchases components from local hardware stores or on Amazon. As with most ShopSabre components, these components remain unreceived in inFlow. Other components—e.g., pre-cut steel—might be ordered through inFlow; however, a purchase order for 20 pieces of 10-gauge steel cut into 12" x 23 5/8" pieces might be shipped with a packing slip for one sheet of 4' x 10' steel, the original sheet from which 20 pieces were cut. In this case, neither the person on the production floor receiving the order nor the person in accounting reconciling the packing slip with the invoice have any idea whether or not what was ordered has been received.

3.3 Production

The production floor consists of a number of subgroups, including welding, milling, paint, electrical, assembly, and shipping. The production process is not necessarily linear, with components moving back and forth between welding and milling and, occasionally, other groups (see Figure 3.3.1 for a general flow of ShopSabre's production process). Most groups follow the build queue, although the milling team mostly mills to stock shelves for the other groups and shipping simply follows assembly and packages the next completed machine on the floor.

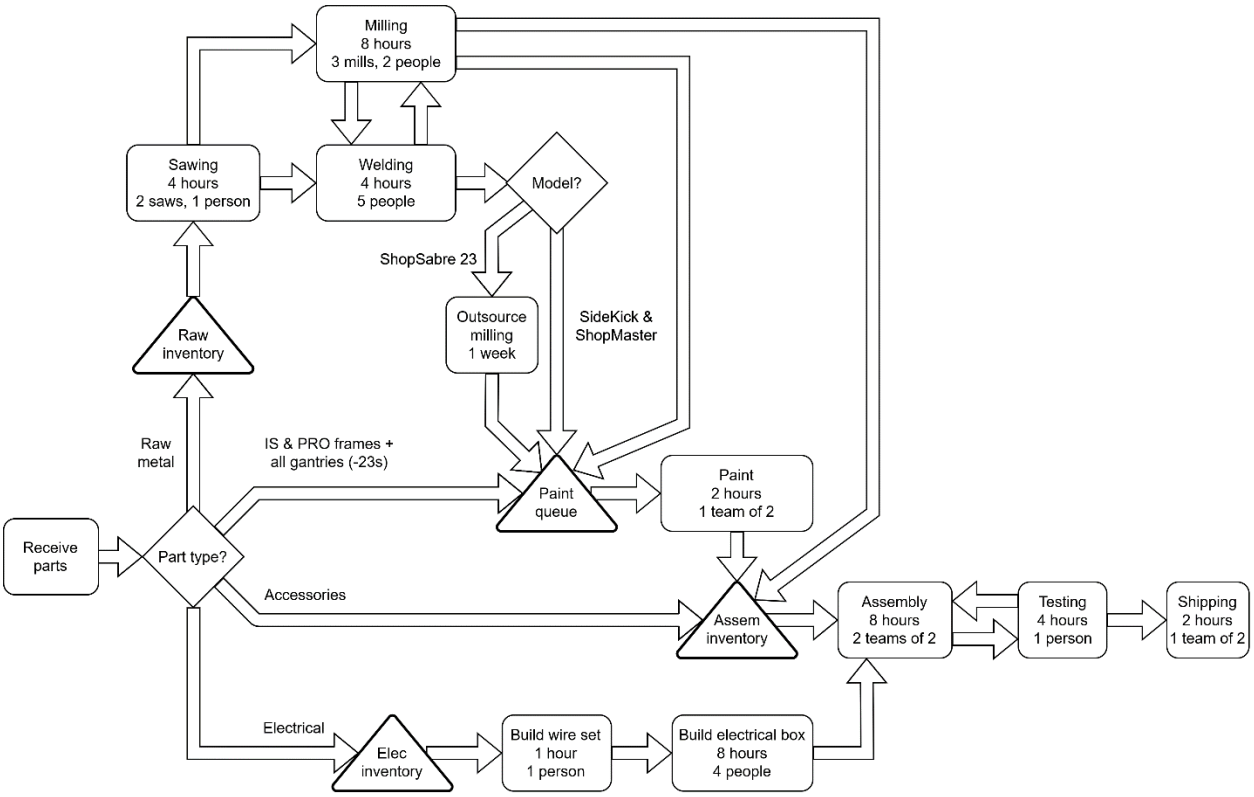

Figure 3.3.1 Production process overview

The production team pulls work orders from a binder, takes note of all relevant options and accessories, and tapes the work order to the table frame for reference during assembly. As mentioned previously, ShopSabre's current work order format is simply a sales order with prices removed. This format intersperses options and add-ons among standard components, forcing the assembly team to carefully comb through a long list of standard descriptions to find the non-standard options to add to the machine. Reading through and highlighting non-standard components is non-value-added time and presents opportunity for error: occasionally the shipping team might discover a missing accessory prior to shipping, requiring the machine to return to the assembly floor and undergo rework.

While the full production process might only take three days of touch-time, a machine might stay on the assembly floor for over one week while assemblers finish up other machines, assembled machines await testing, or tested machines wait to be removed for shipping.

3.4 Physical inventory counts

ShopSabre uses a periodic review system in the form of a monthly physical count for valuing inventory and cost of goods sold. A periodic review system is most common for small businesses with low sales volume and small inventory sizes, since changes to stock on hand is less frequent and physical inventory counts are less time-consuming. This research project helps transition ShopSabre from a periodic to a perpetual system, which better suits its recent growth in sales volume and inventory size. Physical counts have become increasingly unmanageable, and the company lacks accurate information of inventory on hand for the entire month between physical counts.

ShopSabre's inventory resides in six different areas of the shop floor: electrical, parts cage, milled parts, weld, steel/aluminum, paint, and shipping. During a physical inventory count, each area supervisor counts his inventory as follows:

1. Add a new colored sticker on the shelf below inventoried parts (see Figure 3.4.1)
2. Count parts and write quantity on colored sticker
3. Add a new colored sticker next to each part name in a designated inventory binder
4. Record quantity on shelf on corresponding sticker in inventory binder

Figure 3.4.1 Inventoried parts with sticker counts

The parts manager then zeroes out any existing stock levels in inFlow—whether leftover from the previous month's count, augmented by fulfilled purchase orders, or reduced by fulfilled sales orders—and generates a new count sheet based on the previous month's count sheet. There is often a delay between the physical count, conducted on the first day of each month, and when someone can enter the physical count into inFlow. In the interim, the parts manager essentially freezes the system: sales representatives suspend any transactions and any other team member that would interact with the system delays their activities.

Zeroing the system removes any inventory that may have been received or added but was not included on previous count sheets, often because it is ordered under a different name. Unfortunately, by basing each month's count sheet off the previous month's count sheet, errors continue to carry forward, and ShopSabre might continue to assign stock levels to long-deactivated components.

The director of accounting and finance uses the following values to calculate the total value of ShopSabre's inventory:

- inFlow inventory value, based on physical inventory count of parts
- Total value of machines ready to ship, valued at a set percentage of sale price
- Total value of machines in assembly, valued at a set percentage of sale price

3.5 inFlow inventory management software

As of June 2020, ShopSabre held five premium licenses for inFlow, an inventory management software ShopSabre uses to create purchase orders, create aftermarket sales orders, and store monthly inventory counts. These three use cases, however, are entirely independent of one another. For example, the parts team might inventory and sell a CNC accessory using the inFlow item "Material Height Touch Pad" but purchase the same accessory using the inFlow item "Tool Setter Material Height Touch Pad." The differing names across use cases creates a significant barrier to tracking inventory in real time, given that the parts entering the system may not be the same parts leaving the system. There are approximately 4,000 active parts in inFlow, many of which are duplicates or no longer used.

inFlow includes a reorder stock module, shown in Figure 3.5.1, that suggests parts for reorder based on quantities on hand, quantities required to fulfill open work orders and sales orders, quantities on order, and manually-set reorder points. As of September 2020, inFlow had 5,399 or two years' worth of unfulfilled purchase orders, effectively rendering inFlow's reorder stock function useless (i.e., inFlow thinks these outstanding items are on order and, therefore, will not suggest the parts department order more). Similarly, inFlow had two years' worth or 1,077 unfulfilled sales orders, which caused inFlow to reserve parts for orders that had already transacted.

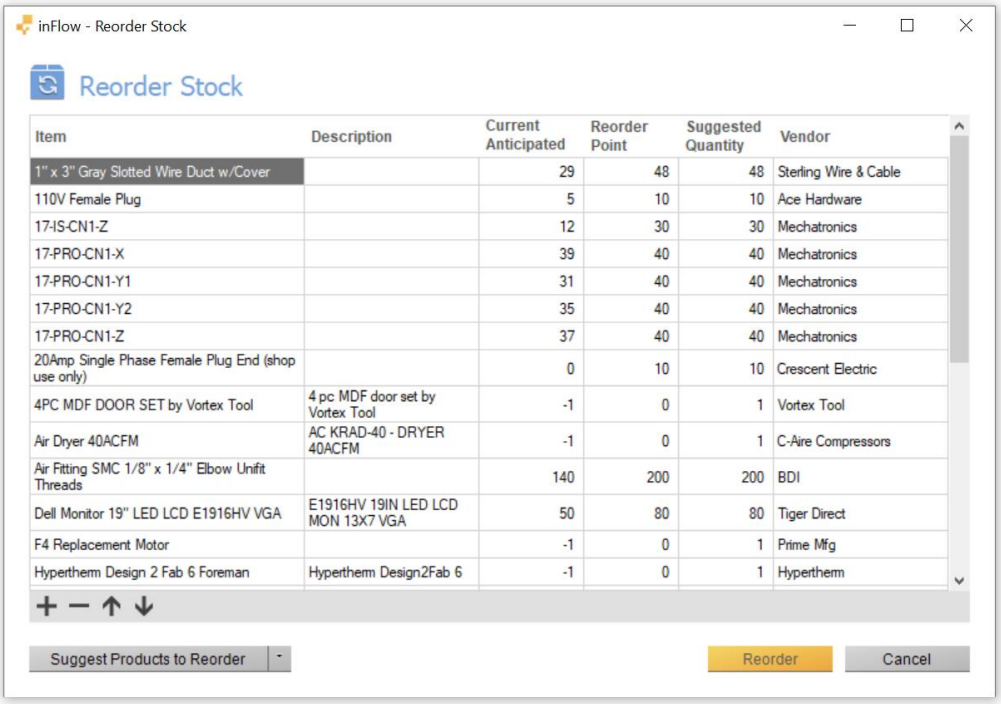

Figure 3.5.1 Suggested products to reorder in inFlow's reorder stock module

There are few common systems synced across departments. Most work occurs in Excel and passes between departments on paper to be input into systems such as QuickBooks, inFlow Inventory Management software, or a different Excel workbook. One problem with this lack of synchronization is there are numerous errors across the systems that require attention before a common system can become operational; however, a centralized system across departments could tie the cost of parts with bills of materials and sales orders to generate a data-driven estimate of cost of goods sold.

3.6 Bills of materials

Since each machine is configured-to-order, the price and cost of goods sold varies by machine. ShopSabre estimates the cost to manufacture each machine at a set percentage of the machine price. However, the company lacks formal bills of materials to accurately journal the cost of each machine at the time of shipping.

Creating bills of materials for all of ShopSabre's CNC tables and accessories enables ShopSabre to analyze cost of goods for each machine sold and forms the foundation for building out ShopSabre's cross-department inventory management system. Key steps for creating bills of materials are as follows:

- Generate a list of components needed using models in SolidWorks
- Identify part names as ordered in inFlow and eliminate duplicate entries
    - Add descriptions and costs to components in inFlow
    - Add locations in inFlow using inventory count sheets or binders
    - Add pictures to inFlow using SolidWorks models
    - Add missing items as needed
- Create bill of materials under a new/existing assembly in inFlow
- Add cost based on bill of materials
- Add description and price using sales pricing list

One of the main challenges to creating bills of materials is that, due to the configure-to-order nature of ShopSabre's sales, there are countless combinations of possible base models and options (see Figure 3.6.2). Each option has an associated set of components and wiring, and these sets will vary depending on the size of the table and other options added to the machine.

As a simple example, customers purchasing IS and Pro models can choose to add pop-up reference pins—shown in Figure 3.6.1 (Poppe, Pro V2 Assembly)—to their tabletop to help align their stock material. While each machine would receive the same five pop-up pins, each machine would also

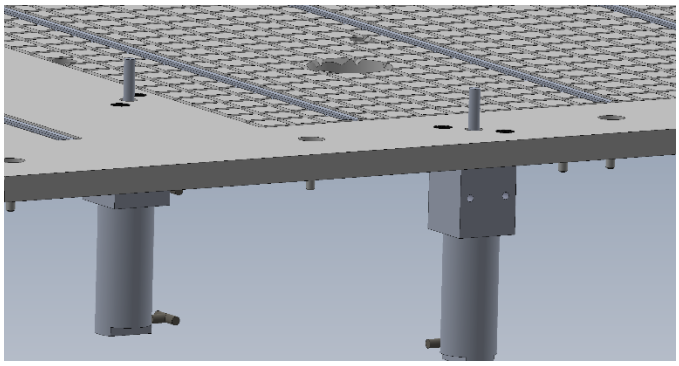

Figure 3.6.1 Tabletop with pop-up pins

require different lengths of wire and airline to reach the control stand and air manifold, respectively. Beyond that, if a customer chooses both a medium-density fiberboard (MDF) tabletop and pop-up pins, ShopSabre will add an additional piece of steel under the MDF to which the pins can attach.

