# Improving Contact Lens Manufacturing through Cost Modeling and Batch Production Scheduling Optimization

by

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Bachelor of Science in Mechanical Engineering, THE OHIO STATE UNIVERSITY, 2012

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

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## Abstract

J&J Vision Care (JJVC) uses production scheduling methods that are not fully optimized, causing over-production of certain SKUs, and reducing capacity for other SKUs on backorder. This makes planning a weekly run-schedule for each line difficult. It is also difficult to understand where to invest capital to create an optimally flexible fleet of production lines. JJVC is currently capacity-constrained, so optimizing the production to increase output will directly translate to additional revenue.

The three main areas that the leadership team wants to explore in this project are:

1. What is our current fleet flexibility?
2. How much capacity can be freed up if our fleet was more flexible?
3. Can we create a cost modeling tool that will provide more granularity in brand and sales channel profitability?

First, the brands and SKUs on each line that are "validated" to run (by FDA, etc.) must be quantified. Not all validated SKUs on a line are "runnable" though: Process issues often arise in the plant that prevent some of these validated SKUs from being produced (e.g. mechanical tolerances, chemistry, etc.). Therefore, the gap between validated and runnable SKUs will be an opportunity to explore. One constraint originally studied was the "runnable" vs "validated" prescriptions at the Jacksonville site; The percentage of runnable vs validated SKUs is only 73%, meaning that 27% of the prescriptions that J&J invested time and money to validate cannot be produced on certain lines due to manufacturing issues. The impact of this constraint and others can be quantified to identify improvement opportunities.

Second, potential additional capacity can be calculated by running a sensitivity analysis with the planning tool (i.e. the optimization model) to analyze how outputs (e.g. throughput, changeover times, etc.) are affected by changing certain inputs: Mold, core, and pack change times, production rate, minimum lot sizes, service level, etc. It is also possible to change the objective function to place more weight on certain user-defined parameters. The impact of these changes were observed by collecting the master planning data for a defined time-period and running optimization scenarios. Various time horizons were used to gain an accurate understanding of the impact.

Third, to understand how the initiatives described above improve both revenue and costs, a clear understanding of the profitability of each lens must be considered before JJVC management makes high-level strategic decisions. To make this possible, a Total Delivered Cost (TDC) model was developed and published a for the Contact Lens supply chain.

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# Acknowledgements

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Cheers, God Bless, and Go Bucks!
- Andy

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# 1 Introduction

## 1.1 Project Motivation

J&J Vision Care (JJVC) wants to have a better understanding of where to invest capital to create an optimally flexible fleet of production lines. Production scheduling is not optimized, causing over-production of certain SKUs, and tying-up capacity for other SKUs on backorder.

Management also wants to better understand the profitability of each contact lens by brand and sales channel. Historically, overhead costs have been simply spread over multiple elements without truly justifying the reasoning. Additionally, the data manually and seldomly updated, making it difficult to visualize trends within each brand.

## 1.2 Project Goals

The JJVC team asked themselves three high-level questions that would enable them to better understand how to solve the previously stated motivation. The three goals were to: 1) Determine the current manufacturing line fleet flexibility; 2) Model how much capacity can be freed up if the fleet was less constrained by increasing the number of SKUs each line can produce; and 3) Create a fleet optimization strategy that balances capacity and cost.

From a cost modeling perspective, management wanted: 1) intuitive cost allocation drivers to determine the overhead rates; and 2) to have profitability visualization dashboards that are easy to use and understand.

## 1.3 Impact of Project

Throughout this report, a recurring theme of creating and tracking key metrics is recommended to personnel at multiple levels within the JJVC organization. The intent is to bring an awareness and transparency of potential issues that have not been given proper attention. While the project was executed at JJVC's Jacksonville, FL, Vision Care facility, the core concepts are applicable not only throughout J&J's other businesses, but also at companies across multiple industries. With a proper management system, the metrics can be "used to drive improvements and help businesses focus their people and resources on what's important. The range of metrics companies can employ vary from those that are mandatory to those that track increase in efficiency, reductions in complaints, greater profits and better savings. Metrics indicate the priorities of the company and provide a window on performance. Ultimately, metrics will help tell the organization where it has been, where it is heading, whether something is going wrong and when the organization reaches its target." [1] Ideally, the scheduling optimization and cost modeling metrics will be used to promote positive change throughout multiple departments within the organization.

Additionally, this research provides the reader with a high-level understanding of the contact lens business, including an overview of the: batch production process, global supply chain network, major corporate competitors, business growth forecast, and other industry trends.

# 2 Background

## 2.1 Industry Overview

### 2.1.1 Contacts Definition and Types

Contact lenses (or "contacts") are prescribed to eye patients based on their individual corrective needs. Medical device companies produce both hard and soft contact lenses, and patients may choose between the two. Soft contact lenses are more popular and provide more options for consumers. According to the American Academy of Ophthalmology [2], the main types are:

**Daily wear contacts:** Worn only when awake and removed before sleep. Many are daily disposable (new pair worn each day). Others that last longer only need to be replaced once a week, every two weeks, or every month (these are also referred to as "reusable". Some ophthalmologists recommend disposable daily wear contacts if they'll be used only once in a while.

**Extended wear contacts:** These can be worn during sleep, but they need to be removed for cleaning at least once a week. Fewer eye doctors recommend these contacts because they increase the chance of getting an eye infection.

**Toric contacts:** These can correct vision for people with astigmatism, though not as well as hard contact lenses. Toric lenses can be for daily or extended wear. They often cost more than other types of soft contact lenses.

**Colored (tinted) contacts:** Vision-correcting contact lenses can be tinted to change the color of your eye. They can be purchased as daily wear, extended wear, and toric lenses.

**Decorative (cosmetic) contacts** (also known as "beauty" contacts)**:** These lenses change the look or color of a wearer's eye. They can be used to correct vision, or one could be a "plane-o" if one eye does not need correction.

**Presbyopia contacts:** Presbyopia contacts are designed to correct the normal vision problems people get after age 40, when it becomes harder to see close objects clearly. There are different options for these corrective lenses, including: bifocal or multifocal contact lenses, and monovision correction, where one eye wears a near-vision lens and the other eye wears a distance-vision lens.

### 2.1.2 Worldwide Demand and Trends

According to market research, "the global contact lenses market size was valued at USD 9.91 billion in 2016 and is expected to sustain its growth pace over the forecast period. The major applications of corrective contact lenses are correction of refractive errors and treatment of visual deficiencies (described above). The rising number of visual inaccuracies is expected to further drive the global market over the forecast period. The soft lens segment provides various applications to the contact lenses market and thus is one of the prominent contributors to the market share. Advancements, such as drug delivering lenses, in the contact lens technology and increasing adoption trends in various regional markets are expected to drive the market demand over the forecast period." [3] In the US alone, contact lens sales have been growing and are projected to grow in all segments through at least 2025, as Figure 2-1 displays.

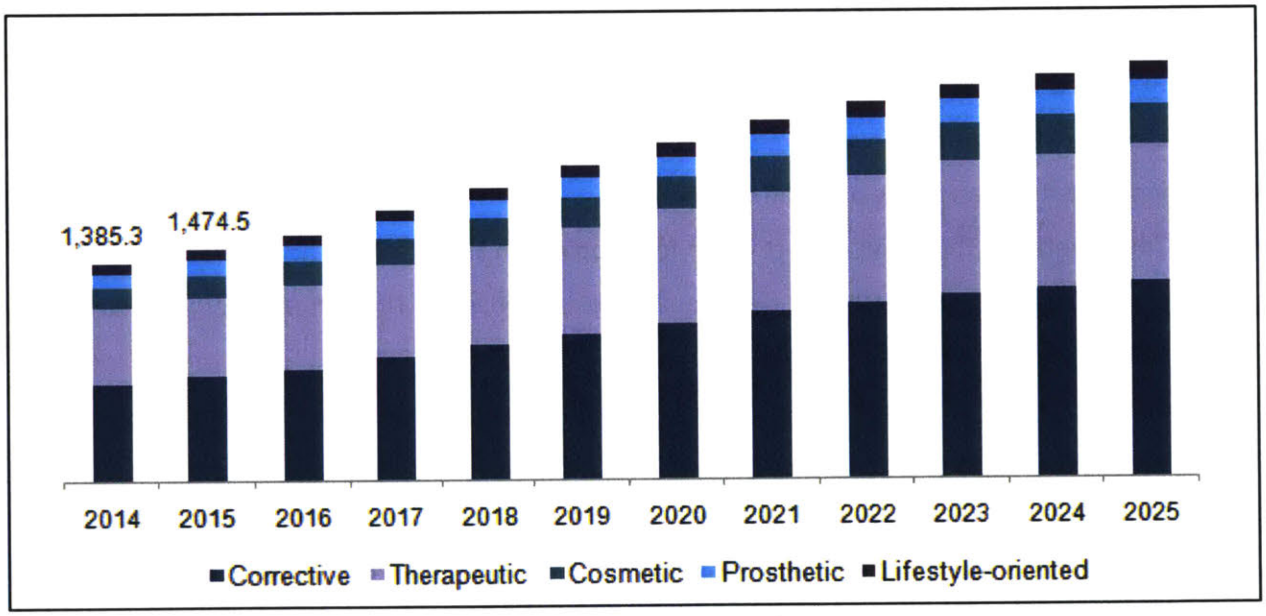

Figure 2-1: U.S. contact lenses market by usage type, 2014 - 2024 (USD Million) [3]

### 2.1.3 Johnson & Johnson Overview

Johnson & Johnson (J&J) was founded in 1886 and is currently in the Fortune 100, trading under stock symbol "JNJ" on the New York Stock Exchange (NYSE). J&J is a global corporation with "more than 260 operating companies located in more than 60 countries, including the U.S., which sell products in virtually all countries throughout the world." J&J segments itself into three main global businesses: Consumer, Pharmaceutical, and Medical Devices. [4] Johnson & Johnson Vision Care (JJVC) operates under the Medical Devices business.