Models	CNC Routers					CNC Plasmas	
	Industrial series - Mitsubishi (IS-M)	Industrial series (IS)	Production series (PRO)	Recreational Craft series (RC)	ShopSabre 23	SideKick series	ShopMaster PRO series
2' x 3'					•		
4' x 4'			•	•		•	
4' x 8'	•	•	•	•		•	•
5' x 10'	•	•	•			•	•
6' x 12'	•	•				•	•
Options							
Unist Coolant Lubrication Systems	•	•	•				
Aggregate and C-Axis Attachments for Auto Tool Changer	•	•					
Boring / Drill Head Attachments	•	•					
Dust Collector Options	•	•	•	•	•		
Dust Dock and Containment Skirt	•	•	•				
Tangential Oscillating Knife System		•	•				
Vision Systems for Registration Mark Reading		•	•				
Table Reference Pins (Pop-Up Pins)	•	•	•				
Material Thickness Calibration Touch Pad	•	•	•	•	•		
ShopSabre F1 & F4 Single Phase Vacuum Pump		•	•	•	•		
Becker Vacuum Pump	•	•	•	•			
FPZ Vacuum Pump	•	•	•	•			
Vacuum Table with Multiple Zones and Table Pipes	•	•	•	•	•		
Hybrid T-Slot/Flat Table Top	•	•	•	•	•		
Hybrid T-Slot/Vacuum Table Top	•	•	•	•	•		
Auto Tool Changer Options – 5 and 10 Position	•	•	•	•			
Manual Change HSD Spindles in 4HP or 9.3HP	•	•	•	•	•		
2D/3D Parts Digitizing Touch Probe		•	•		•	•	•
Vibratory Plate Marking Scribe		•	•			•	•
Wireless Pendant Control with Jog Wheel	•	•	•	•	•	•	•
Warning Light Bar	•	•	•	•	•	•	•
Laser Sight for Quick Zero Reference	•	•	•	•	•	•	•
On-Table 4th Axis /Rotary Indexing Heads	•	•	•	•	•	•	•
SideCar 4th Axis						•	•
Down-Draft Single or Zoned Tables						•	•
Water Tables						•	•
Plasma Cutter Options						•	•
Torch Collision Detection						•	•
CNC Router Upgrade for Plastic and Wood Cutting						•	
Router Table Top for Plasma Tables						•	
CNC Plasma Drill Feature						•	•
Oxy-Fuel Torch System						•	•
Marker Pen Attachment						•	•
Automated Air and Amp Control Feature						•	•

Figure 3.6.2 Matrix of CNC models and their corresponding accessory options

The engineering department maintains SolidWorks models of each barebones ShopSabre product; however, the assembly team makes frequent (e.g., monthly) minor improvements to the design (e.g., bolt sizes), which are not necessarily communicated back to the engineering team; therefore, existing drawings do not always represent what is built on the manufacturing floor. Furthermore, the parts names used in SolidWorks do not necessarily align with the parts names used in inFlow or on the shop floor. For example, the plate shown in Figure 3.6.3 (Poppe, 4HP with Backplate) might be a “back plate” in SolidWorks, a “tool plate” in inFlow, and a “spindle plate” on the shop floor.

Finally, in addition to creating bills of materials for seven CNC base models and relevant accessory options, fully building out ShopSabre’s production process in inFlow requires bills of materials for 180 milled parts and 7 welded tables. As an example, the production team cuts and mills both the spindle plate and stiffeners in Figure 3.6.3 in-house.

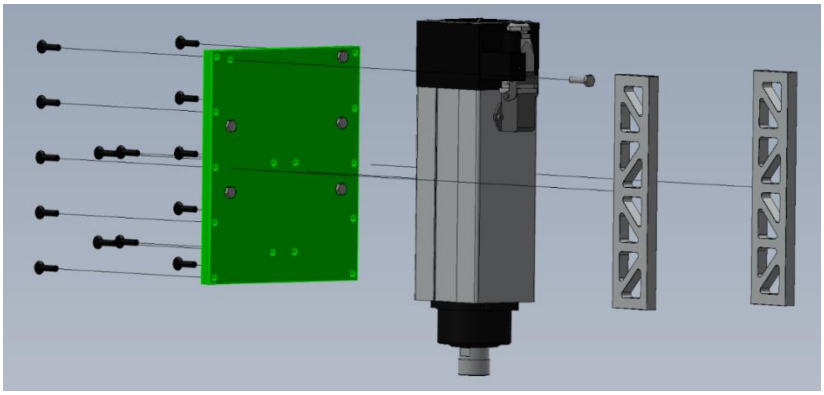

Figure 3.6.3 Four horsepower spindle assembly with back plate and side stiffeners

The completed bills of materials are the final major building block needed to develop a cohesive system. Tying all of the existing pieces together requires adding missing items in inFlow, changing part names for accuracy and consistency, fixing discrepancies between how inFlow identifies parts on count sheets vs. purchase orders, and adding images to inFlow to avoid confusion between similarly named parts.

3.7 Stakeholder analysis

Integrating ShopSabre's existing processes into inFlow (and vice versa) first entails a thorough analysis of major stakeholders and appropriate measures to ensure buy-in. Long-term success is only possible by continuing to keep stakeholders informed and aware of how the new inventory management system benefits them. Ultimately, all stakeholders want their jobs to be easier and for the company to be successful. While each stakeholder's ideas for how this happens varies, focusing on those two overarching goals contributes to greater buy-in. The following analysis provides an overview of ShopSabre's organizational culture and its effect on rolling out a new and improved inFlow system.

ShopSabre operates on a culture of minimal documentation and tribal knowledge. In a sense, synchronizing information across departments is the first step in ShopSabre's shift from informal business to small enterprise. For employees who have been with the organization for years, the growth is welcome but changes to longstanding processes are not.

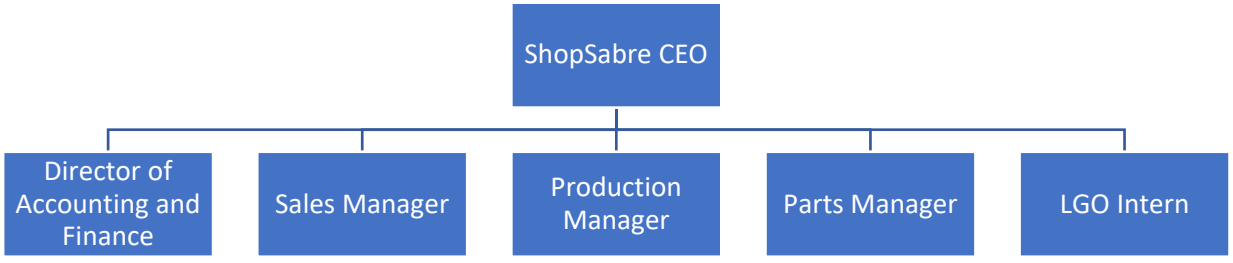

Figure 3.7.1 Reporting structure to ShopSabre CEO

As depicted in Figure 3.7.1, the organizational structure of ShopSabre is flat, with each department head reporting directly to the CEO. Key stakeholders, in order of relative power within the organization, are as follows:

CEO/Founder: ShopSabre's CEO launched the company in 2001, and he is deeply knowledgeable about both the machines and the business. It is clear that the CEO is backing the project, and therefore, his management team understands that change is imminent. He facilitates conversations with less powerful parties such as the assembly teams, the parts cage, and accounts payable and gathers input from employees as to how the new system can work best for them. To the first-time computer user, the CEO asks what type of setup would be easiest, and to accounts payable, the CEO asks how inFlow affects her document verification process.

Director of Accounting and Finance: The director of accounting and finance holds a stake in the inventory management system's success because more accurate inventory management will lead to more accurate accounting—e.g., calculating cost of goods sold. For her, a perpetual inventory system provides a long-awaited single source of accurate, real-time data. She and her team play an important role in motivating stakeholders to maintain the system post-implementation.

Production Manager: For the new system to function properly, the production team must update inFlow with the products they are building and have completed. Research began spending full days shadowing assemblers on the production floor, allowing space for unknown unknowns to surface and the formation of invaluable relationships with the assembly team. The majority of the assembly team understands the need to document the work they are doing, and the production manager allows them to take as much time as needed to assist creating bills of materials. The production manager also sees the benefit of an improved template for work orders that will reduce the time each assembly team spends searching work orders for relevant parts.

Sales Manager: For the new system to function fully, the sales team must use inFlow to create sales invoices. The sales manager, however, is the most change-averse of the key stakeholders, and he is less willing to dialogue about the implementation of the new system. That said, there are elements of the custom sales order template that appeal to him—e.g., printing without line item prices and consolidating all standard line items into a single line item.

Parts Manager: The parts manager manages the inventory system directly and, therefore, is essential to ensuring its success and sustainability. In addition to completing purchase orders in inFlow, the parts team must receive items through inFlow and continue to update bills of materials. The parts department is slow to warm up to the project, likely because it infringes most upon how they operate. Over time, however, the team sees improvements in the system and is increasingly willing to answer questions and exchange ideas.

Other stakeholders, listed in Table 3.7.1, must interact with the inventory system for it to function properly, whether it be placing purchase orders (purchasing), receiving parts (parts cage), or updating bills of materials in order for the system to function (engineering/parts manager). While these stakeholders are typically happy to oblige with the decisions of upper management, their full buy-in will guarantee sustainability of the initiative.

Key Stakeholders	Block It	No Commitment	Let It Happen	Help It Happen	Make It Happen
1. CEO/Founder					X0
2. Accounting director					X0
3. Production manager				X0	
4. Parts manager			X →		→ 0
5. Sales manager		X →		→ 0	
6. Engineering manager		X0			
7. Electrical manager				X →	→ 0
8. Purchasing				X →	→ 0
9. Assembly				X0	
10. Parts cage		X →		→ 0	

Adapted from *Organizational Transitions: Managing Complex Change*, R. Beckhard & R. Harris

Table 3.7.1 Key stakeholders with initial and desired levels of commitment

While no stakeholders are explicitly opposed to the project, the parts manager, sales manager, and parts cage supervisor will need special attention to ensure project success. A summary of action steps for managing their commitment levels is included in Table 3.7.2.

Key Players	Relationship & needs	Perceived challenges	Actions to overcome
1. CEO/Founder	Project supervisor; good professional relationship	Pulled in many directions	Take advantage of opportunities to discuss project
2. Director of accounting and finance	Good professional relationship; wants data and organization	More concerned with financial implications than part availability	Avoid getting bogged down with financials
3. Production manager	Very helpful; ultimately wants parts available when needed	Will need to use inventory software on shop floor	Listen to needs of production team to build good will
4. Parts manager	Helps as needed; needs systems to accompany growth	Will need to own changes to inventory management	Update regularly on changes to current system
5. Sales manager	Limited interactions; resistant to change	Wants limited changes to sales process	Listen to needs of sales team to build good will

6. Engineering manager	Limited interactions; very helpful	Pulled in many directions	Email requests to be addressed at his convenience
7. Electrical manager	Helpful; understands inventory software	Limited time to help with bills of materials	Find creative ways to ask for help with bills of materials
8. Purchasing	Very helpful; needs systems to accompany growth	Will need to own changes to inventory management	Update regularly on changes to current process
9. Assembly	Willing to teach; happy to work smarter, not harder	Will need to use inventory software on shop floor	Listen to needs of production team to build good will
10. Parts cage	Limited interactions	Limited willingness to use computer	Keep processes simple

Table 3.7.2 Action steps for managing commitment levels

4 Implementing a centralized system for managing inventory

As evidenced by the previous pages, the bulk of this research lies in understanding ShopSabre's existing systems and building relationships within the organization. This analysis ultimately informs the implementation of the new inventory software and its associated business processes.

The following pages outline ShopSabre's new process for fulfilling customer orders and managing inventory in inFlow. A diagram of the process, Figure 4.3.1, can be found after the narrative description. Note: the sales department is not using inFlow yet, so accounting currently implements the sales department's inFlow responsibilities.

4.1 Machine sales

The responsibilities of the sales department are as follows:

- The sales team builds sales quotes, sales orders, and work orders for machines in Excel and distributes printed copies throughout the office.
- Upon receiving a sales order from the sales department, the accountant enters the sales order into inFlow. This entails
    - Adding customer info, order #, etc.
    - Adding base model and options using search function
        - Expanding window(s) for improved readability
        - Selecting options with standard sales description
        - Adding standard options—e.g., MDF, Porter Cable, and breakaway Z as needed
    - Facilitating final calculations
        - Adding discount in discount column
        - Adding crating & materials as line item
    - Adding any special remarks
- The sales team updates any existing sales orders in Excel and redistributes the updates throughout the office.
- The accountant updates relevant orders in inFlow.

The sales department felt that recreating ShopSabre's sales quote with the same level of customizability was too tedious in inFlow, particularly for the second and third pages that the sales department uses to advertise possible upgrades and modifications. Instead, sales decided it would work best to maintain the current quoting format, and after finalizing a sale, enter the sales order in inFlow. Though sales is not currently using the inFlow software, the system is set up to produce printed sales orders comparable to ShopSabre's current Excel template.

Entering sales orders into inFlow is straightforward. inFlow includes prices for specific CNC base models and options, and therefore, if all the correct sales items are added to the sales order, the order total should match the printed sales order, providing a convenient sanity check.