J&J was named a 2018 Fortune World's Most Admired Company, which is a direct result of the corporate culture. J&J's mindset is guided by its "Credo", which states in full as follows (bolded words added for emphasis of the 4 main stakeholders):

> "We believe our first responsibility is to the **patients, doctors and nurses, to mothers and fathers** and all others who use our products and services. In meeting their needs everything we do must be of high quality. We must constantly strive to provide value, reduce our costs and maintain reasonable prices. Customers' orders must be serviced promptly and accurately. Our business partners must have an opportunity to make a fair profit.
>
> We are responsible to **our employees** who work with us throughout the world. We must provide an inclusive work environment where each person must be considered as an individual. We must respect their diversity and dignity and recognize their merit. They must have a sense of security, fulfillment and purpose in their jobs. Compensation must be fair and adequate and working conditions clean, orderly and safe. We must support the health and well-being of our employees and help them fulfill their family and other personal responsibilities. Employees must feel free to make suggestions and complaints. There must be equal opportunity for employment, development and advancement for those qualified. We must provide highly capable leaders and their actions must be just and ethical.
>
> We are responsible to **the communities in which we live and work and to the world community** as well. We must help people be healthier by supporting better access and care in more places around the world. We must be good citizens — support good works and charities, better health and education, and bear our fair share of taxes. We must maintain in good order the property we are privileged to use, protecting the environment and natural resources.
>
> Our final responsibility is to **our stockholders**. Business must make a sound profit. We must experiment with new ideas. Research must be carried on, innovative programs developed, investments made for the future and mistakes paid for. New equipment must be purchased, new facilities provided and new products launched. Reserves must

be created to provide for adverse times. When we operate according to these principles, the stockholders should realize a fair return." [5]

### 2.1.4 JJVC Current State Overview

JJVC is the leader in contact lens manufacturing. It offers a strong portfolio of brands, led by market-leading Acuvue. A complete listing of its products is provided in the Appendix (Table 7-2). The lenses sold throughout the world are manufactured in just two locations: Jacksonville, Florida, and Limerick, Ireland. The distribution network to sell and deliver the contact lenses to consumers, however, is much more complex. Figure 2-2 provides a preview into the complexity. Managing this network optimally is key to maintaining customer satisfaction and business profitability. It is important to have positive relationships with all stakeholders along the value chain, as the satisfaction levels among consumers, ECPs, and distributors are all interconnected. In the US, a few of the key distributors and retailers include ABB Optical Group, Walmart, CVC, Walgreens, 1-800 Contacts, LensCrafters, and Lens.com.

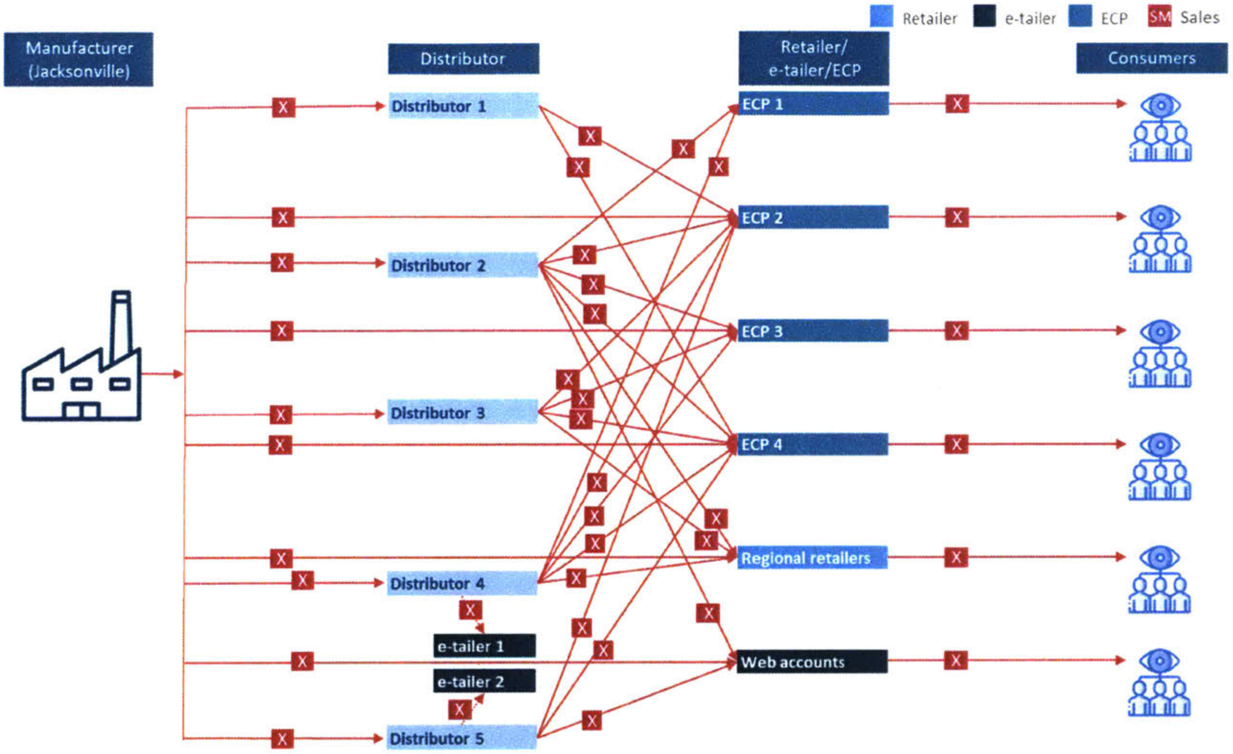

Figure 2-2: Condensed JJVC US Distribution Network [6]

### 2.1.5 Competitors

The primary manufacturers within the contact lens market[1] are CooperVision, Bausch & Lomb, Alcon, Largan Medical, Seed Co., BenQ, Ginko International Co. Ltd., Pegavision, and Menicon.

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[1] As of 2018.

# 3 Project Methodology

## 3.1 Manufacturing Overview

JJVC manufactures contact lenses at two locations: Jacksonville, Florida, and Limerick, Ireland. Each location uses similar technologies, which enables knowledge sharing between the two. The manufacturing lines are currently designated either "2GT", "3GT", "4GT", or "5GT" ("GT" standing for "generation technology"). Each of these types of lines have different characteristics, including production rate, volume of SKUs it can produce, footprint (production area), as well as many others that are detailed in the following section. Figure 3-1 shows a schematic overview of each line along with the mix/volume characteristics.

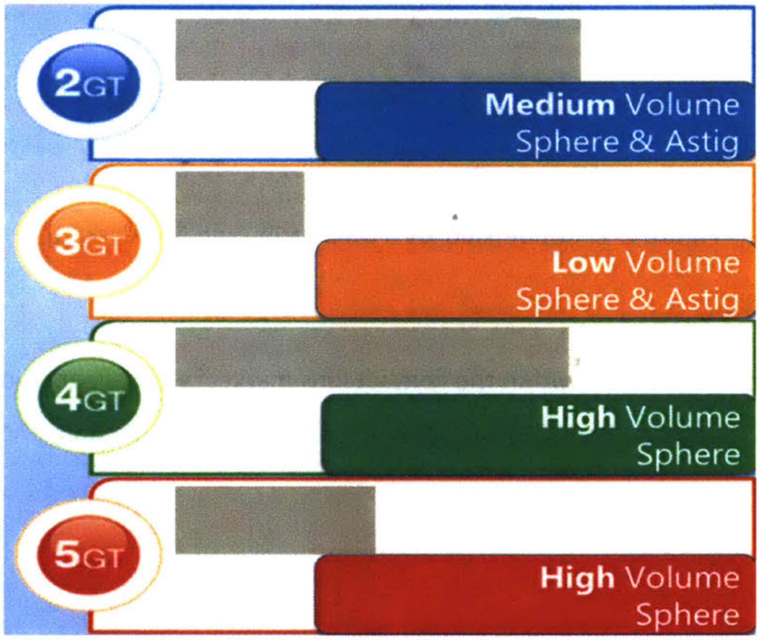
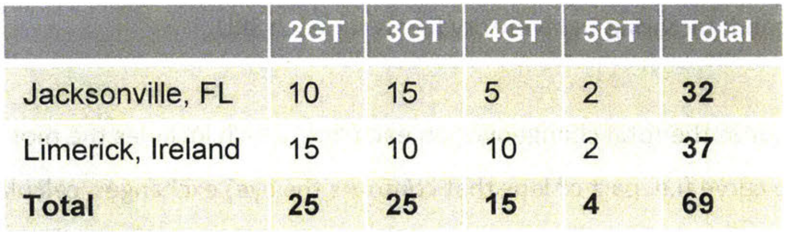


Figure 3-1: The Size and Mix/Throughput Changes With Each Generation

In general, the contacts produced in Jacksonville are distributed to customers in the Americas, and Limerick supplies the rest of the global market (with certain exceptions). This is a strategic decision determined by factors including tax rates, currency hedging, distribution costs, manufacturing differences between the two plants, and quantities of certain types of contacts demanded in each region. The quantity of each line type at each location is listed below in Table 3-1.

Table 3-1: Type and Number of Mfg. Lines by Location[2]



| | 2GT | 3GT | 4GT | 5GT | Total |
|---|---|---|---|---|---|
| Jacksonville, FL | 10 | 15 | 5 | 2 | **32** |
| Limerick, Ireland | 15 | 10 | 10 | 2 | **37** |
| **Total** | **25** | **25** | **15** | **4** | **69** |

While each of these technologies have the noted differences, the following overview shown in Figure 3-2 is consistent among the manufacturing lines.

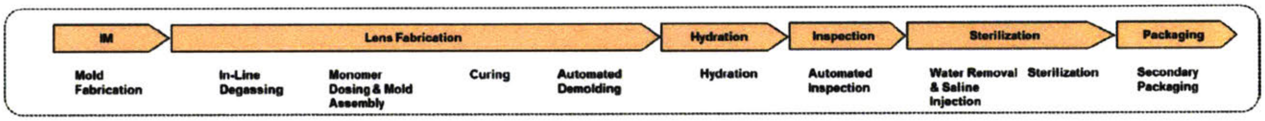


Figure 3-2: Overview of Contact Lens Manufacturing Process

## 3.2 Planning/Scheduling Optimization

### 3.2.1 FICO Optimization and Modeling Tools

JJVC uses FICO® Xpress Optimization ("FICO") software to generate a locally optimal (i.e. in Jacksonville, not across both sites) weekly SKU production schedule for all manufacturing lines in Jacksonville. FICO offers multiple planning functionalities, including "scalable high-performance solvers and algorithms, flexible modeling environments, rapid application development, comparative scenario analysis, and reporting capabilities." [7] It uses mixed integer optimization (MIO) with over 1 million decision variables and constraints. FICO is a web-based model platform that allows the production planners to simultaneously run output scenarios.

The line-by-line optimization code cannot be shared (via the supply chain analytics team in order to protect J&J intellectual property), but what can be shared is an overview of the objective function, constraints, and inputs, as explained below:

**Objective Function:**

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[2] Actual data censored to protect IP.