The printed sales order includes many line items that come standard with each base model (see Figure 3.1.2). In general, the accountant does not enter these into inFlow since inFlow already includes them in the base model's item description and bill of materials. However, inFlow does require some standard components—i.e., MDF tabletop, Porter Cable router, and breakaway Z—to be entered separately from the CNC base model in inFlow. These specific components do not actually end up on the majority of

machines; customers more commonly replace them with phenolic tabletops, HSD spindles, or collision options, respectively.

Another key difference between the Excel sales order and inFlow sales order is that the crating and materials is listed as a line item in the inFlow sales order rather than alongside the tax and freight as it is in the Excel sales order. This is due, in part, to the fact that the price of crating and materials for each machine is actually related to the cost of the raw materials used to package the machine—namely wood, plastic wrap, and strapping. These crating and materials line items are necessary sections of each machine's work order that decrements the relevant wood, et al., from inventory.

One potential pitfall lies in the sheer number of items in inFlow with similar names. The Material Height Touch Pad, for example, exists as its own entry in inFlow as a standard component of ShopSabre's material height option. A machine sales order, however, needs to use a line item such as Pro408 Material Height Touch Pad that includes the necessary lengths of wire in the bill of materials for that specific machine size. One can avoid choosing the raw material (Material Height Touch Pad) rather than the finished good (Pro408 Material Height Touch Pad) by ensuring the inFlow item includes the lengthy sales description associated with finished goods. Raw materials generally do not include a sales description in the description field. Figure 4.1.1 shows a sample sales order with various line items and accompanying sales descriptions.

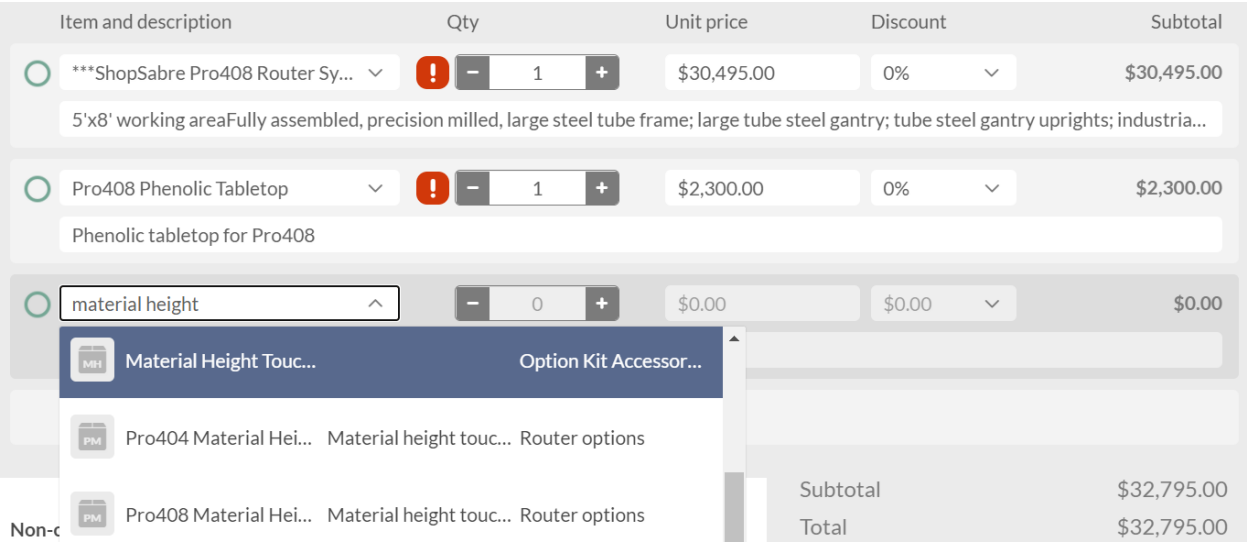

Figure 4.1.1 Creating a sample sales order

In order to recreate the level of detail in ShopSabre's Excel-based sales orders, the inFlow sales order must utilize inFlow's item description field, though inFlow's default setting is to hide this field. The description field allows the sales team to include its usual descriptive length of text for each line item (e.g., "Fully Assembled Precision Milled Large Steel Tube Frame, Large Tube Steel Gantry, Tube Steel Gantry Uprights, Industrial Designed") while allowing the item name to remain short and searchable (e.g., "Pro408 Frame and Gantry). Including the item description—but not the item name—on the sales order as it appears in ShopSabre's current format requires creating custom templates which can be uploaded to and then populated by inFlow. inFlow populates document templates made in Microsoft Word by using the "Write & Insert Fields" functions in the Mailings tab, shown in Figure 4.1.2.

ShopSABRE

ShopSabre CNC
21763 Cedar Ave.
Lakeville, Minnesota 55044, USA
1-800-493-6021 Ext. 116

Sales Order

Order # «OrderNumber»
Date «OrderDate»

Customer
«CustomerName»
«ContactName»
«Phone»

Shipping Address
«FormattedShippingAddress1»
«FormattedShippingAddress2»
«FormattedShippingAddress3»
«FormattedShippingAddress4»

Salesperson	PO#	Payment Terms	Financing Available
«SalesRep»	«PONumber»	«PaymentTermsName»	shopsabre.com/financing

Quantity	Description	Line Total
«ItemQuantity»	**«ItemName»** • «ItemDescription»	**«OrderSubTotal»**
«ItemQuantity»	«ItemDescription»	

Figure 4.1.2 Auto-populating sales order template

With sales orders now entered into inFlow, accounting has access to a digital, line-by-line sales order rendering the line item prices on the Excel-based sales order obsolete. The inFlow custom sales order template only includes the lump sum pricing and highlights the balance due, relieving the customer liaison of having to transform each sales order manually before sending to customers.

Creating a new sales order template also provides an opportunity to create a new work order template that auto-populates through inFlow and segregates the standard and optional machine components. By creating a single entry in inFlow that lists out the standard components for each base model, only non-standard components appear as separate line items on the work order (see Figure 4.1.3), saving the assembly team time searching for options and reducing any likelihood of overlooking add-ons.

Quantity	Description
1	***ShopSabre IS408 Router System** • 55"x100" cut area • Please select power for control center: 3 phase operation • Fully assembled, precision milled, oversized steel tube frame; oversized tube steel gantry; tube steel gantry uprights; industrial designed • Limit switches on X, Y, Z axes with auto-squaring and boundary alarms • Emergency stop switch • X, dual drive Y, and Z axis driven with industrial precision anti-backlash ball screw drives • Digital A/C brushless servo motors with amplifiers on X, dual Y, and Z axes - closed loop with Z axis brake - twin 1kW servos on Y axis • Industrial 25mm precision linear guide rails & bearings on all axes, Y axis hidden design, all mating surfaces machined for precision • Tool measure switch - measures tooling height without changing Z height for fast tool change & increased accuracy • Quick release dust skirt, 4" outlet for connecting to dust collector • ShopSabre rolling enclosed steel fan-cooled machine operator control stand • ShopSabre computer system - full size desktop system with solid state hard drive, 8GB memory, 19" flat screen monitor, keyboard, mouse • ShopSabre WinCNC industrial controller hardware & software • Vectric VCarve Pro CAD/CAM software
1	ShopSabre wireless handheld controller pendant with jog wheel
1	USB wireless for computer internet/network connectivity
1	Phenolic tabletop for IS 408
1	T-slots installed every 8" on center in standard tabletop with clamp kit
1	10HP Becker VTLF 2.250 non-SK vacuum system with 4 zone manifold, requires 3 phase 208/230/460V 27.3/25.8/12.9, motor starter optional, 168 SCFM @ 24" HG *Add $2,000 for single phase
1	Industrial pop-up table reference pins (3 on left side, 2 along front)
1	Material height touch pad - electronic Z setter
1	8kW 10HP HSD auto tool change package - 24,000 RPM, 10 position (10 ER32 collets, cones, tool forks), mounted tool rack, collet wrench, chuck holder, auto spindle on/off & RPM; super Z w/ air balancer
1	Upgrade to dust dock skirt with containment design
1	2.5" spoil board cutter
1	Advanced bit kit for wood - (2) 1/4" x 7/8" DE DC finisher, 1/2" x 1 1/4" DE DC finisher, 1/4" x 7/8" DE UC finisher, (2) 3/8" x 7/8" DE mort XP viper, (2) 3/8" x 7/8" DE mort XP viper P, 1/4" x 7/8" DE mortise viper, 5mm x 70mm RH CT brad point, 8mm x 70mm RH CT brad point

Figure 4.1.3 Custom work order template

4.2 Production

The responsibilities of the production floor are as follows:

- The production team continues to build machines using the printed work orders from sales.
- As machines reach the assembly floor, the production manager uses inFlow to open machine work orders and pick all the relevant parts from inventory.
- As machines leave assembly, the production manager completes work orders in inFlow.
- Similarly, managers in mill, weld, and electrical use new inFlow terminals on the production floor to open and close work orders for milled parts, welded frames, and control boxes.
- Any part failures should be reported to the production manager who, in turn, reports the part failures to the front office.
- As parts failures are reported to the front office,
    - For components that can be unstocked without replacement, the parts manager creates a daily stock adjustment, shown in Figure 4.2.1, that removes any damaged components from inventory that would not leave the building attached to a machine.
    - For components that require replacement from the vendor, the production manager reports the parts failure to the parts manager. The parts team will create a purchase order in inFlow that documents both the returned item and the replacement item requested, using the original purchase order number followed by “R” for return

Figure 4.2.1 Daily stock adjustment for damaged components

Within inFlow, ShopSabre has three categories of inventory:

- Finished goods: Completed assemblies constituting individual line items on a machine sales order. Examples include CNC base models, tabletop options, spindle options, and crating. These are the assemblies that are “put away” when a work order is completed. These items remain in inventory as finished goods until the sales order for which they were created is fulfilled (i.e., the machine ships) and are generally located on the shipping dock rather than the production floor.
- Raw materials: Components assembled to create finished goods assemblies. Examples include raw steel, sheets of phenolic, HSD spindles, and plywood. These components are “picked” and decremented from inventory when a work order is completed.
- Consumables: Shop supplies and tooling that ShopSabre typically does not sell to customers and does not leave the building as part of a machine. These items do not leave inventory as parts of work orders and sales orders and, therefore, continue to require physical counts and adjustment in inFlow.

Alongside entering sales orders in inFlow, opening and closing work orders is one of the key steps for the perpetual inventory system to function properly. When the production manager opens a work order for a specific machine sale, inFlow takes bills of materials for each line item in the sales order and includes each component in the work order. Picking the components in the work order then takes all the components off inFlow’s virtual “shelf,” and inFlow considers the picked components work in progress until the work order is closed. Closing the work order then transforms all the picked components into completed assembles and places them back on inFlow’s virtual “shelf” as finished goods, which are available to fulfill the machine sales order.

The main challenge to completing work orders in inFlow, particularly during early stages of implementation, is that quantities in the system do not always match quantities on the floor. In these instances, inFlow might insist there is an insufficient quantity of parts to complete a work order even though the work order is already physically assembled. The production manager must then figure out where the discrepancy exists and correct it before inFlow will permit the work order to close.

An insufficient quantity of parts displays as one of the following flags on an inFlow work order:

- A blue clock  indicates a part is out of stock but on order
- A red alert  indicates a part is out of stock and not on order

These flags might indicate one of the following:

- A part is out of stock and needs reordering
- Parts physically arrived from the vendor, but the parts cage has not yet received the purchase order in inFlow, creating a discrepancy between physical and virtual inventory quantities
- inFlow is picking parts for work orders faster than the production floor is truly picking parts on the floor, meaning bills of materials require adjustment

Similar to how the production manager opens and completes work orders for each CNC machine, the electrical manager opens and completes work orders in inFlow for each machine’s electrical control box. Opening work orders for control boxes picks all the relevant components and completing work orders puts the assembled control box on the shelf. The completed control box is then available for the

machine work order to pick. This generally works because the electrical team is roughly one week ahead of the assembly teams. Occasionally, however, assembly may begin building a machine (i.e., open a machine work order) before the electrical control box is completed (i.e., before the control box work order is closed). In this scenario, inFlow might show that no control boxes are available for the machine work order to pick, so the machine work order picks all the components for a control box, assuming that a new box still needs assembly. This picks control box components twice in the system.

4.3 Parts sales and purchasing

The responsibilities of the parts department are as follows:

- The parts team continues to enter sales quotes and sales orders for parts in inFlow.
- For any parts sale with a bill of material associated, the sales representative opens and closes a work order in inFlow to remove the relevant components from inventory and create an assembly to fulfill the parts sale.
- The parts team continues to purchase high-value components based on machine sales orders.
- The parts team uses inFlow's reorder stock module to purchase remaining components in bulk.
- As ordered components arrive in-house, the parts cage marks purchase orders as fulfilled in inFlow, scans pack slips, and attaches pack slips to the purchase order.

The greatest source of error for parts sales is the added step of opening and closing a work order. This often manifests itself in inFlow's Current Stock module, which shows negative inventory of a finished good (e.g., Plasma Defense 5 gallon) because no work order is transforming the raw goods in inFlow into a finished good before the finished good leaves inventory.

4.4 Accounting

The responsibilities of the accounting department are as follows:

- As machines ship, the accountant marks sales orders as fulfilled in inFlow. This removes the completed assemblies or finished goods from inventory.
- The accountant is then able to run a sales order profit report in inFlow to generate the cost of goods sold and profit margin for each machine sale.
- Accounts payable compares vendor invoices to records of fulfilled purchased orders in inFlow.
- Upon paying the invoice, accounts payable marks the purchase order as paid.
- Parts that ShopSabre does not physically receive—e.g., drop ships—are marked as received by accounts payable after checking the tracking number to confirm delivery and before paying the vendor invoice.

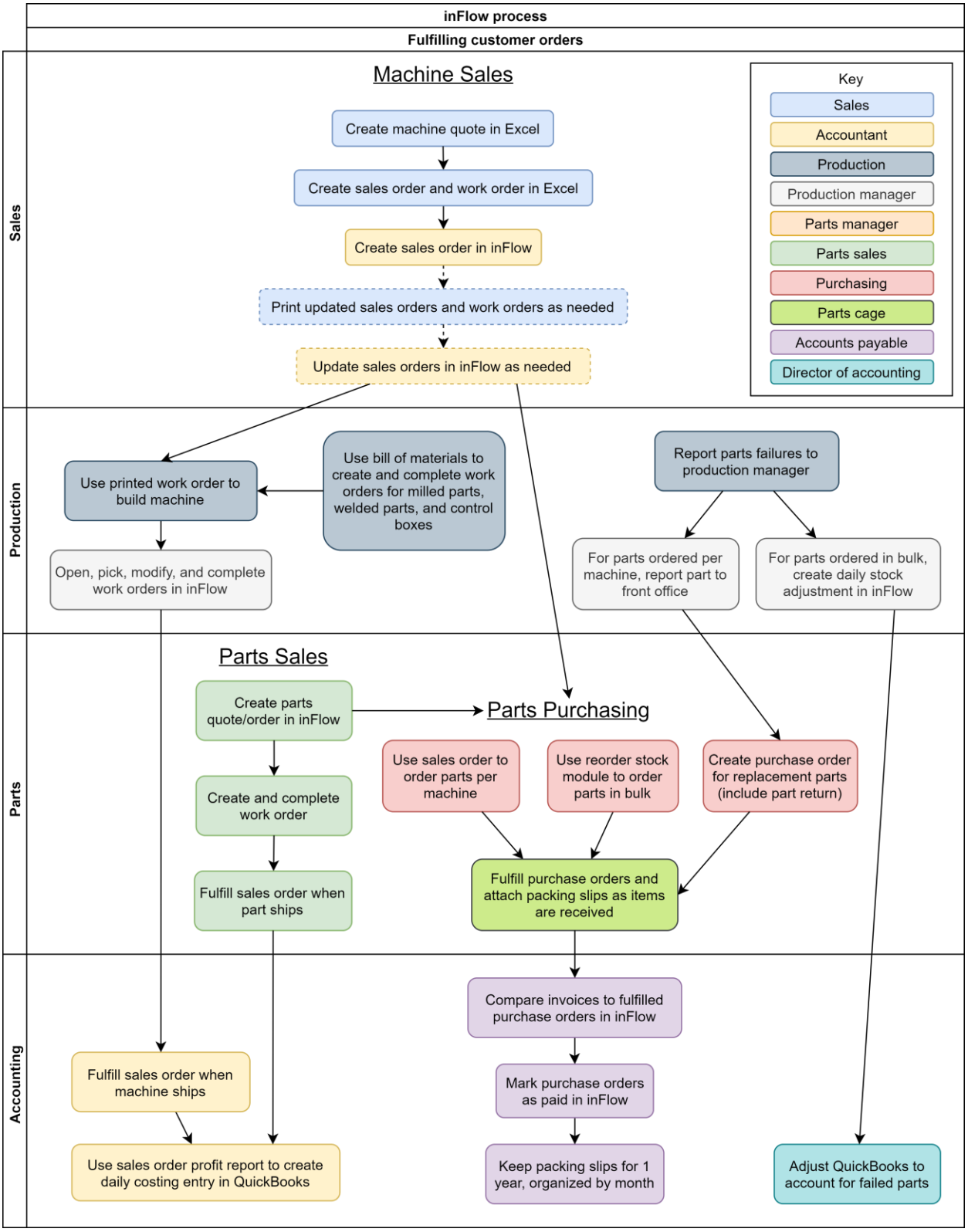

Figure 4.4.1 inFlow process overview

4.5 Toward a perpetual inventory

The physical inventory count at the end of August 2020 is the final count in which the parts manager zeroes out all quantities and enters a fresh count into inFlow. The next two months are spent analyzing lessons learned and fixing errors in hopes of completing one final full physical inventory count at the end of October 2020. Key lessons learned are below.

Picked quantities in inFlow

Zeroing counts in inFlow zeroes out quantities on hand (or on the "shelf") but not picked components on open work orders. These picked items, which represent work in progress at the time of the physical count, remain as picked in inFlow and contribute toward ShopSabre's quantity owned. Due to ShopSabre's traditional practice of valuing work in progress (or machines in assembly) separately as a percentage of machine price, these picked components are effectively valued twice in August: first in the inventory valuation report from inFlow and second in the estimated value of work in progress, calculated as a percentage of the value of machines on the floor. Figure 4.5.1 shows an example of how inFlow differentiates between quantities on hand and quantities picked.

ITEM	QTY ON HAND	QTY OWNED	QTY PICKED
Boring Head, 5+4 Vertical Spin	0	0	0
Borui ER25 Spanner Wrench	97	101	4
Braided Sleeving 1 1/4 -- Unit of measure: feet	1,846	2,021	175
Braided Sleeving 2 1/2 -- Unit of measure: feet	657	733	76

Figure 4.5.1 inFlow inventory summary with quantity on hand vs. quantity picked

Finished goods

Every machine sales order consists of a series of finished goods, namely a CNC base model followed by additional line items for each additional machine option. Most machine options are assembled on the production floor using a variety of components; however, some options, such as the PowerMax 65, 85, 105, and 125 come preassembled from the vendor and do not require other components to make up the entirety of the machine option on the sales order. For example, a PowerMax 65, as shown in Figure 4.5.2 (Hypertherm Powermax 65 Hand System - 25 ft Lead - Power Plasma Cutters, 2020), might physically leave the parts cage to join a machine assembly; however, inFlow does not pick the

Figure 4.5.2 Hypertherm PowerMax 65

PowerMax for the machine work order because the software considers the unit a finished good, ready to ship. This can create the appearance of discrepancies during a physical count because any PowerMax units bundled with machines on the dock still appear on inFlow's virtual shelf.

Inventory timing

The parts manager historically distributes count sheets on the first or last day of the month, and supervisors count inventory in their respective areas at various times of the day while production continues. In order to achieve a more accurate count, production now picks all parts necessary for work in progress both in inFlow and on the floor prior to the physical count and is no longer able to access parts during the count. This way, picked items in the system match picked items on the floor (with the exception of a few large items marked "Do Not Inventory").

inFlow's count sheets list quantities on hand at the time of the physical count, allow the user to enter physical count numbers, and adjusts stock based on the calculated discrepancy between the system count and the physical count; the system does not adjust to the specific counted quantity. This means that if an inFlow user makes any changes retroactively to work orders, purchase orders, sales orders, etc., the changes affect the quantities adjusted to match the physical count.

Furthermore, inFlow adjusts stock as of the date and, importantly, *time* that the count sheet is completed and adjusted. inFlow automatically time stamps all entries; however, if a user makes an entry or adjustment retroactively and manually changes the date of the entry, inFlow time stamps the entry as 12:00 AM the morning of the date entered. Therefore, if the parts manager enters the count sheet a few days into the month but dates the count sheet retroactively to the last day of the previous month, inFlow adjusts stock as of midnight, the morning of the last day of the month.

Counting kits

ShopSabre historically counts the following raw materials as kits or packages in the physical count, but procurement orders and receives the items as individual components:

- Hiwin packages: ball screws, rails, and bearing blocks
- Igus kits: x, y, and z axis wire carriers
- JTECH laser engraver packages: laser, lens, stickers
- EcoCam tangential knife packages: blade, hub, connectors
- Hypertherm XPR plasma units

When inFlow's count sheet adjusts these kit quantities, the kits effectively double count the individual components received into the system. To address this discrepancy, ShopSabre now includes individual components rather than kits on count sheets. The kits still exist in inFlow as a convenient way to bundle components in work orders.

Scrap material

ShopSabre orders MDF in pallets of 32; however, the top and bottom sheets of MDF suffer significant damage during shipping and, therefore, are regularly thrown away. The production manager needs to remove these two sheets through a daily stock adjustment in order to keep the quantities on hand accurate.

Average costing

ShopSabre's inFlow cost settings are currently set to calculate a moving average. Switching to first in, first out (FIFO) results in a significant number of component costs moving to zero, and therefore, ShopSabre continues to maintain a moving average calculation.

Each product in inFlow contains a link to its moving average cost history, which shows each transaction of the product and its effect on the moving average. inFlow calculates the cost of the product as the price paid to the vendor plus a weighted average of any freight or services included on the same purchase order. Accounts payable now adds freight costs to purchase orders in inFlow, a new development prompted by the implementation of the system, resulting in a higher but more accurate average cost to ShopSabre.

One problem in analyzing the average cost history is an occasional "blanket purchase order," which the purchasing team uses to communicate ShopSabre's forecasted demand to the vendor. However, when ShopSabre has actual demand for the items, procurement submits a new purchase order for the vendor to fulfill. Vendors do not actually fulfill blanket purchase orders. As a result, the parts team leaves these purchase orders outstanding indefinitely or inaccurately marks them as fulfilled. These blanket purchase orders might also list a $0 unit price, so marking blanket purchase orders in inFlow as fulfilled not only inaccurately increases ShopSabre's inventory on hand but also decreases the average cost of the product, as shown in Figure 4.5.3. However, leaving purchase orders outstanding causes inFlow to believe that an item is on order and, therefore, will not prompt the parts department to order more.

Moving Average Cost History

Transaction Type: All

Date	Transaction Type	Quantity	Quantity After	Total Cost Change	Total Cost	Unit Cost
9/10/2020 4:01 PM	Purchase Order Receive	1	7	$5,428.31	$38,114.66662	$5,444.95237
9/10/2020 4:05 PM	Purchase Order Receive	1	8	$5,428.31	$43,542.97662	$5,442.87208
9/10/2020 4:05 PM	Purchase Order Receive	7	15	$0.00	$43,542.97662	$2,902.86511
9/10/2020 4:31 PM	Purchase Order Receive	1	16	$5,428.31	$48,971.28662	$3,060.70541
9/10/2020 4:32 PM	Purchase Order Receive	1	17	$5,428.31	$54,399.59662	$3,199.97627
9/10/2020 4:46 PM	Purchase Order Receive	1	18	$5,428.31	$59,827.90662	$3,323.77259
9/10/2020 4:47 PM	Purchase Order Receive	1	19	$5,428.31	$65,256.21662	$3,434.53772
9/11/2020 8:32 AM	Purchase Order Receive	1	20	$5,428.31	$70,684.52662	$3,534.22633
9/11/2020 8:33 AM	Purchase Order Receive	1	21	$5,428.31	$76,112.83662	$3,624.42079
9/11/2020 8:35 AM	Purchase Order Receive	10	31	$0.00	$76,112.83662	$2,455.25279
9/11/2020 8:40 AM	Purchase Order	1	32	$5,428.31	$81,541.14662	$2,548.16083

Figure 4.5.3 Effect of blanket purchase orders on average cost history

Any completed work order adjusts the average cost of its finished goods based on the current cost of the components used. However, inFlow does not adjust the cost of intermediate subassemblies, which

ShopSabre uses to maintain a hierarchy of components on machine work orders. This results in discrepancies between the cost of goods sold appearing on the sales order profit report, which incorporates average costs of finished goods, and the cost of goods sold appearing on a base model's bill of materials, which sums the cost of subassemblies to generate a total cost.

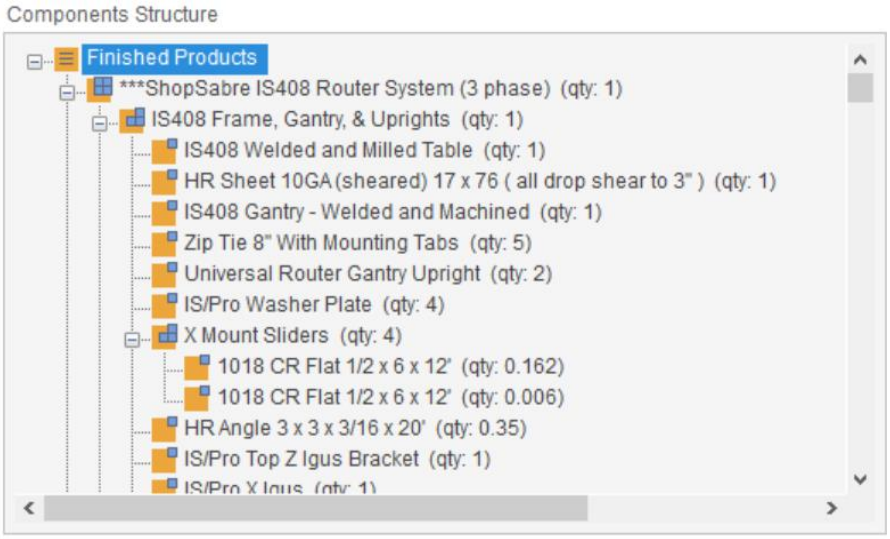

Figure 4.5.4 Examples of intermediate subassemblies in a machine work order.