The objective function has 3 main components:

1. Maximize the mix adherence to the JDA (software that produces weekly demand forecast) plan. In mathematical terms, minimize the difference between supply and demand, factoring-in inventory levels for each SKU.

2. Minimize the total changeover on each line, which includes the mold, front curve, and base curve (i.e. part of lens that contours the eye) exchanges, calculated by:

$$Production\ lost\ to\ changeovers = (changeover\ time) * \frac{lens\ production}{minute} \tag{3-1}$$

3. Maximize capacity utilization in terms of lens production (minimize lenses not produced during idle time).

The weight of each of these three objectives varies depending on which brand is running on a specific line. Generally though the priority is highest for #2 and lowest for #3, with #1 falling in the middle. Therefore the main goal of the model is to minimize changeovers (#2), but sometimes next week's demand is too high and inventory level constraint must be satisfied (making the minimum days of supply constraint outweigh changeover-downtime). Therefore if this week's demand is higher than the capacity, the model will try to schedule the SKUs that are in higher priority (based on days of supply, with backorders scheduling first) and according to the most efficient way of minimum number of changeovers (such as scheduling more from the same core break) as well as best capacity utilization. If the demand for the subsequent week is lower than the capacity, then the model will look further into demand (as determined by planner) and will start scheduling for future lots in the most efficient way.

**Constraints:**

The model operates under many constraints, including:

1. Available capacity for each manufacturing line in each week. The planners will work with the production teams to determine how many shifts or hours (1 shift is equivalent to 12 hours) of *planned* downtime will occur in the planning horizon. Reasons for shutting the lines down include brand conversions, holidays, capital projects, research and development testing, and predictive or preventive maintenance activities. The total

number of downtime hours is subtracted from the 168 hours in each week, and then converted to lens capacity using each line's lenses/hour (lph) capability.

2. Maximum mold run time for each brand and SKU. There is a mechanical limit for each mold that determines how many days a SKU run continuously on a line. This constraint may be reduced by installing molds that are capable of handling a greater number of cyclic loads.

3. Maximum and minimum days of supply of inventory at the end of each week. The model will not allow the week-end days of supply above the maximum days of supply or below minimum days of supply for each SKU in each week. Figure 3-3 shows the acceptable range and actual inventory levels for an example brand. This data is pulled from an internal system, "Jonova", that global planners own. The calculation and process to set the inventory ranges for each brand is described in more detail in Section 3.2.4.

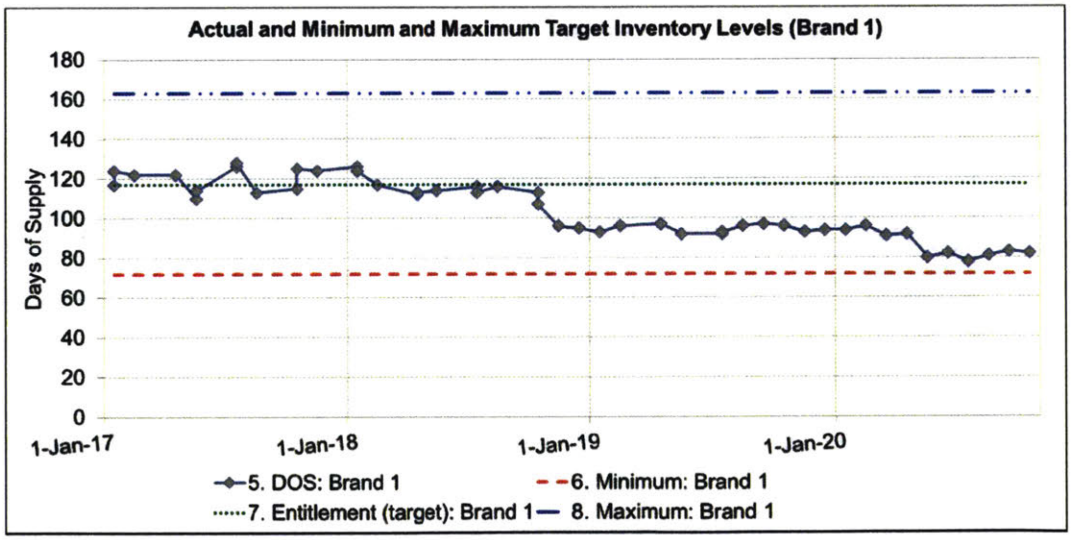

Figure 3-3: Actual and Min-Max Target Inventory Levels[3]

4. Minimum lot size for each SKU. This specifies the minimum quantity to put into production for each SKU, each brand and each specific line. Production of contact lenses

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[3] Actual data changed to protect IP.

is a batch manufacturing process, so this constraint ensures that a small order will not be scheduled, preventing inefficiency due to changeover and process stability ramp-up and calibration. As discussed in Section 3.1 Manufacturing Overview, the lines are characterized as either high-mix and low-volume, or low-mix and high-volume. This constraint therefore depends largely on that characteristic. The high-mix machines are able to change SKU production quickly, which allows for a smaller minimum lot size and a more relaxed constraint.

5. SKU-to-line assignments and configuration. There are two main elements to consider here. First, the same SKU can be produced on multiple lines. And second, a line is capable of producing SKUs of multiple brands and cores. The planner is responsible for keeping these variables updated with any validation changes. Table 3-2 shows example variables that the model will consider. "UOM" refers to the packaging size unit of measure (12 contact lens per package in this example). Table 3-2 provides an example of how one brand can have just one different variable, yet it requires a different core setup. In this case, the only variable changed is the power (i.e. sight correction factor).

Table 3-2: Example SKU-to-Line Assignments and Configuration

|  | Power | Base Curve | UOM | Rx/Dx | Brand | Line 1 | Line 2 |
|---|---|---|---|---|---|---|---|
| SKU 1 | -12 | 84 | 12P | R | PH | Core 1 | Core 1 |
| SKU 2 | -1.5 | 84 | 12P | R | PH | Core 2 | Core 2 |

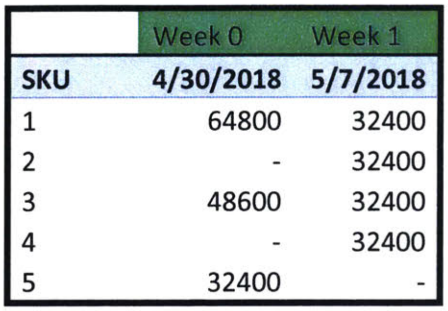
**Inputs:**

The model receives many inputs from the FICO GUI and multiple Excel spreadsheets, including:

1. Current inventory level for each SKU, open customer orders, and the remaining week's production schedule on each line for each SKU. The net number of lenses from these variables are calculated to determine the required production for next week. As an example, for SKU "1" in Table 3-3 below, if the difference between inventory and demand was 97,200 lenses, and 64,800 lenses were already on the current week's

production schedule, only 32,400 lenses (the difference) would need to be scheduled for next week.

Table 3-3: Example Weekly Production Demand



| | Week 0 | Week 1 |
|---|---|---|
| **SKU** | **4/30/2018** | **5/7/2018** |
| 1 | 64800 | 32400 |
| 2 | - | 32400 |
| 3 | 48600 | 32400 |
| 4 | - | 32400 |
| 5 | 32400 | - |

2. Last SKU remaining on each line. This information is necessary for the optimization tool to minimize the total changeover time. Without the last SKU known, the model may output a schedule that requires multiple mold or core changes at the beginning of the week, even though other SKUs could have run on the same molds and cores.

3. Production output rate, unit changeover time for mold, core, and base curve changes on each line. Note that these are all manually input numbers, and don't change based on which brands or SKUs are running on the line. An improvement can be made here by using a feedback system to update the actual speeds of each of these variables for each SKU. Table 3-4 below shows an example of the typical inputs into the model. Note that Lines 3 and 4 in this example do not have a stated pack change time, meaning that they can only package one size (e.g. a 30-pack).

Table 3-4: Line Production and Changeover Characteristics

| Line # | Lenses/ shift* | Lenses/ hr | Mold Change (hrs) | Core Change (hrs) | BC Change (hrs) | Pack Change (hrs) |
|---|---|---|---|---|---|---|
| LINE1 | 100,000 | 8,333 | 0.25 | 0.5 | 0.1 | 6 |
| LINE2 | 120,000 | 10,000 | 0.25 | 0.5 | 0.1 | 6 |
| LINE3 | 100,000 | 8,333 | 0.4 | 0.75 | 0.2 | NA |
| LINE4 | 140,000 | 11,667 | 0.4 | 0.75 | 0.2 | NA |

* 1 shift is 12 hours

4. SKU priority based on current days of supply and chronological order of required demand.

5. Demand and number of weeks in horizon for the demand input file. Since expected demand accuracy is higher when viewed in a closer timeframe, planners may elect to only look at next week's demand. However, shortening that window can increase the constraints on the model and therefore make the schedule output less efficient. The planners can therefore view the tradeoff between potential overproduction verse decreased asset utilization. If the total sum of demand in a chosen period is lower than capacity, then there may be some idle capacity unless there is a limitation in the model that production can't be scheduled for more than the chosen demand in the horizon.

6. Expected product release delay. This input captures the number of weeks that a product will be held for quality testing on each line before being released for shipment. The length depends on the brand and backlog of testing in the system.

### 3.2.2 Outputs

After the planner completes uploading the demand file and Excel input file, FICO will run through its mixed integer optimization to provide an optimal production schedule for the proceeding week. The planner can view multiple calculations before submitting the plan to the production team:

1. Optimal plan- For every manufacturing line, FICO will provide the chronological order and number of lenses of a particular SKU to produce for the entire week. A calculated

summary of the schedule is also produced. An example is shown in Table 3-5. Note that in this example, Line 4 is the only line that was able to schedule more than next week's demand, and the other three fall short of producing to demand, potentially causing the need to reach into safety stock inventory- or worse, create backorders.

Table 3-5: Example Demand and Summary of Scheduled SKUs

| | **Week1 Demand** | | | **Scheduled** | |
|---|---|---|---|---|---|
| **LINE** | **Lenses** | **SKUs** | **52 Week Avg.** | **Lenses** | **SKUs** |
| **Line 1** | **550,000** | 290 | 482,817 | **500,000** | 66 |
| **Line 2** | **600,000** | 210 | 619,250 | **550,000** | 62 |
| **Line 3** | **650,000** | 236 | 562,337 | **600,000** | 63 |
| **Line 4** | **600,000** | 276 | 531,529 | **650,000** | 49 |
| | **2,400,000** | | **2,195,933** | **2,300,000** | |

2. Changeover Time - As discussed in the objective function, this is the main driver of the optimization. If changeover time is high, the planner may elect to relax certain constraints to decrease the number of changeovers.