As an example, a bill of materials for a CNC base model (the ShopSabre IS408 Router System in Figure 4.5.4) might include several intermediate subassemblies that naturally group components together, such as the industrial steel (IS408 Frame, Gantry, & Uprights). Because the production floor does not assemble these components except during a machine build, the listed cost of the IS408 Frame, Gantry, & Uprights may never have changed since the initial creation of the bill of materials. Given the number of changes to bills of materials and updates to pricing over the course of building out inFlow, the original costs are rarely still valid. The full machine work order will still cost accurately in the sales order profit report, however.

Milled work-in-progress

Milled parts exist as a sort of cross between raw materials and finished goods in inFlow. The mill supervisor opens and closes work orders to transform bars of raw metal into finished components such as the spindle plate and stiffeners in Figure 3.6.3. These milled parts are then available to assembly teams as completed subassemblies used in the machine build.

Figure 4.5.5 Shelf of milled work-in-progress

Components milled in-house often change hands multiple times between saw, mill, and weld. In their intermediate stages, these components sit on and around a large blue shelf between mill and weld (see Figure 4.5.5). Since these pieces are neither raw material nor completed milled parts, the mill supervisor typically does not count the shelf of work-in-progress during physical inventory counts. In inFlow, however, not counting the material on this shelf creates a deficit of raw material available for future milled parts.

As a stopgap, the director of accounting and finance values the shelf at roughly $15,000 of raw material. If inFlow claims there is insufficient stock of any raw material, the mill is unable to close work orders that require that specific material. In this case, the mill team notifies the director of accounting and finance, who increases the quantity on hand using an inFlow stock adjustment and decreases the value of the blue shelf in QuickBooks accordingly.

Unit of measure

ShopSabre staff cannot reasonably count some components in the same unit of measure as the components' purchased or received unit of measure listed in inFlow. As an example, ShopSabre purchases 4' x 8' sheets of 16-gauge steel pre-cut into different size pieces (e.g., 3 ¼" x 5 ¼"). Procurement orders these cut pieces as single sheets; however, during the physical count, there are no sheets to count, and thus, staff can only the number of 3 ¼" x 5 ¼" pieces on hand. To accommodate this, inFlow has the ability to set the purchased unit of measure to a larger unit (e.g., sheets, cases, rolls) and the standard unit of measure to a smaller unit (e.g., pieces, gallons, feet) that make up the larger unit. When the parts cage marks a 4' x 8' sheet as received, for example, inFlow will calculate the number of pieces per sheet (as specified by the user in the product information) and increase the quantity on hand by the appropriate number of pieces rather than the number of sheets.

4.6 Maintaining the system

With the implementation of the inFlow in place, the research identifies three key tasks helpful in maintaining the system and anticipating problems. These tasks provide early warnings of neglected tasks within the inFlow process. Following up with responsible parties helps keep everyone engaged with the system and demonstrates that their part in the system matters.

Work orders and flagged components

Monitoring open work orders can help a) identify parts that need ordering, b) locate discrepancies between physical and virtual quantities on hand, and c) ensure the production manager is able to open and close work orders easily.

More often than not, the production floor physically has all of the components needed to complete a work order, so a flagged component on a machine work order typically indicates some part of the system is prone to error.

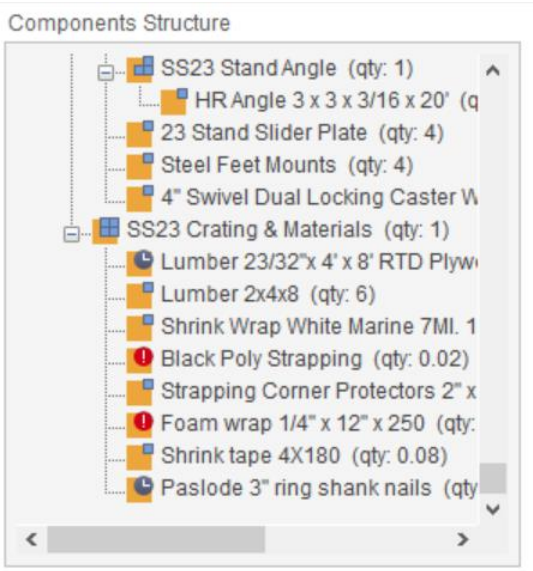

Figure 4.6.1 Work order with flagged components

In the case of Figure 4.6.1, ShopSabre sources all the flagged components from Home Depot. The shipping team, the primary users of these materials, receives these shipments and immediately puts them to use. When areas other than the parts cage receives raw materials, the receiver places the packing slip in a plastic file holder on the wall. The parts cage picks up packing slips throughout the day and receives the relevant items in inFlow. In this case, the flagged components are physically present on the production floor, but the purchase order remains unfulfilled in inFlow, causing inFlow to think there is insufficient stock.

Checking for these types of errors regularly keeps everyone on the production floor accountable for accomplishing their respective tasks in the system, and keeping work orders free of flagged components prevents the production manager from losing interest or patience with the system and abandoning the work orders entirely.

Occasionally, the flagged components do indicate that procurement accidentally missed a component in the ordering process. Catching these flags before the part causes a work stoppage contributes directly to the overarching goal of reducing lead times.

Current stock and negative inventory

Another opportunity to monitor the upkeep of the system is via inFlow's current stock module, shown in Figure 4.6.2. This window lists all ShopSabre's active inFlow items and respective quantities. By sorting item quantities in ascending order, one can quickly see any items that have gone into negative inventory.

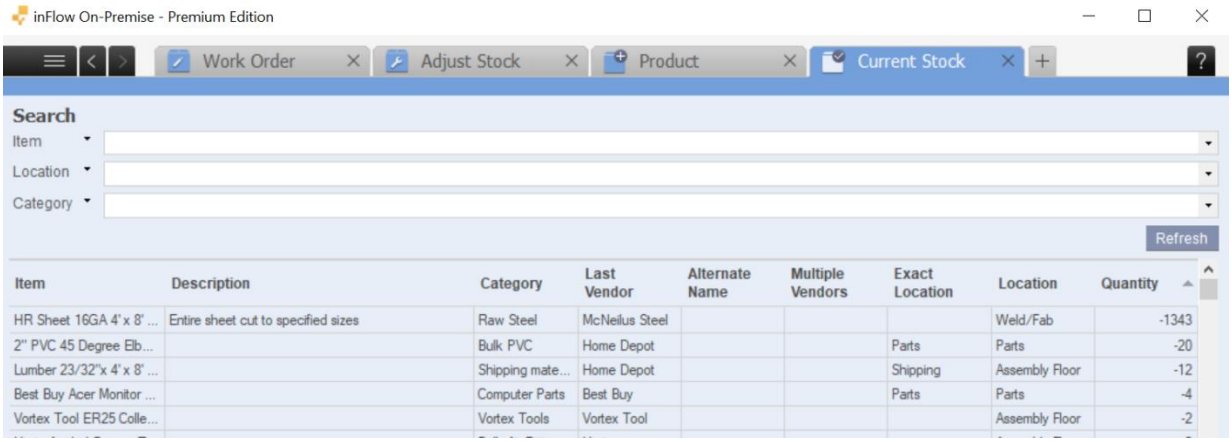

Figure 4.6.2 inFlow's current stock module showing negative inventory

inFlow has a few barriers and warnings in place to prevent item quantities from going negative; however, items can still go into negative inventory when, for example, the parts team sells a finished good without completing a work order in inFlow.

A common culprit of this problem is ShopSabre's plasma defense. Plasma defense is a treatment applied to water tables on CNC plasma machines that reduces problems associated with standing water. ShopSabre mixes plasma defense from a number of raw ingredients, meaning inFlow expects a work order to transform raw materials into a finished good. Without a work order, the parts team is still able to override inFlow's negative inventory warning and fulfill a sales order with plasma defense. This essentially picks a finished good that is not on the shelf, causing plasma defense quantities to dip below zero and resulting in an inflated quantity of raw ingredients.

Monitoring the current stock module allows ShopSabre to catch any missing work orders or similar errors and course correct before inventory quantities stray too far from reality.

Outstanding sales orders and purchase orders

The third key task for maintaining accuracy in inFlow is monitoring the number of outstanding orders, shown in Figure 4.6.3, on inFlow's dashboard. This dashboard shows how many sales orders, purchase orders, work orders, and count sheets are open; it also shows the number of products that need reordering. By monitoring this dashboard, one can see if the relevant parties are fulfilling and completing orders in inFlow or if, perhaps, inFlow tasks have taken a backseat to other priorities. If used properly, the number of outstanding sales orders can give ShopSabre an idea of how many machines are

in the backlog, and the number of work orders open can show how many machines are on the production floor.

Prior to the implementation of the new inFlow process, the volume of outstanding orders was so large that the numbers would not fully display on the dashboard. If these numbers steadily increase again, ShopSabre can look more in depth into the cause of the increase and address any neglected steps in the inFlow process.

Figure 4.6.3 Dashboard of outstanding orders

5 Using data to improve inventory management

With a centralized inventory system and process in place, ShopSabre is finally building some of the data necessary to analyze its replenishment processes more scientifically.

The research captures two months of movement history for the key components in the following pages to draw greater insights about ShopSabre's inventory replenishment process. These components constitute some of the highest total cost value items in ShopSabre's inventory, totaling anywhere from $12,000 to $50,000 for each line item. For simplicity, all lead times and demand calculations are inclusive of weekends.

Calculated standard deviations of demand may be higher than actual standard deviations due to inconsistent data entry in the early days of implementation. Daily demand calculations average the number of components picked on each day; however, the production manager occasionally opens work orders and picks items in inFlow in batches. This causes demand to peak some days and remain at zero on others. While this does not affect the calculation of average demand, the inconsistency does affect standard deviation, which skews the calculation of safety stock upward.

Since ShopSabre typically orders based on realized demand, safety stock is mostly required to account for uncertainty in lead times rather than uncertainty in demand. Even so, the speed at which machine builds begin and end varies depending on the complexity of the build. Therefore, the production floor's daily demand on components is still uncertain due to variability in the daily production mix and speed.

5.1 HSD 10HP spindle

A CNC router's cutting tools attach to a spindle, forming the heart of any router table. ShopSabre purchases the majority of its spindles from HSD Mechatronics, a global company headquartered in Italy. Customers have the option to purchase spindles with a variety of motor strengths; among the most common and highest dollar spindles is the HSD 8kW 10HP spindle, shown in Figure 5.1.1 (H6161H0233B ES919 HSD Spindle Motor - HSD USA, 2020). This spindle—valued just over $3,900 per unit—carries the highest total cost value of any item in ShopSabre's inventory.

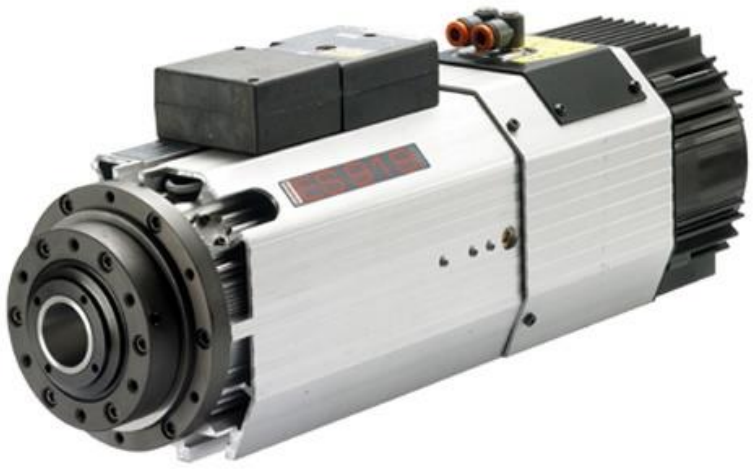

Figure 5.1.1 HSD 8kW 10HP spindle

Over a two-month period, the average lead time for HSD 10HP spindles was 19.4 days with a standard deviation of 6.5 days. According to the parts manager, this average is slightly lower than what is typically a three- or four-week lead time. Variability in lead time often depends on spindles in stock at HSD's distribution facility in Florida versus stock that needs to ship from Italy.

inFlow shows that roughly two to three HSD 10HP spindles are picked each week, creating an average daily demand of 0.4 spindles. Since ShopSabre orders spindles for specific machine numbers and inFlow shows which machine number a spindle is picked for, one can glean from inFlow that the average spindle spends about 12.5 days on the shelf between receiving and entering the build process.