3. Capacity Utilization - When demand is outpacing supply, this number will be extremely high, which is the current state of JJVC. The target is around 85%, but the current actual is nearly 100%. It is important that the capital planning teams use this FICO tool to assist in anticipating future manufacturing line purchases. While there would be an extra capital cost to "buying" that extra 15% average extra capacity (100% minus 85%), it is far outweighed by the capability to produce to plan as well as well as to lower inventory level targets.

4. Multi-Scenario Summary - The planners have discretion to re-run the optimization scenario if they are unsatisfied with any of the above results. The manual requirements of this job responsibility can add multiple manhours per week.

5. SKUs below minimum days of supply – This is a simple summation that is tracked and the trends are followed to determine if any brands are falling behind schedule.

### 3.2.3 Input Spreadsheet

A large amount of manual interaction by the planner is required to prepare the Excel input file to be uploaded by FICO. Every week, the planner for each brand must manually update three main templates. First the planner has to access the "gFPS" website (the internal system that interfaces with the manufacturing floor) to copy and paste the remaining week's schedule into Excel. The planner also has to filter and move certain columns around to ensure the format will be recognized by FICO. Second, the planner then has open the JDA files (demand files from the global planning team) and paste the future demand files into Excel and ensure proper formatting. Third, the planner then also has to communicate with multiple parties to determine how much downtime is planned for each of the manufacturing lines.

The planner also must note if any changes have occurred in the past week on the manufacturing lines, including SKU-to-line assignments, each SKU's line preference, production rates, changeover times, maximum run times, minimum lot sizes, and any other variables that will affect the scheduling process.

There is potential to reduce the manual requirements that each of the above steps requires. Benefits to improving this process include reduced amount of stress and work-hours for the planners, less likelihood for manual errors, and a transparent system for plant management to make more informed decisions.

### 3.2.4 Jonova

Global planning uses an in-house model to determine minimum and maximum days of supply for each brand. Those targets are then uploaded to Jonova, which is a web-based software package that stores and tracks inventory levels within JJVC. An example range was shown in the Constraints definitions in Section 3.2.1 (Figure 3-3).

The model considers multiple inputs for each brand, including the desired type II volume fill rate, average demand, variation of demand, the order interval (time units), processing/manufacturing time, transportation lead time, shipping days per week, standard inventory cost per lens (USD), holding cost rate, and production capacity (lenses/time).

The model uses the following supply chain equations to set optimal target inventory levels for each brand with modifications in the Jacksonville distribution center:

**Expected Inventory Levels:**

$$Pipeline\ Stock\ (\#\ of\ lenses) = L * \mu \tag{3-2}$$

$$Cycle\ Stock\ (\#\ of\ lenses) = \frac{r*\mu}{2} \tag{3-3}$$

$$Safety\ Stock = z * \sigma\sqrt{r + L} \tag{3-4}$$

**Where:**

$L$ = Processing time (weeks)
$\mu$ = Average weekly demand (lenses/week)
$r$ = Order placement interval (weeks)
$z$ = Inverse of the standard normal cumulative distribution, with a probability of the desired **service level**
$\sigma$ = Standard deviation of weekly demand (lenses/week)

Therefore, the expected inventory level for each brand, with simplified assumptions, is calculated by the following:

$$Expected\ Inventory\ Level = Cycle\ Stock + Safety\ Stock \tag{3-5}$$

$$= \frac{r*\mu}{2} + z * \sigma\sqrt{r + L} \tag{3-6}$$

The previous equations can assist the inventory planners in setting optimized inventory levels for each brand. However, these base levels are typically set using one service level. As the optimization model continues to evolve, the net effect of changing service level at the SKU level will be calculable. Some SKUs within each brand have a very low demand and are referred to as "tail-end SKUs", meaning they are only used by consumers with either very high positive or very low negative correction factors. While there are many business reasons that JJVC wants to continue providing for these tail-end users, it comes with a higher cost per-lens to due shorter production batches. JJVC can reduce this cost by employing one or both of the following options: 1) Change the safety stock policy for tail-end SKUs. The safety stock can be increased to maximize the lot size, which will have a minimal holding cost effect since demand volume is low; 2) Relax the inventory constraint in the model. To relax the inventory constraint in the optimization model, the service level for these tail end SKUs can be reduced. There are risks and benefits to reducing tail-end SKU service levels:

*Risks:* The major risk is the potential of losing customers and even ECPs or distributors who are upset with not receiving the same level of service as other customers. Since the inventory for the above calculations is only for Jacksonville though, a reduced service level to distributors may be offset by increasing inventories at warehouses down the supply chain network (at an increased cost to them).

*Benefits:* Two major benefits will arise. First, more lenses will be produced because there will be less downtime required for changeovers to produce the tail end SKUs. And second, there will be less inventory cost. The equations below show how the cost saving potential is derived. Note that the safety stock equations - Equations (3-9) and (3-12) - are the only two that contain the service level factor. However, the pipeline and cycle stock costs are also important costs to consider for the entire value chain.

**Inventory Investment** (total dollar value of contact lenses in inventory):

$$Value\ of\ Pipeline\ Stock\ (\$) = \frac{c_{in,i}+c_{out,i}}{2} * L * \mu \qquad (3\text{-}7)$$

Note: This equation assumes the costs are linear across the lens production stages, which is a reasonable, given the short amount of time between each stage. Figure 3-2 above along with the rate of production (in lenses/hr) help illustrate this.

$$Value\ of\ Cycle\ Stock\ (\$) = c_{out} * \frac{r*\mu}{2} \qquad (3\text{-}8)$$

$$Value\ of\ Safety\ Stock\ (\$) = c_{out} * z * \sigma\sqrt{r+L} \qquad (3\text{-}9)$$

**Where:**

$c_{in,i}$ =incoming cost **per lens** to stage "i" (total cost input into each lens prior to stage "i") (\$/lens)

$c_{out,i}$ = total outgoing cost **per lens** to stage "i+1" (\$/lens)

**Inventory Holding Cost** (the expected average amount of value lost in holding inventory over a defined length of time):

$$Pipeline\ Stock\ Holding\ Cost\ (\$) = h * \frac{c_{in,i}+c_{out,i}}{2} * L * \mu \qquad (3\text{-}10)$$

$$Cycle\ Stock\ Holding\ Cost\ (\$) = h * c_{out} * \frac{r * \mu}{2} \tag{3-11}$$

$$Safety\ Stock\ Holding\ Cost\ (\$) = h * c_{out} * z * \sigma\sqrt{r + L} \tag{3-12}$$

**Where:**

$h$= inventory holding cost rate (%)

## 3.3 Access to Model and Software

### 3.3.1 Test Version

Due to intellectual property censoring, running FICO for this project was limited to the standard testing model, meaning that certain features were disabled. The main hindrance this created was disabling the ability to change the weights of the variables in the objective function. However, most other inputs were able to be manipulated through running macros. Figure 3-4 shows the complete FICO optionality available to planners with full-access.

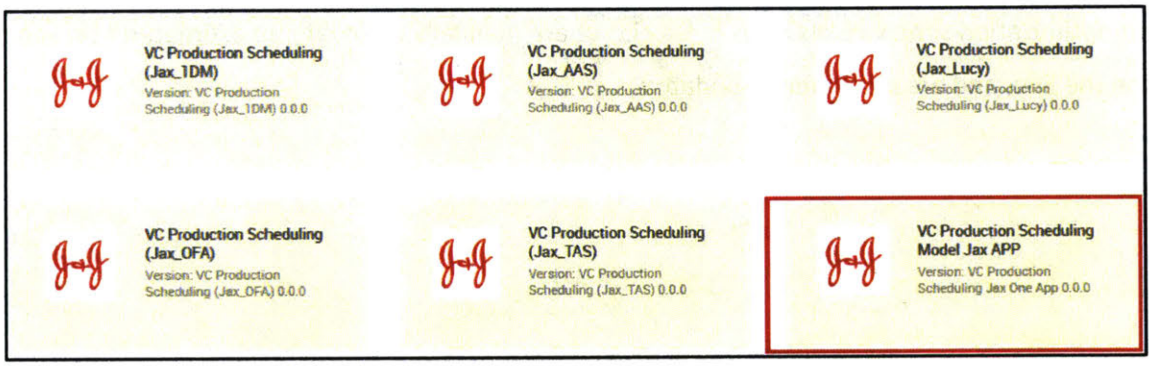


Figure 3-4: Different Access Required for Each Brand

## 3.4 Model Capabilities and Assumptions

### 3.4.1 1-Brand Planning

One of the limitations of this model is that the brand-to-line assignments for each week are preset by the global production planners. As previously mentioned, certain lines are able to produce SKUs of more than one brand. The months to run a brand on each line is not determined by the weekly production planners, so the model operates within this constraint. The frequency and length of brand changeovers varies for each line, but each changeover requires multiple months to shut down, retool, validate, and ramp-up production (the exact times cannot be shared per JJVC confidentiality guidelines).

It may be possible to adapt the FICO production model to determine the optimal months to switch-over production by increasing the planning horizon. Extensive new coding would be required though, and the length of time to convert a line to a new brand would need to be defined for each scenario.

### 3.4.2 Manual Process and Recommendation

Each planner is responsible for scheduling production lots for one or more brands. The number of brands for each planner depends mainly on the complexity of the brand (i.e. number of SKUs). The current manual process of copy and pasting data from multiple sources into Excel consumes the planners' time, and it creates the potential for human error. There is also no way to validate that the schedule is optimized. Skilled planners can typically notice if the output looks "off" though.

With the rise in accessibility to machine learning (ML) software, JJVC will be able to invest in software to truly optimize both the process of scheduling and the schedule itself. As observed in the later in Section 4.2 (Sensitivity Analysis), the rate of production on each line (in lenses per shift or lenses per hour) has a large effect on schedule optimization. ML software will be able to calculate actual rates and use a feedback system to determine which SKUs should be scheduled on each line in the future. The current optimization simply reads rates in Excel that are manually input, are an estimated average of all SKUs on the line, and are infrequently updated.

# 4 Manufacturing Fleet Flexibility and Optimization

## 4.1 Current Flexibility (Runnable and Validated SKUs)

The first constraint studied at the Jacksonville manufacturing site was the "runnable" vs "validated" SKUs for each brand and each manufacturing line. The percentage of runnable vs validated is only 73%, meaning that 27% of the prescriptions (i.e. SKUs essentially) that J&J invested time and money to validate cannot be produced on certain lines due to manufacturing issues. Section 4.1.2 drills down into the brand, GT, and specific line "runnable" flexibility. The impact of these constraints is quantified to identify improvement opportunities in Section 4.2.