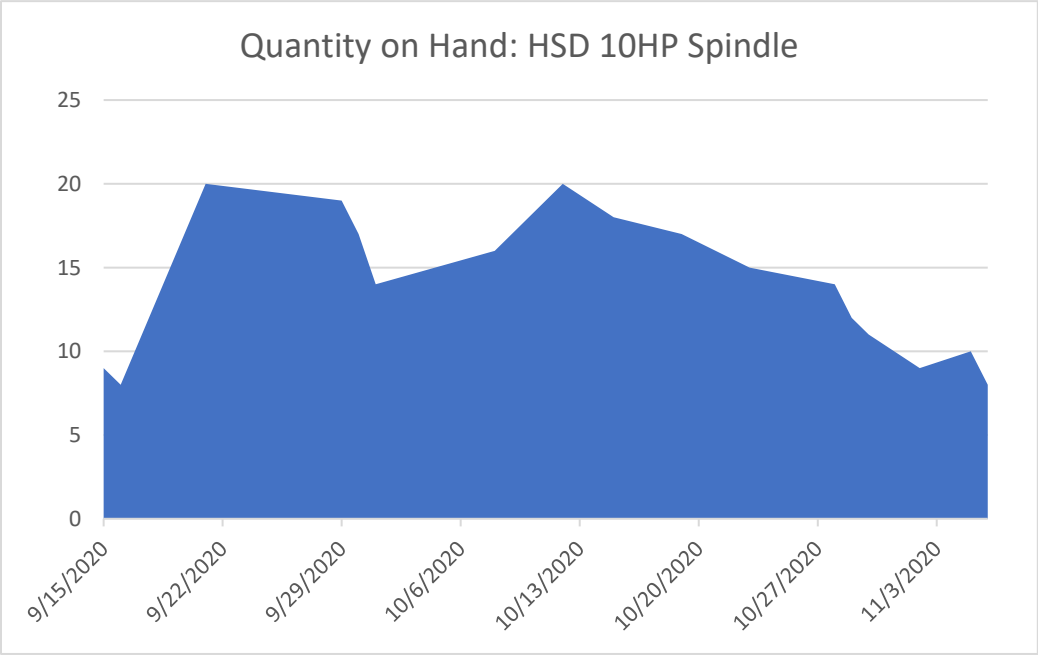

Figure 5.1.2 HSD 10HP spindles on hand over a two-month period

In order to achieve a desired service level of 99, ShopSabre needs to maintain a safety stock of 10 spindles, reordering when quantity on hand reaches 17. As shown in Figure 5.1.2, over the course of roughly two months, the number of 10HP spindles on hand never dipped below eight, which seems reasonable to achieve a relatively high service level. Based on this chart, at any given time, ShopSabre is carrying anywhere from $30,000 to $78,000 in 10HP spindles.

5.2 Pro408 welded and milled table

Each CNC table starts as an industrial steel frame, welded and milled externally, internally, or a combination of the two, depending on the model. ShopSabre currently outsources the welding and milling of the table frame for the Pro408, by far ShopSabre's most commonly sold CNC; however, this may change in the next year after the installation of ShopSabre's new, larger mill. Each frame, shown in Figure 5.2.1 (Poppe, Pro V2 Frame), is valued at approximately $4,500, causing the Pro408 table frame to be the second highest-ranking inventory item by total cost value.

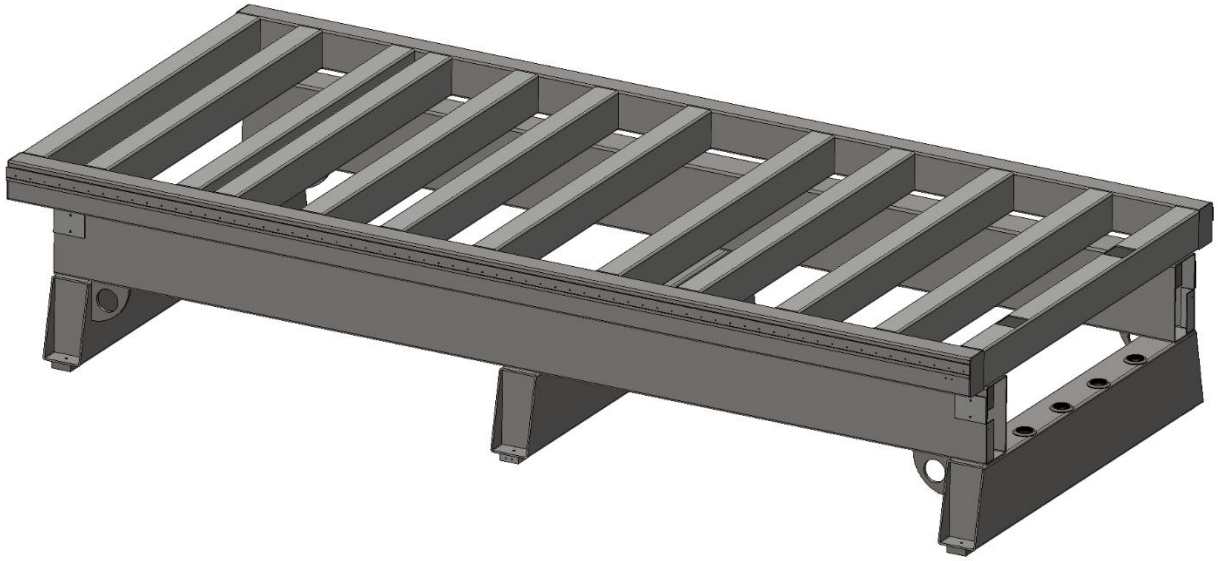

Figure 5.2.1 Pro408 table frame

Table frames hold the longest lead times of any CNC component, requiring a minimum of eight weeks but averaging closer to twelve. Due to these lead times, the demand for specific table frame sizes at each reorder point is unknown and, consequently, table frames are one of the few (perhaps only) machine components that demand a push strategy.

ShopSabre currently accounts for this uncertainty by periodically placing orders for table frames based on a historical product mix when the company experiences significant increases in throughput. For example, the parts manager created one such order when ShopSabre shifted from producing 50 machines per month to 70. While these orders serve to fulfill upcoming machine sales, the parts manager also places new orders for table frames based on demand from actual sales orders. While the purchase order associates these orders with a machine number, these frames actually replace the previously bulk-ordered frames in inventory.

ShopSabre's main supplier for table frames is ProFab, whose average lead time is 83 days. ShopSabre supplements ProFab's supply from a smaller supplier, C4 Welding. C4's average lead time for the same Pro408 frame is just 48 days; however, C4 also receives fewer orders from ShopSabre, which may account for the faster turnaround. Based on the significant gap between ProFab and C4 lead times, ShopSabre may consider increasing order quantities from C4 to balance the load between the vendors and potentially provide ProFab with some friendly competition and incentive to reduce lead times.

In order to achieve a desired service level of 95, ShopSabre would need to maintain a safety stock of eleven to fourteen Pro408 frames, reordering when quantities on hand are between 34 and 54 (based on lead times for C4 and ProFab, respectively). As evident in Figure 5.2.2, ShopSabre is able to maintain significantly lower inventory levels of these frames, perhaps due to the high number of frames on order at any given time. As of March 16, 2021, for example, ShopSabre had eight Pro408 frames on hand and 39 frames on order.

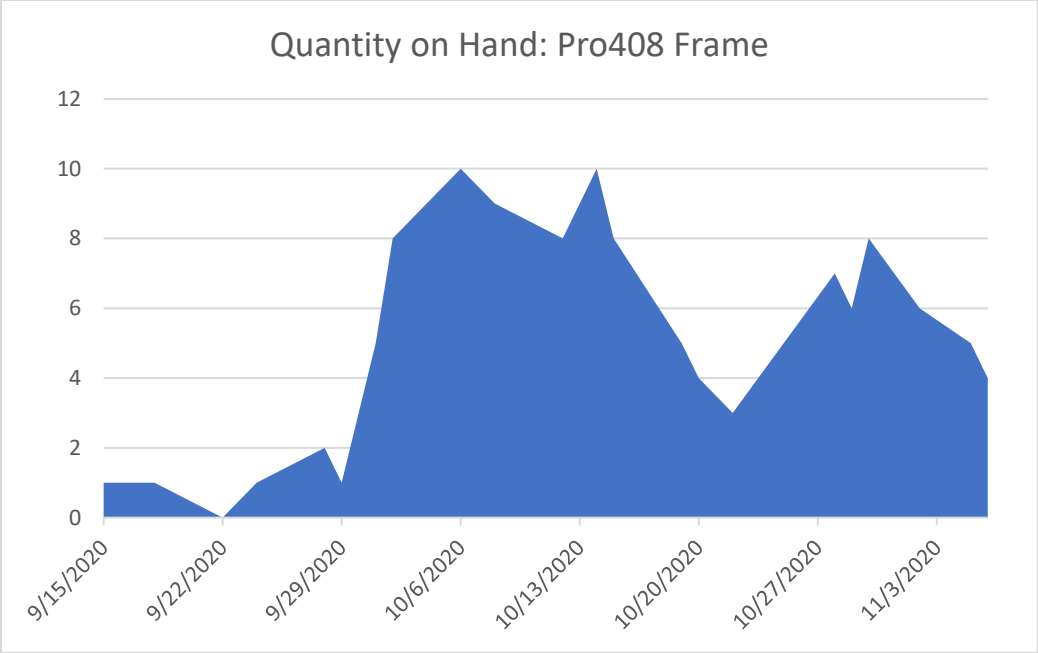

Figure 5.2.2 Pro408 table frames on hand over a two-month period

5.3 Small bearing block

Small bearing blocks, shown in Figure 5.3.1 (Poppe, Pro V2 Assembly), are a relatively low-cost component at just $30 each; however, *all* machines use eight small bearing blocks regardless of size or product line, and as of October 31st, 2020, small bearing blocks were the 8th highest-ranking inventory item by total cost value with over 1,000 units on hand.

Procurement orders small and large bearing blocks for each machine in a single order with the machine's requisite ball screws and linear rails. The lengths and number of ball screws and rails vary based on the type and size of machine, and therefore, procurement orders each set well in advance to ensure it is available during its designated build week. However, aside from the difference between small and large, the same bearing blocks are used on all machines and do not need to be ordered individually per machine.

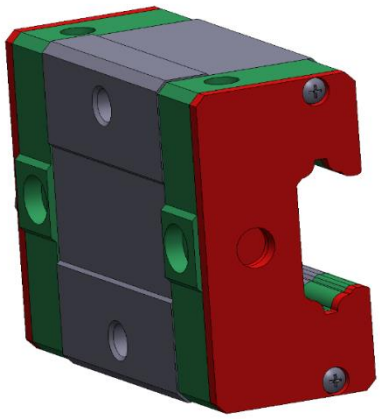

Figure 5.3.1 Small bearing block

Due to this ordering strategy, ShopSabre maintains a minimum of nearly 600 small bearing blocks in stock, tying up almost $18,000 in excess inventory. The average small bearing block spends about 19 days on the shelf between receiving and entering the build process.

Lead times for the sets of ball screws, linear rails, and bearing blocks average around 31 days. Occasionally, ShopSabre places a separate bulk order for bearing blocks, which may sell directly to customers in need of a replacement. When ordered separately, these bearing blocks have significantly shorter lead times of just six days on average.

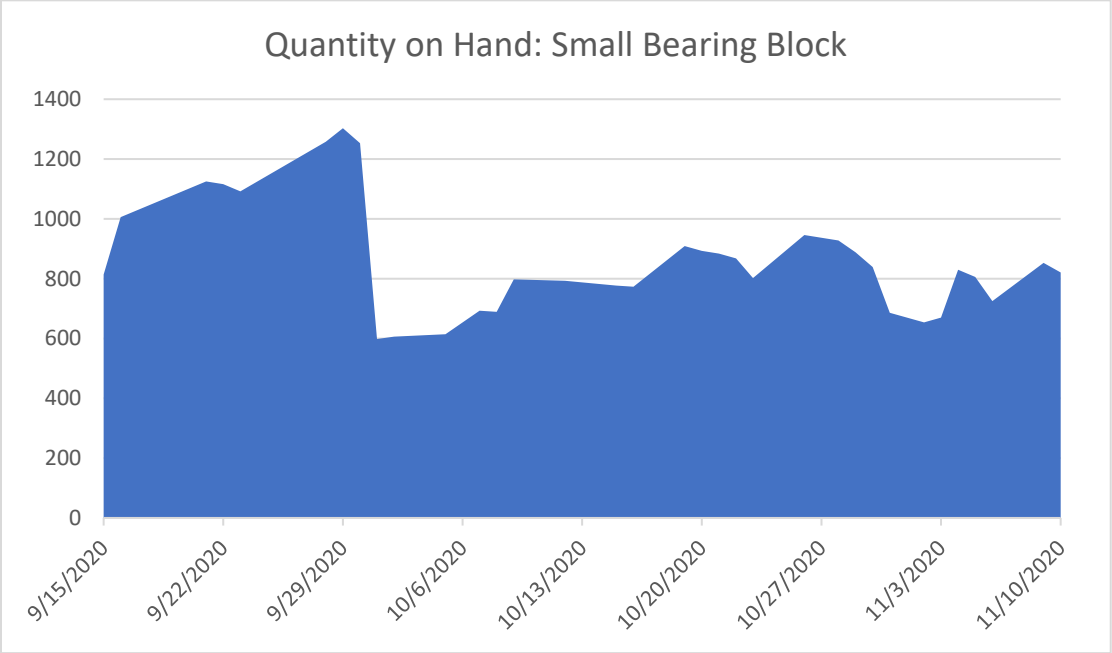

Figure 5.3.2 Small bearing blocks on hand over a two-month period

Based on a 31-day lead time, with an average daily demand of eleven small bearing blocks, ShopSabre would need to maintain a safety stock of 170 small bearing blocks, reordering when quantities on hand reach 500. As evident in Figure 5.3.2, ShopSabre's inventory levels for these bearing blocks rarely even reach the calculated reorder point. By aggregating the demand for small bearing blocks and replenishing them separately rather than part of an order for an individual finished product, ShopSabre would only need to maintain a safety stock of 90 units, reordering when quantities on hand dip to 160, effectively reducing inventory on hand by roughly $25,000.

5.4 WinCNC computer package (standard)

ShopSabre equips each CNC table with a desktop computer, solid-state hard drive, and 8GB of memory. The majority of machines come with a standard size computer with the exception of ShopSabre's IS product line, which requires a smaller computer to fit in the control stand.