### 4.1.1 Validation Process

A significant investment in time is required to validate a range of SKUs on each line to meet government qualification criteria. Each additional validation has the opportunity cost of producing lenses, so it is critical to *only* validate the SKU ranges that will create long-term value. Depending on the brand, the number of SKUs to be validated ranges from 120 (for spherical brands) to 4,860 (for astigmatism brands).

### 4.1.2 Runnable and Validated SKUs

The more lines that are validated to produce each SKU, the less constrained the scheduling optimization model is, and therefore the weekly capacity can increase. However, after validating each SKU range, sometimes a line cannot physically produce the lenses (e.g. due to machine breakdowns or defects in the finished product that didn't surface during the validation). When a certain SKU range is deemed "unrunnable", the planner will remove the range from the model, effectively constraining it. The number of runnable versus validated SKUs for each brand and each line had not been tracked, so the following four graphs provide that information to the JJVC management team. This data can be used to determine which brands and lines are the biggest issues. It can then be determined how much capacity can be freed up if the un-runnable constraints are removed.

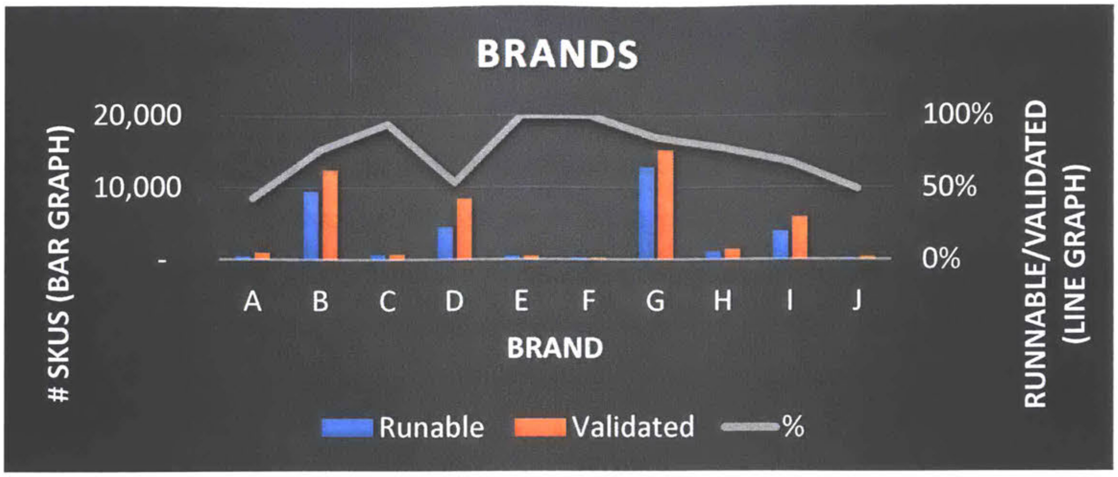


Figure 4-1: Percentage of Runnable SKUs is Under 100% for All Brands Except Two

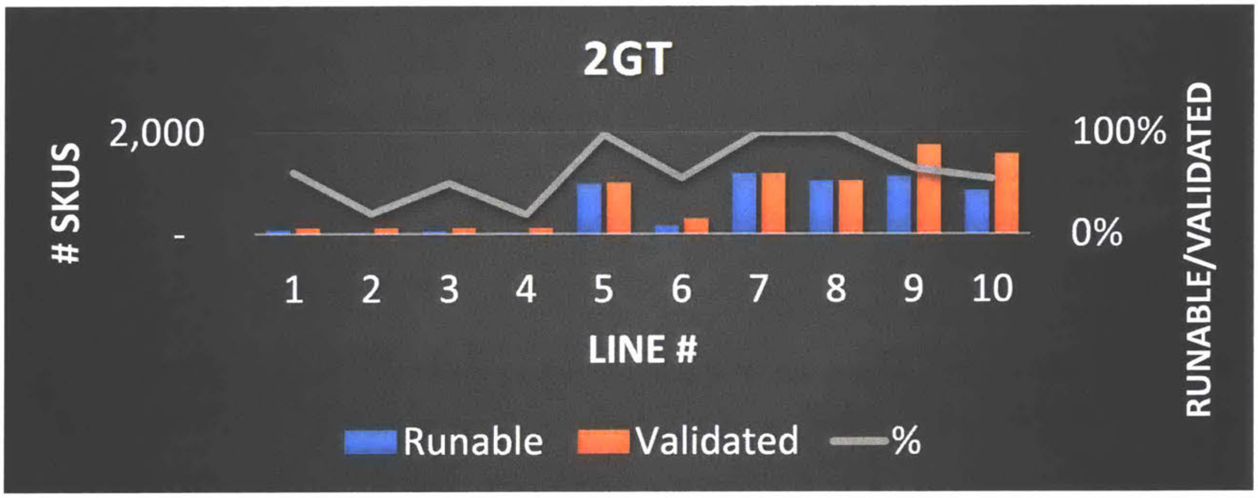


Figure 4-2: Wide Variation of Runnable to Validated SKUs on 2GT Platform

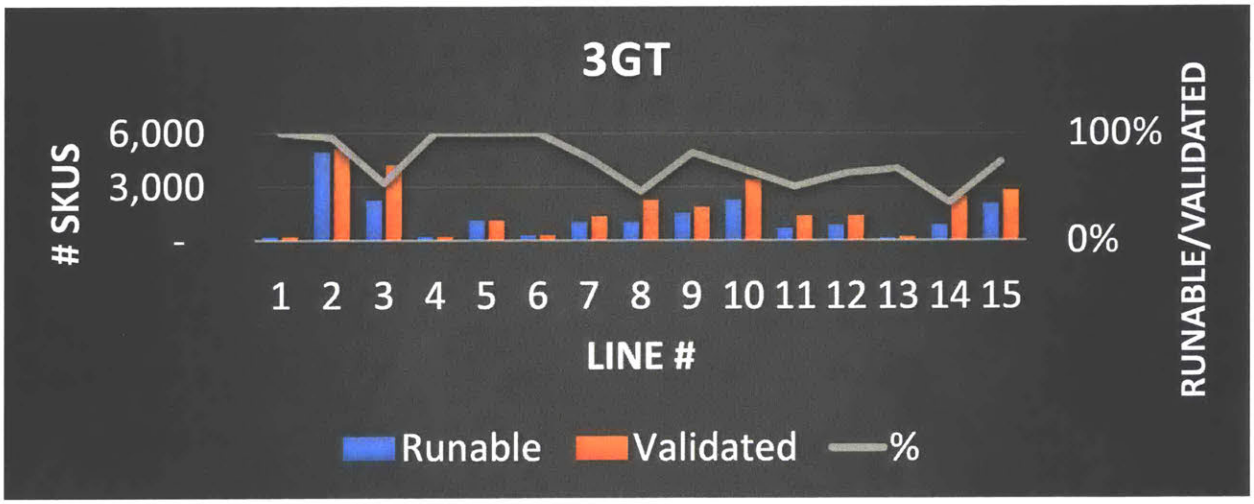


Figure 4-3: Multiple 3GT Lines Operating Under 75% Runnable to Validated

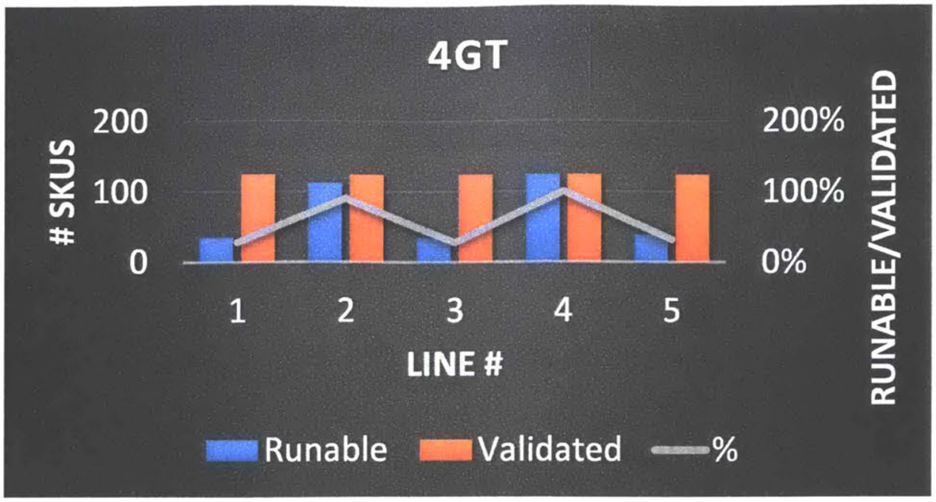


Figure 4-4: Lines 1, 3 and 5 Have Very Low Runnable Percentages

## 4.2 Validation and Sensitivity Analysis

In addition to running a sensitivity analysis on the runnable vs validated lines, multiple inputs are analyzed in this section. To validate the data accuracy, the model was run multiple times for multiple weeks to confirm that the results were identical. The model produced a production schedule that ordered the same during repeat calculations. While only the Acuvue Oasys for Astigmatism (OFA) brand was modeled due to the software's limitations discussed in Section 3.4, the same process can be repeated for any existing or new brand.

The sections below examine the effects of changing characteristics in the production process. While the changes to the inputs are hypothetical, the expected change in results can be assumed to be accurate due to the validation described above. It would also be possible to analyze any other combination of scenarios that JJVC is interested in exploring.

### 4.2.1 Capacity and OEE

The capacity of the plant has the largest and most direct effect on production output. However, the demonstrated capacity does not equal the actual volume of lenses that the plant will produce. Plant Overall Equipment Effectiveness (OEE) will determine the actual amount of lenses able to be produced. OEE "identifies and categorizes major losses or reasons for poor asset performance. It provides the basis for setting improvement priorities and beginning root cause analysis. OEE also fosters cooperation and collaboration between operations, maintenance and equipment engineering to identify and reduce and/or eliminate the major causes of poor performance." [8] OEE is defined by:

$$OEE = Availability\ (\%) * Performance\ Efficiency\ (\%) * Quality\ Rate\ (\%) \quad (4\text{-}1)$$

**Where**: $$Availability\ (\%) = \frac{Uptime\ (hrs)}{Total\ Available\ Time\ (hrs) - Idle\ Time\ (hrs)} * 100\% \quad (4\text{-}2)$$

$$Performance\ Efficiency\ (\%) = \frac{Actual\ Production\ Rate\ (\frac{Lenses}{hr})}{Best\ Production\ Rate\ (\frac{Lenses}{hr})} * 100\% \quad (4\text{-}3)$$

$$Quality\ Rate\ (\%) = \frac{(Total\ Lenses\ Produced - Defective\ Lenses\ Produced)}{Total\ Lenses\ Produced} * 100\% \quad (4\text{-}4)$$

**And:** $$Uptime = Total\ Available\ Time\ (hrs) - [Idle\ Time\ (hrs) - Total\ Downtime\ (hrs)] \quad (4\text{-}5)$$

$$Total\ Downtime = Scheduled\ Downtime\ (hrs) + Unscheduled\ Downtime\ (hrs) \quad (4\text{-}6)$$

To help understand this OEE, Figure 4-5 has been provided to visualize the mechanics of the calculation. Note that the "Total Available Time" can be any length chosen by the user. Additionally, Table 7-3 in the Appendix provides a full walkthrough of how to calculate OEE on a lens production line. According to the Society of Maintenance and Reliability Professionals, the best-in-class target OEE value for batch-type manufacturing is above 85%.

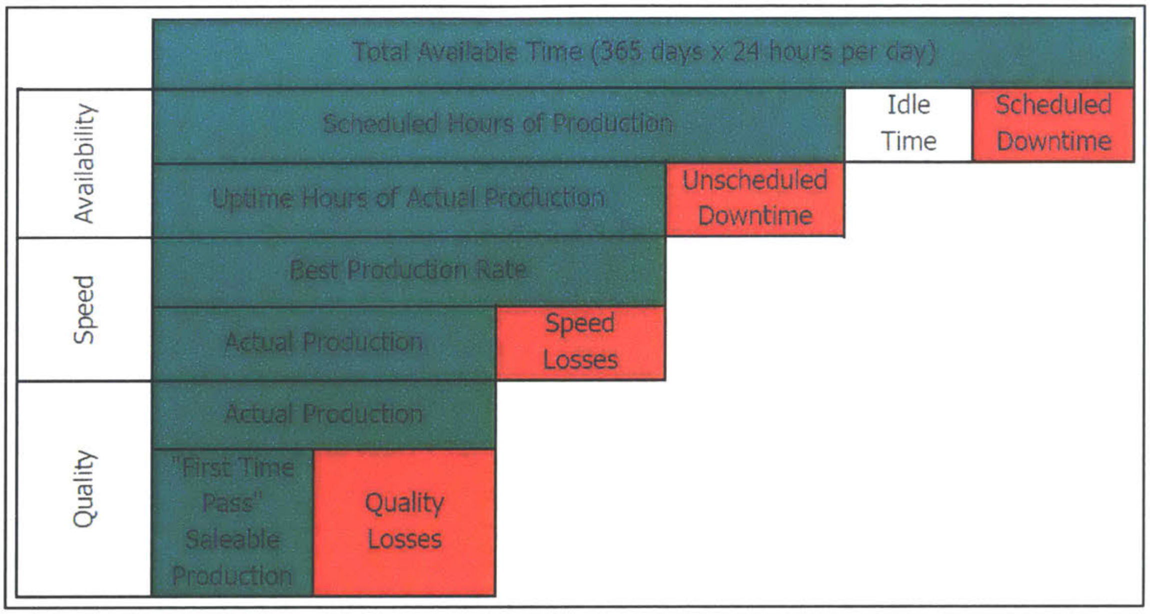


Figure 4-5: Overall Equipment Effectiveness Visual Calculation [8]

Due to the availability, speed, and quality effects within the OEE calculation, a manufactured-lenses output profile over a 15 day period looks like the profile shown in Figure 4-6, where efficiency losses are displayed in the green area. Improving OEE will increase capacity and lower costs. Shown in Figure 4-7, by increasing OEE, the plant was able to shift from a profile seen on the left to a profile on the right.

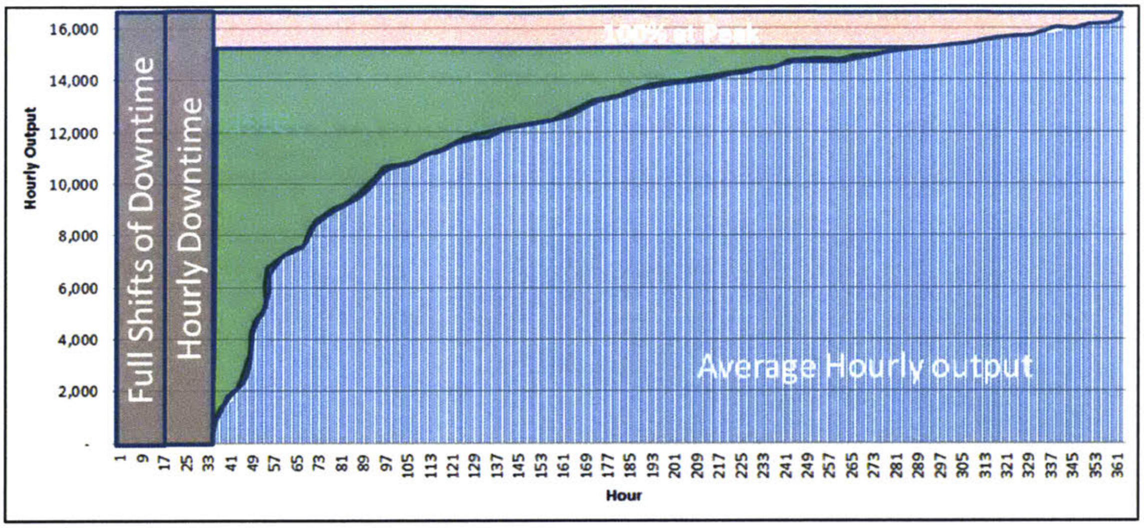


Figure 4-6: Lens Production Profile (15 days)

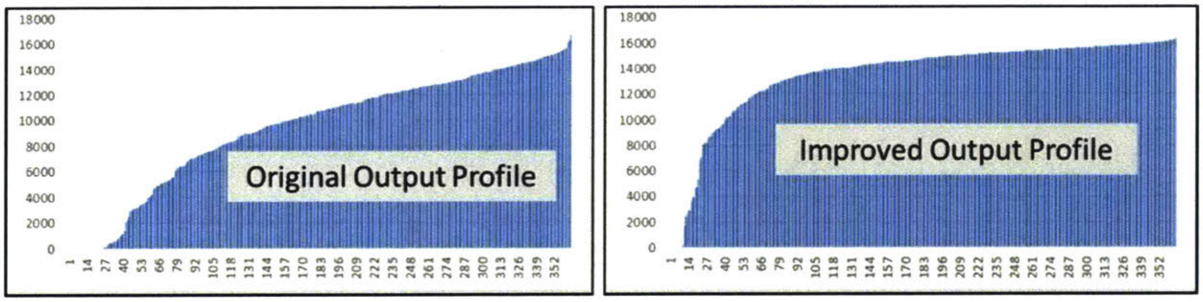


Figure 4-7: Comparing High vs Low OEE Production Lines

Process reliability has a large impact on the plant's OEE. Plant management should have a robust reliability program that trains, tracks, and improves on reliability initiatives. Figure 4-8 summarizes the main causes for downtime across all production lines (the cause type for each percentage is hidden to protect IP). While this tracking program is a great start, there are flaws that must be corrected to provide more accuracy. Depending on the production line, many of the downtime causes are indiscriminately written on paper by the operators and then summed at the end of each shift. This leaves room for plenty of human error. Most of the software that runs the lines can be upgraded or reprogrammed to automatically track downtime and scrap.

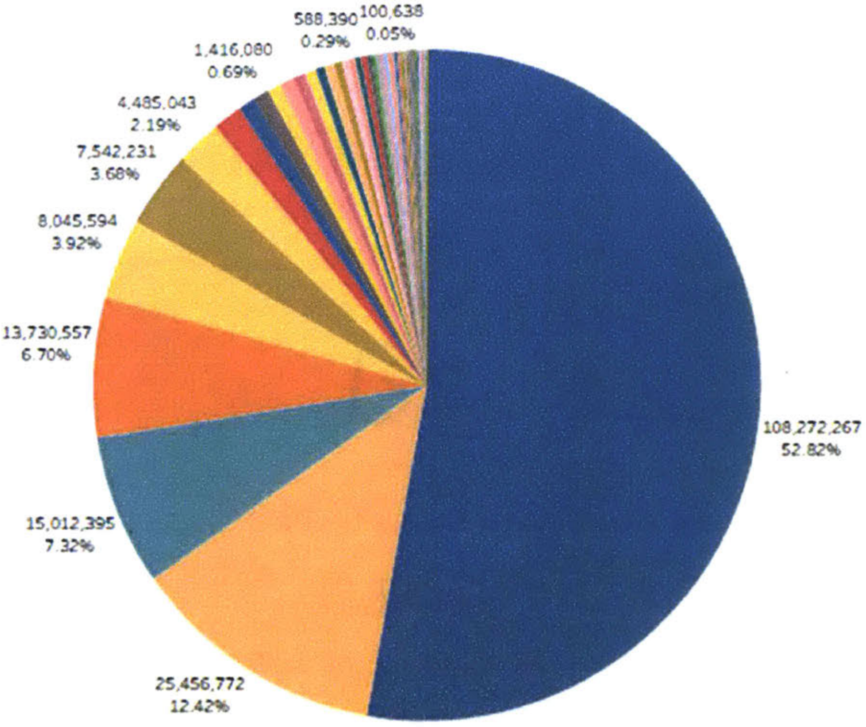


Figure 4-8: One Failure Mode Dominates All Others

### 4.2.2 Changeover Times: Mold, Core, Packaging

A metric that heavily influences the amount of changeover time is how many times each line requires a changeover to produce a different SKU. Figure 4-9 shows the summation of the number of times a SKU changeover occurs across all lines. When the optimization model is yielding efficient production plans, the number of changeovers in this graph will be low, since the main objective of the model is to reduce changeover time. However, the constraints for each week may prohibit a low amount of changeover. Plant management should study why these cases arise and take corrective actions to prevent future inefficiencies.