Depending on the type of machine, this computer package might also be ordered with torch height control (for plasma cutters), tool changer support (for automatic tool change spindles), or spindle speed control. While the unit price for the standard computer package is only $550, the addition of software components increases the inventory value to roughly $1,500, depending on the software. The vendor,

WinCNC, programs these software modifications onto the board, and therefore, the computer packages arrive at ShopSabre differentiated.

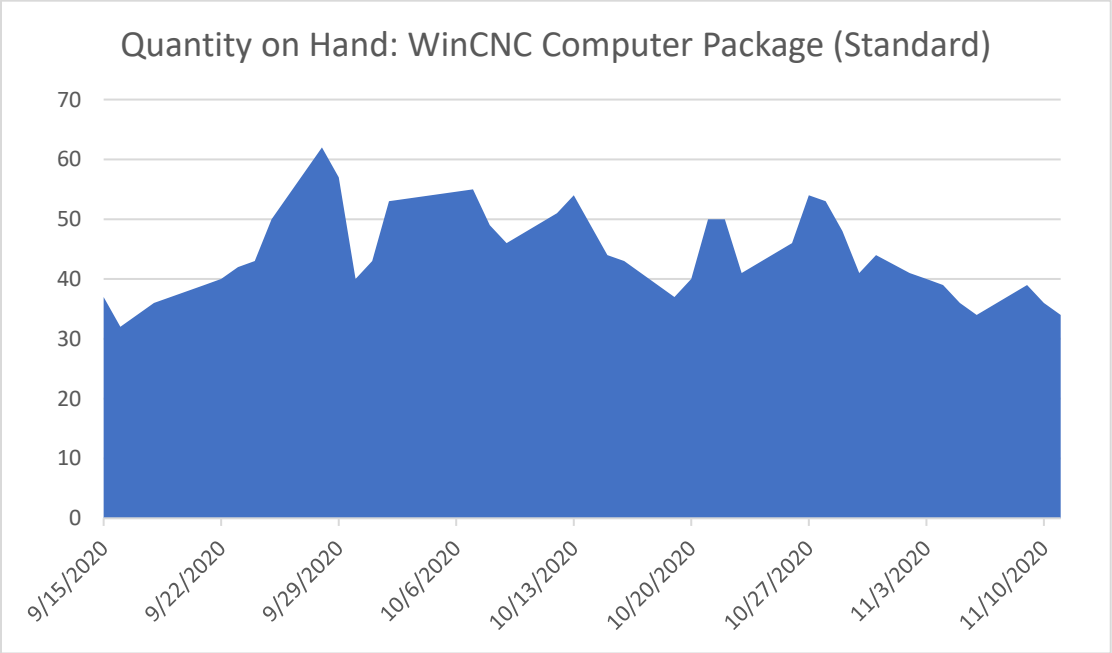

Figure 5.4.1 Standard computer packages on hand over a two-month period

At first glance, the Figure 5.4.1 might appear similar to the graph representing small bearing blocks, Figure 5.3.2, with a large swath of unnecessary stock on hand. In this case, however, each standard computer package represented on the graph is not necessarily interchangeable with the other due to the aforementioned software modifications. While the graph does not follow a typical replenishment "curve," ShopSabre's quantity of computer packages on hand seems to align most closely with a service level of 99, which requires a safety stock of 31 and a reorder point of 57.

The average lead time for WinCNC computer packages is 11 days, ShopSabre's production floor uses an average of two to three computer packages per day, and each unit spends an average of 19 days on the shelf between receiving and picking. Given the average lead time is less than the average number of days on the shelf, there may be opportunity to delay ordering the computer in order to reduce unnecessary inventory on hand.

5.5 Servo motor 200W with oil seal

ShopSabre uses Mitsubishi 200W servo motors, shown in Figure 5.5.1 (MITSUBISHI servo motor HG-KN23JK, 2020), on the X and Z axes of its Pro and ShopMaster series machines.

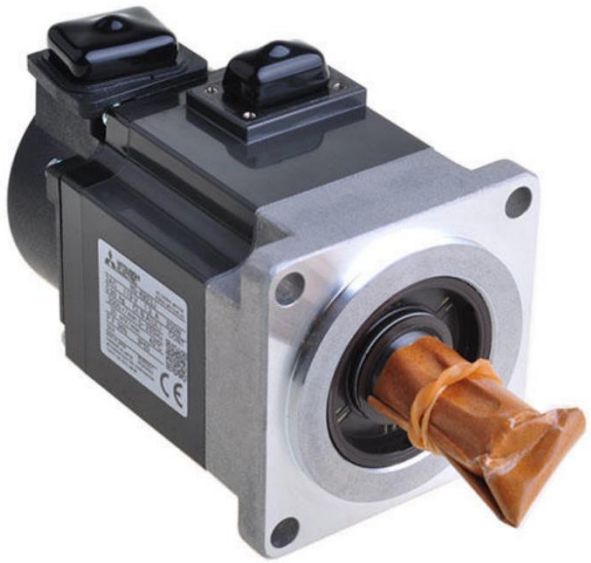

Figure 5.5.1 Mitsubishi 200W servo motor

These servo motors experience an average demand of two units per day, an average lead time of 10 days, and spend an average of 18 days on the shelf between receiving and picking. While each motor costs roughly $210, ShopSabre orders the motors alongside other motors, amps, cables, connectors, and a variable-frequency drive, which brings the total value of the ordered package to approximately $1,500. If ShopSabre has approximately 15 of these packages on the shelf at any given time as indicated in Figure 5.5.2, the total value of that inventory might be upwards of $22,000.

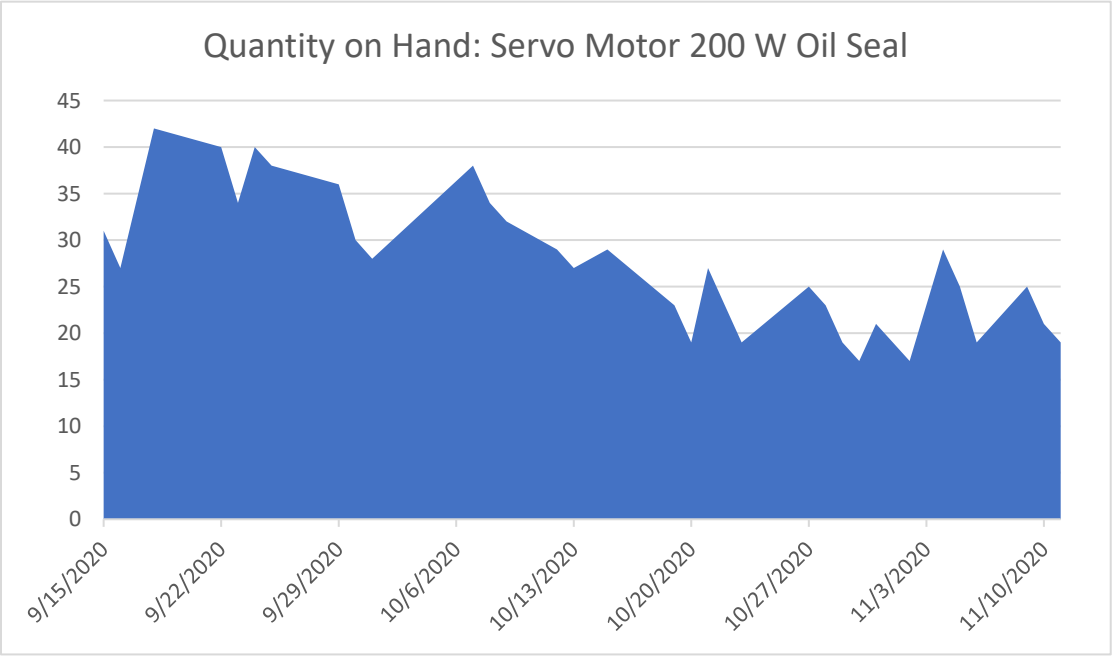

Figure 5.5.2 200W servo motors on hand over a two-month period

Taking a loose interpretation of Figure 5.5.2, ShopSabre appears to maintain a high service level, operating with an effective safety stock of 15-20 motors, well below the recommended safety stock of

26 units to achieve a service level of 95. ShopSabre is able to maintain this high service level with less inventory on hand by ordering continuously by machine rather than intermittently in bulk.

5.6 Teknic servo motor

The Teknic servo motor, shown in Figure 5.6.1 (CPM-SDSK-3411S-ELN, 2020), is purchased in bulk for all axes on the SideKick and RC product lines.

Figure 5.6.1 Teknic servo motor

ShopSabre orders these motors once per month, once the parts cage receives the preceding order. The lead time for the motors is almost exactly 30 days with little to no variation. The average daily demand for the Teknic motors is 3.5 units per day, and therefore, ShopSabre purchases 100 units per order with an effective safety stock of approximately 30 units.

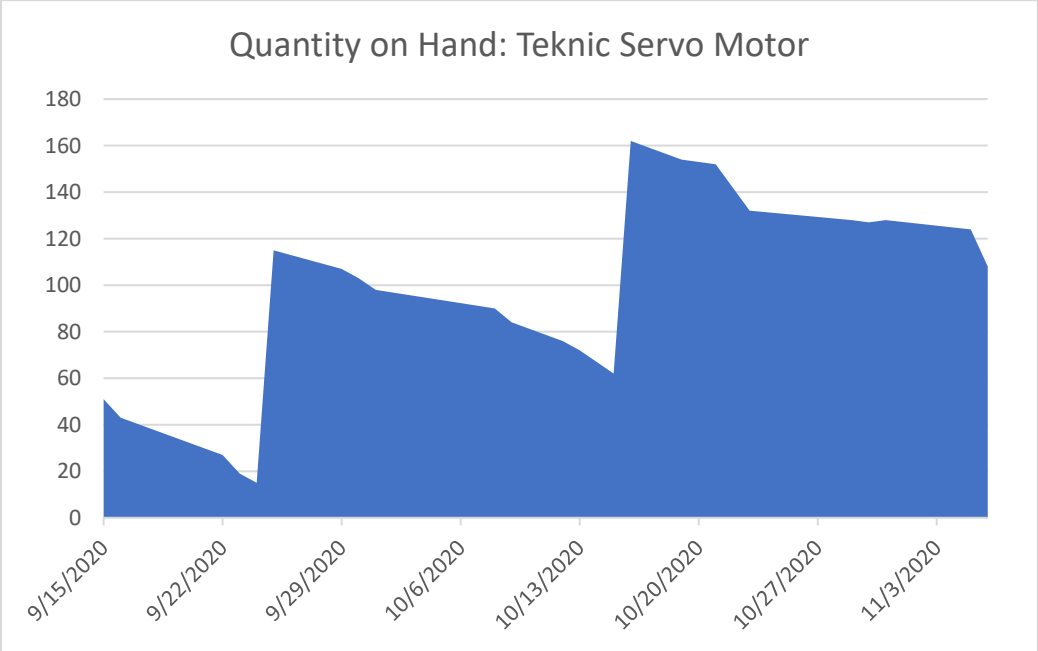

Figure 5.6.2 Teknic servo motors on hand over a two-month period

Using this replenishment strategy to back-calculate, the effective service level of this strategy is technically 80, meaning every one in five days, no Teknic servo motors will be available to the production teams when needed. This appears not to be the case (see Figure 5.6.2), which perhaps indicates an error in the standard deviation of the daily demand, which is over six units. This error could be due to the fact that, as the production manager begins to use inFlow, work orders might not be opened (and components picked) every day, causing there to be large swings in the number of components picked a few days later, when the work orders were finally opened.

5.7 Vectric VCarve Pro

All CNC routers include a license for Vectric VCarve Pro, a computer-aided design software. ShopSabre's customer liaison allocates Individual software licenses to customers shortly after the machine sale even though the machine might not enter production for another eight weeks.

The software is issued as a digital license, and therefore, the lead time is almost negligible. As a conservative calculation and to account for processing times, this lead time has been accounted for as one day with no standard deviation.

ShopSabre typically orders 40 licenses at a time at a unit cost of $350. To account for processing times and an average daily demand of two licenses per day, the parts team typically reorders VCarve licenses when quantity on hand reaches five licenses. Figure 5.7.1 appears to depict a different reorder point because software licenses still appear in inFlow as inventory until the actual machine ships. While it may appear as though ShopSabre maintains upwards of 40 licenses on hand at all times, in reality the customer liaison has already allocated the majority of those licenses to customers waiting to receive their machines.