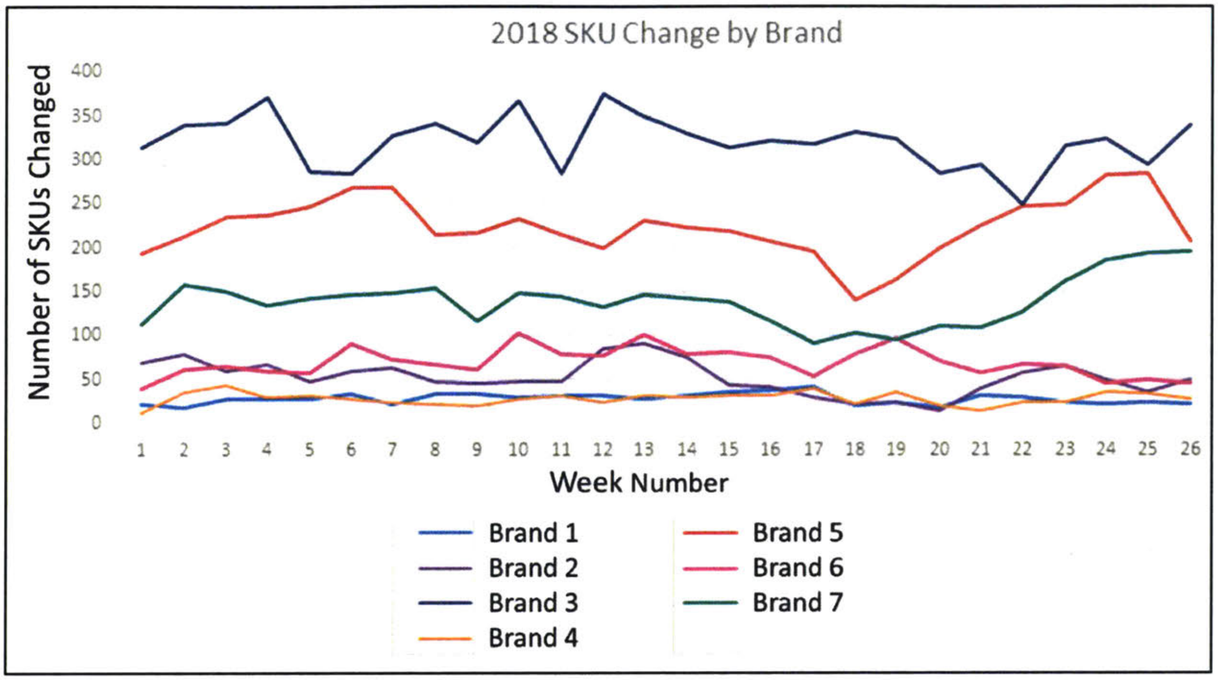


Figure 4-9: Number of SKU Changes by Brand per Week

On a similar note, to validate that the characteristics of each technology are being properly utilized, management should ensure that each GT line is performing as intended. Recall from Section 3.1 (Manufacturing Overview) that each GT has a different volume-to-changeover tradeoffs. The average time to changeover each GT is captured below in Table 4-1. Note that the indirect correlation between production rate and changeover times agrees with the "high-mix, low-volume" designation of 3GT and "low-mix, high-volume" designation of 2GT and 4GT. Another way to view this effect is to determine how many times each line type changes SKUs during a given production window. Figure 4-10 below provides that information. The higher number of changeovers for 3GT (high-mix) confirms the hypothesis that the machine will produce a greater number of SKUs on a weekly basis. Should the number of 3GT SKU changeovers decrease while 2GT and 4GT increase, that is a signal that improvement opportunities exist in the planning system, either at the multi-year level or at the weekly planning level.

Table 4-1: Production Rate vs Changeover Time by GT[4]

| Line Type | Lenses/ shift | Lenses/ hr | Mold Change [min.] | Core Change [min.] | BC Change [min.] |
|---|---|---|---|---|---|
| **2GT** | 100,000 | 8,333 | 20 | 30 | 20 |
| **3GT** | 50,000 | 4,167 | 5 | 20 | 15 |
| **4GT** | 200,000 | 16,667 | 30 | 45 | 45 |

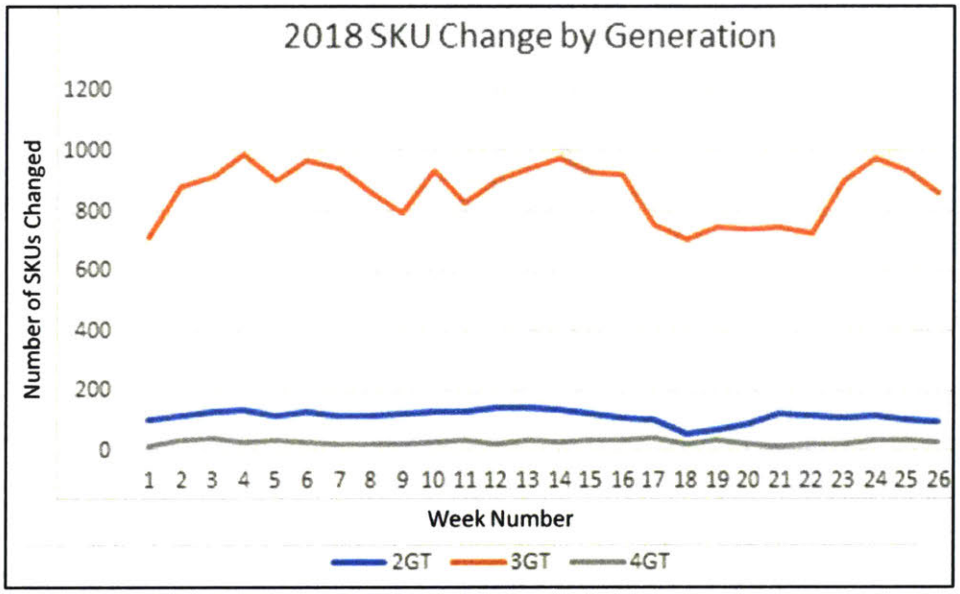


Figure 4-10: Number of SKU Changes by GT per Week

The validated model shows that for a 20% reduction in the baseline changeover time for the mold, core, and base curve, an increase of 0.5% production capacity should be realized (for Oasys for Astigmatism).

### 4.2.3 Rate (Lenses per Shift)

The number of lenses per shift is a metric that all production managers should track, and running a sensitivity analysis on this input gave interesting results. When the lenses per shift rate increased just 10%, the number of lenses produced in the week increased about 15%. Also, increasing the rate by just 20% increased the weekly output by about 30%. This network effect is important to model when purchasing new lines, as discussed in the next section.

---

[4] Actual data censored to protect IP. However, the general magnitude and trends of the data displayed is accurate.

### 4.2.4 Minimum Lot Sizes

Each brand and line has a minimum lot size constraint. For OFA, there was no significant change in the number of lenses produced when increasing the minimum lot size from 5,000 to either 2,000 or 8,000. This is evidence that minimum lot size is not a limiting constraint (for OFA). However, this constraint may become a factor for other brands. Regardless, it may be worthwhile for JJVC to eliminate this constraint because the optimization function should automatically determine the smallest lot size, assuming the code is properly written.

### 4.2.5 Planning Horizon

Increasing the planning horizon to 2 and 3 weeks also showed no significant change in the number of lenses produced. This is most likely because the OFA brand's demand is greater than capacity, so the optimization function favors decreasing the backlog over increasing asset utilization via large batch sizes. Brands that are not supply-constrained would most likely benefit from an increased planning horizon.

### 4.2.6 Changing Objective Function

Changing the weights of the three variables in the objective function code would enable a deeper understanding of the tradeoffs between capacity, inventory, demand response, changeover times. As mentioned in Section 3.3.1 however, changing the objective function in the test version of FICO is disabled. Internal J&J employees with full FICO access may benefit from exploring this opportunity.

## 4.3 Outcomes and Interpretations

Any of the above scenarios can be combined and re-calculated to determine the overall effect of production capacity. This will be important for justifying improvement projects and for determining capital expansion needs. Continuous investment required to maintain 10-15% buffer capacity. Each new line and retrofit's costs vary as well as the amount of time required to build. Using the projected supply and demand gap data from Figure 4-11, a capital investment outlay can be created.

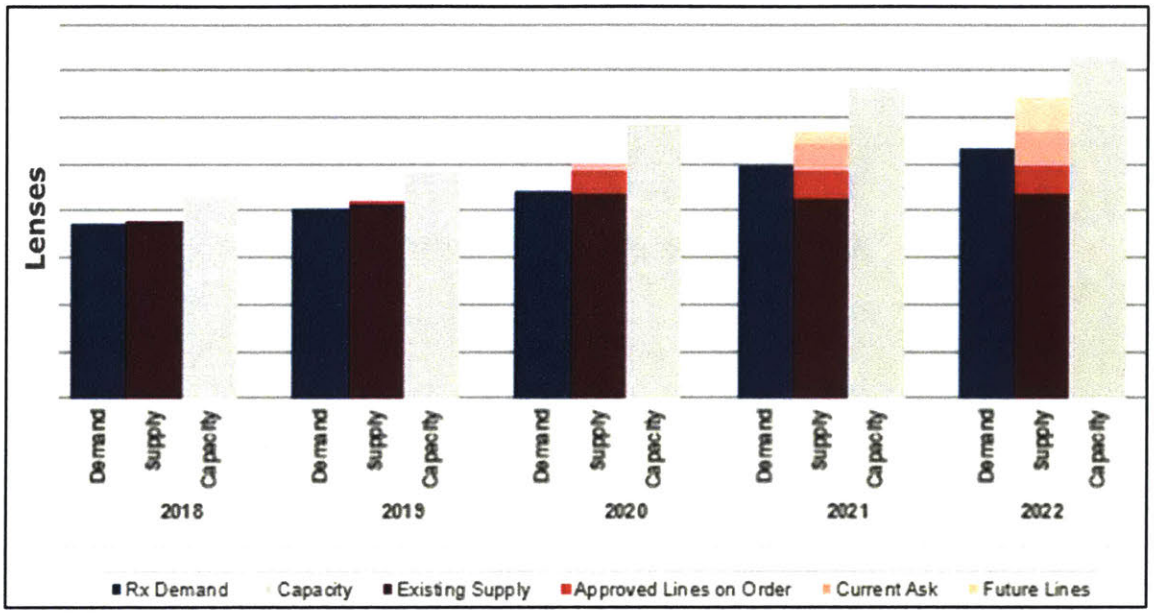


Figure 4-11: Creating the Demand-Capacity Buffer[5]

The optimal type of lines (high-mix, low-volume or low-mix, high volume) should be determined by running the optimization scenarios used above along with the following optimization calculation [9]:

$$Minimize\ Cost = \sum_{m} C_m x_m + \sum_{m} \sum_{n} g_{mn} x_m y_{mn} \tag{4-7}$$

Subject to the constraints:

$$\sum_{m} x_m y_{mn} = F_n \quad for\ all\ m, n$$

$$y_{mn} \geq 0 \quad for\ all\ m, n$$

$$x_m = 0, 1 \quad for\ all\ m$$

Given:

$C_m$ = Incremental capital investment required to produce a brand at plant location *m* (Jacksonville, Ireland, or a new location);

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[5] Actual numbers not used for IP protection.