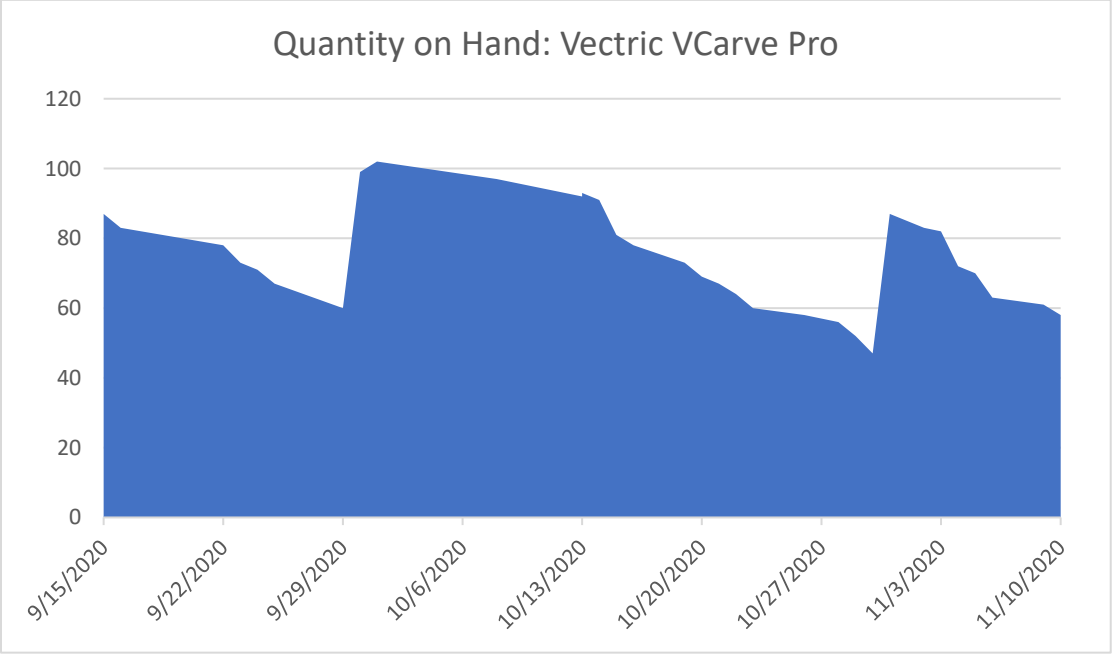

Figure 5.7.1 VCarve licenses on hand over a two-month period

Based on the aforementioned reorder point, reorder quantity, lead time, and daily demand, ShopSabre appears to be operating at a service level of 85. Similar to the case of the Teknic servo motors, this back-

calculation seems to be flawed due to a daily demand standard deviation of nearly three licenses. However, given both the almost instant lead time and the way in which VCarve licenses are allocated to customers, operating at a lower service level for this product is of almost insignificant consequence.

5.8 Phenolic

For all CNC routers, ShopSabre allows customers to choose a tabletop cut from either phenolic or MDF. The phenolic tabletop material, however, can be one of the most problematic raw materials in inventory. While the average lead time from the vendor is only one day, there is a high risk of vendor stock outs due to an eight week lead time from the manufacturer. ShopSabre builds the majority of its CNC routers with a phenolic tabletop, using an average of 2.33 sheets per day, approximately the number of sheets required for one average-sized machine.

In order to achieve a desired service level of 99, ShopSabre needs to maintain a safety stock of 12 sheets, reordering each time quantity on hand dips to 15 sheets or less. This is typical of ShopSabre's existing replenishment process for phenolic (reordering 30 sheets of phenolic when quantity on hand reaches 15). However, Figure 5.8.1 shows that phenolic on hand reached zero in September due to a vendor stock out, leading to work stoppages on the production floor. The repercussions of this stock out likely contributed to procurement overcompensating with increased levels on inventory through the end of October.

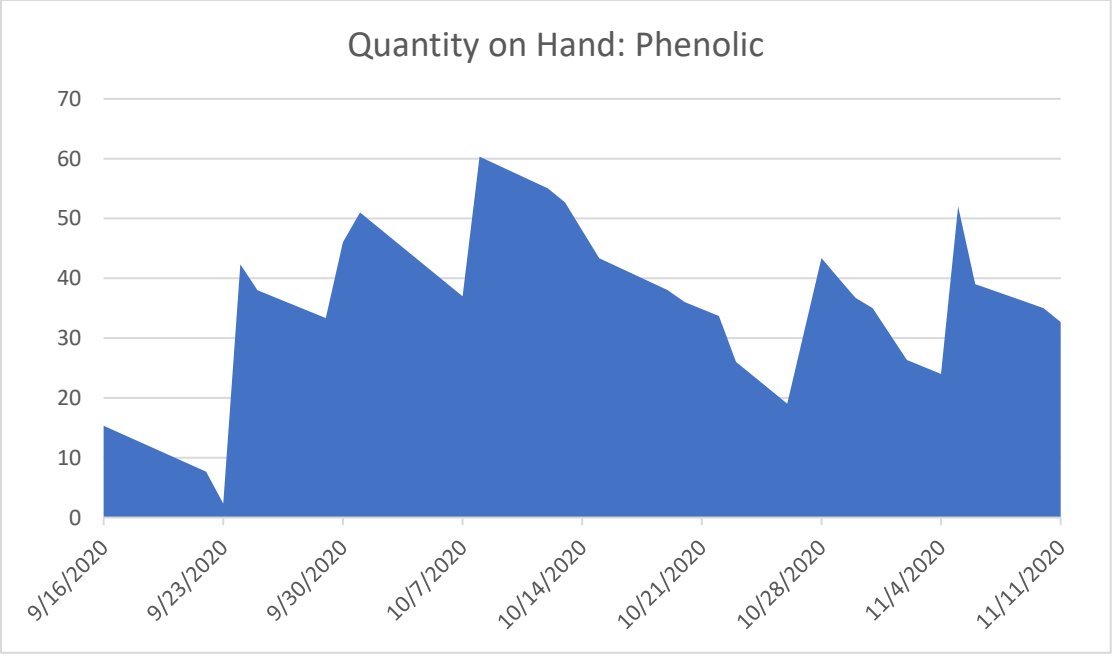

Figure 5.8.1 Phenolic on hand over a two-month period

5.9 igus® 23 X

ShopSabre uses igus® wire carriers, shown in Figure 5.9.1 (Miniature Cable Carriers & e-chains® for Confined Spaces | igus®, 2020), to contain and facilitate the movement of electrical wires during machine operation. The parts department orders wire carriers in sets of specific lengths and widths for each size and type of machine.

Figure 5.9.1 igus® wire carrier

Figure 5.9.2 shows the inventory on hand for the x-axis igus® wire carrier used on a ShopSabre 23. The average demand for the 23 model's x-igus® on the production floor is two units per week, and the lead time to receive an order is 10 days. While ShopSabre does not base its replenishment process on specific reorder points or quantities, the trend in quantity on hand somewhat reflects a service level of 99, which correlates with a safety stock of 11 units and a reorder point of 15.

According to inFlow, these particular igus® wire carriers spend 23 days on the shelf on average. Each unit only costs $50, but ShopSabre orders the x-igus® as a set with the y-axis wire carrier for a total value of $115. With an average lead time of only 10 days, there may be an opportunity to order less in advance of the machine build in order to reduce excess inventory on hand.

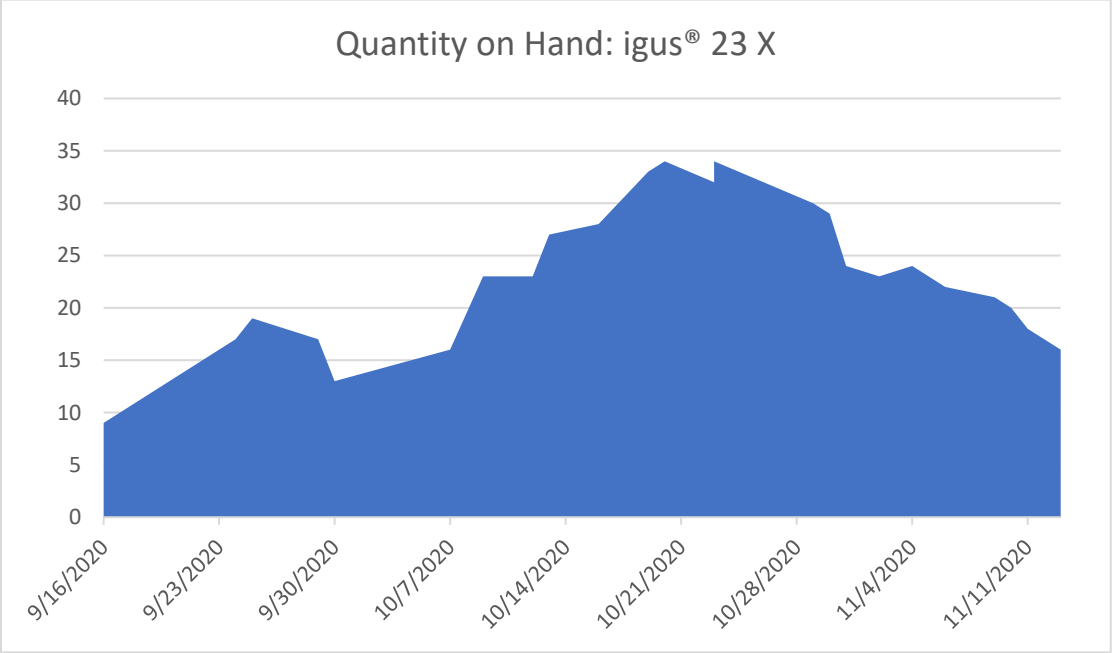

Figure 5.9.2 igus® 23 X on hand over a two-month period

6 Conclusions and recommendations

At the conclusion of on-site research, ShopSabre was fulfilling machine orders with historically low lead times of four to five weeks for routers and seven weeks for plasmas/23s. This is ShopSabre's first year under 10-12-week lead times. Table 6.1 shows the general trend of improvement over the course of the research. Based on this research and metrics to-date, implementing a centralized, perpetual inventory system and processes appears to result in a reduced backlog and, consequently, an increase in profitability.

	Unit of measure	Mar 2020	Jul 2020	Nov 2020	Goal 2021
Productivity	Machines/month	52-56	70	72-80	100
Lead time	Weeks	12	8	5	4-6
Backlog	Machines	220	130-140	126	<100
	Millions of dollars	$4.4M	$2.7M	$2.5M	<$2M

Table 6.1 Progress to-date

While the metrics above are encouraging, developing an inventory management system is only a first step toward improving inventory management and increasing profitability. Chapter 5 describes a number of preliminary insights available to ShopSabre through the data generated by inFlow. As the data improves in quality over time, ShopSabre can use the information to calculate formal reorder points and quantities, further reducing the risk of insufficient parts while also decreasing unnecessary inventory on hand.

In addition to establishing formal reorder points and quantities, other key recommendations for ShopSabre to consider include

- Increasing table frame order quantities from C4 to help reduce ProFab lead times
- Ordering bearing blocks in bulk rather than with linear rails and ball screws to reduce unnecessary inventory on hand
- Encouraging regular use of inFlow's reorder stock module
- Transitioning the sales department to enter sales orders in inFlow in order to take advantage of the following time savings:
    - Accountant no longer needs to recreate sales orders
    - Custom sales template reduces manual work for customer liaison
    - Assembly team can more easily find options on custom work order templates
- Creating an auto-populating production log to automate the creation of the build queue based on customer payments, parts availability, and types of machines
- Creating an auto-populating temporary invoice log to reduce human error, standardize entries, and eliminate access problems

Furthermore, in the process of learning about ShopSabre's existing systems and processes, other potential opportunities for improvement surfaced outside the scope and timeline of this research. Based on conversations with a wide range of stakeholders and observations on the production floor, the changes below may also contribute toward reducing ShopSabre's lead times and increasing profitability:

- *Full conversion to metric:* Major vendor-supplied components use standard metric measurements while most ShopSabre's raw materials historically use standard imperial measurements simply due to availability and ease of access.
- *Check tolerances on table frames prior to assembly:* ShopSabre conducts thorough testing of each machine using a FARO Vantage Laser Tracker as the final step prior to shipping. Testing may reveal that the table frame is out of tolerance, requiring significant rework. Purchasing a second FARO to check table frames prior to assembly could reduce required rework.
- *Machine all holes prior to assembly:* Assembly teams spend a considerable amount of time drilling and tapping missing holes in the table frame, gantry, and smaller components.
- *Cut and pre-drill all tabletops using CNC router:* ShopSabre has programmed a CNC router to cut and drill phenolic tabletops to specification; however, there is no program for MDF tabletops, and assembly teams still cut and drill the MDF by hand.
- *Strip bags for bolts:* Assemblers bolt each component in place using a wide range of both metric and imperial screws, which the assembly teams take as needed from a centrally located cart of bolts. These bolts could be kitted in strip bags by the supplier and added to the machine assembly kits.
- *Pre-configuration of bearing blocks:* Assembly teams must wipe down 12 bearing blocks and reconfigure them with grease fittings prior to assembling each machine. Occasionally, the plastic body of the bearing blocks need resetting or light hammering for the bearings to run smoothly.
- *Return dented grease tubes:* Grease tubes in inventory occasionally arrive dented; assembly teams must bend dented tubes to create a better seal in the grease gun and are prone to developing air pockets that prevent grease from exiting the gun.

In the three months since this research concluded, ShopSabre has already transitioned from an on premise version of inFlow to a cloud-based version, indicating that the system and processes are gaining traction and ShopSabre is willing to continue investing in it. ShopSabre has also hired a director of continuous improvement to continue formalizing ShopSabre's processes, implementing some of the aforementioned recommendations, and building upon this research. Prior to the conclusion of the research, ShopSabre already began the installation process for the new, larger mill, which will provide new opportunities to increase profitability as well as new use cases for inFlow.

As ShopSabre continues to grow, its ability to adapt and adjust business processes accordingly is vital, and as suggested by this research, perhaps most integral to the implementation of such changes is spending time understanding existing systems and processes in order to ease any transitions. Continuing to innovate within business processes while also holding the existing knowledge in high regard will position ShopSabre well to maintain its growth trajectory and status as a leading CNC designer and manufacturer.

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