$g_{mn}$ = Cost of making one lens of the brand at plan *m* and transferring it to the distribution center *n* for delivery to the final customer. If *m=n*, the transfer cost is zero.

$F_m$ = Forecast demand in the region of the world that plant *m* services, during the economic life of the capital investment.

$$x_m \begin{cases} = 1, \text{if the brand is assigned to plant } m; \\ = 0, \text{otherwise} \end{cases}$$

$y_{mn}$ = Production at plant *m* to fill demand in the distribution center *n*'s region.

The cost of making one lens at Jacksonville and delivering it to a specific distributor, *n*, ($g_{mn}=g_{Jacksonville,\ n}$) for this optimization is explored in-depth in Section 4.4 (Cost Modeling). Running the above optimization will produce a forecast capital purchase and installation plan such as in the example shown in Figure 4-12. The accuracy of the optimal solution improves with the accuracy of the forecast demand, $F_m$, so the capital planning team should re-run the analysis on a quarterly to yearly basis as global demand projections are updated. The optimization model must also be used when calculating the estimated additional capacity created by installing a new line. The additional capacity created by each new line will actually add a higher percentage than assuming the same output of the existing lines. Adding a new line relaxes the constraints by reducing the required changeover time required to produce to demand. Each line may be able to run longer lots or produce batches with the same molds.

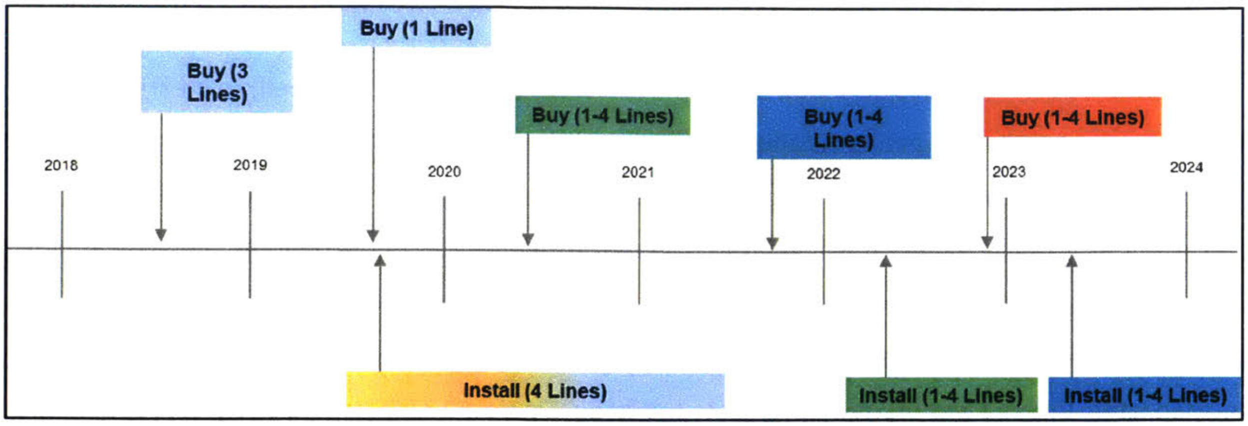

Figure 4-12: Capital Ask Projection Timeline for a Specific Location[6]

## 4.4 Cost Modeling

Increasing the amount of contact lenses produced by the methods described above is a worthy goal. But how does this effect the financial results of the company? To truly understand how the initiatives described above improve both revenue and costs, a clear understanding of the profitability of each lens must be considered before JJVC management makes high-level strategic decisions. The data collected had to be structured in a way that key insights could drive strategic actions. To make this possible, a Total Delivered Cost (TDC) model was developed and published a for the Contact Lens supply chain.

At a high-level view, the cost to produce the lenses may seem straight-forward; the unit lens cost would be calculated:

$$Unit\ Lens\ Cost = \frac{Total\ Fixed\ Costs + Total\ Variable\ Costs}{Total\ Lenses\ Produced} \tag{4-8}$$

$$= \frac{People + Equipment + Materials + Utilities + Other}{Total\ Lenses\ Produced} \tag{4-9}$$

However, there are many factors within both fixed and variable costs that are difficult to assign to specific brands and SKUs. Most brands share resources in the entire value chain (e.g. people, machines, labs, utilities, marketing, etc.), so creating accurate and fair cost allocations can be difficult and result in disagreements between management. The assumptions, sources, and methodology of how each cost was allocated is defined below in Section 4.4.1 (Cost Drill Down).

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[6] True requirements not shown to protect IP.

### 4.4.1 Cost Drill Down

This model integrates data from three main sources (Make, Serve, and Sell) to create a full end-to-end supply chain tool, creating visibility and granularity by pack size, brand, geography, and more. The *Cost to Make* includes the traditional costs of goods sold, including material costs, depreciation, overhead, repackaging, downtime, and scrap. The *Cost to Serve* includes distribution, transportation, and customer service. The *Cost to Sell* includes the overall P&L. Each of these three sources and their sub-sources uses their own software packages, which makes creating a data pool difficult to manage. As detailed later, Tableau was utilized to alleviate this issue. Figure 4-13 is provided to show the high-level cost categories that were divided into the additional categories that JJVC management was interested in analyzing.

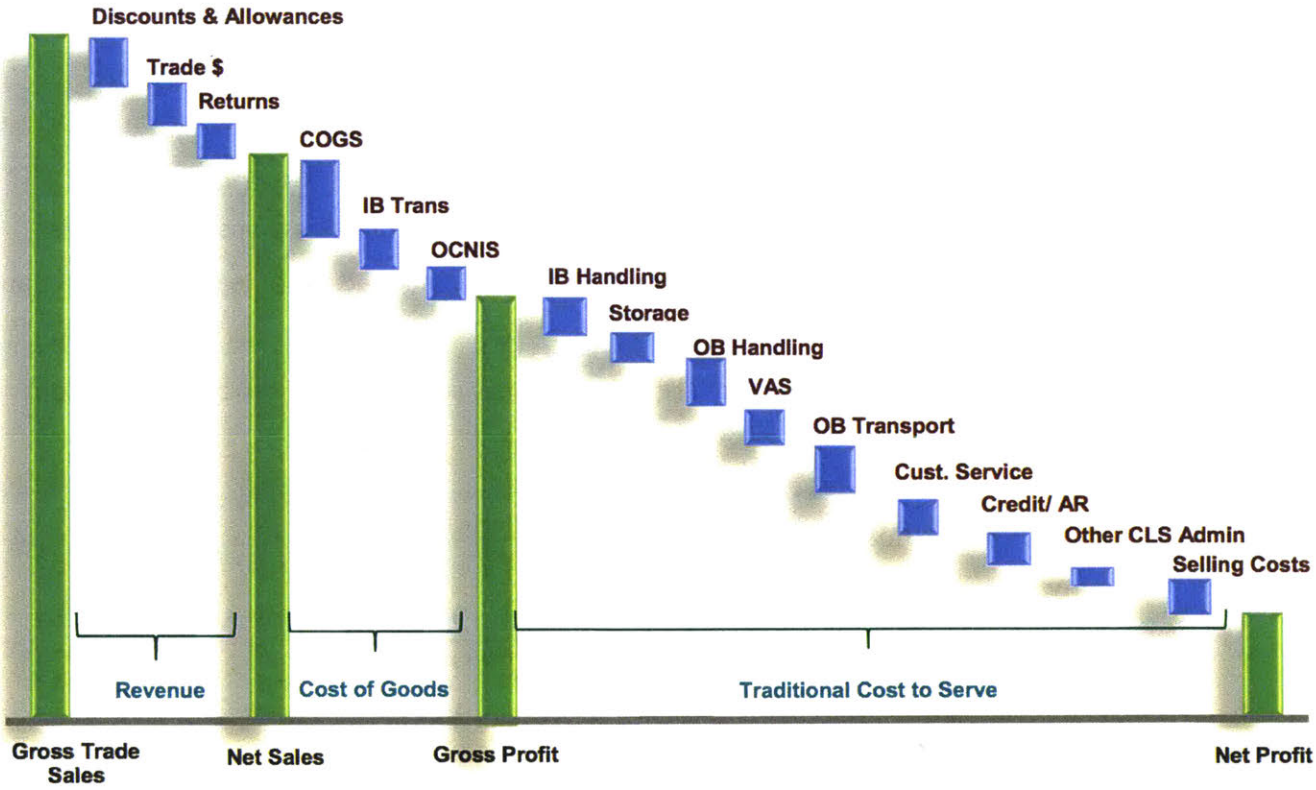

Figure 4-13: Total Delivered Cost Model – Waterfall Chart[7]

The waterfall chart above shows the aggregate sum of all SKUs. The most powerful part of the TDC tool though is the ability to drill-down to a granular level. The user can filter by year, region

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[7] Not to scale.

(Canada, Latin America, Europe-Middle East-Asia, Japan, Pacific Rim, and USA), country, brand, platform (astigmatism, beauty, presbyopia, sphere, daily disposable, and reusable), Dx:Rx ratio (explained after Figure 4-17), pack size, and manufactured location (Jacksonville or Ireland). Key examples of these drill-downs are displayed in the following sections.

To arrive at the gross profit and net profit figures for each of the combinations of the variable just listed, the following definitions and assumptions were made:

> The Gross Trade Sales figure is determined by multiplying the number of Rx lenses sold by the average selling price (ASP). To arrive at Net Sales, any sales discounts/incentives/ promotions and any trade related adjustments (i.e. deviation from foreign exchange hedging) are subtracted from the Gross Trade Sales.
>
> Cost of Goods Sold (COGS) contains many elements within the manufacturing facilities. Some elements are easy to allocate to specific SKUs/brands, whereas others use managerial accounting assumptions and rationale. The assumptions and rationale are included after each element in parentheses. The main COGS elements are: raw materials, machine/equipment depreciation (specific to the GT and allocated by the number of shifts), hourly labor (specific to GT and allocated by number of shifts), production overhead (allocated by GT), scrapped lenses, and repackaging. Inbound transportation accounts for all the costs associated with transporting material or products to JJVC-owned facilities (i.e. not to customers). Other costs not in standard (OCNIS) is an accumulation of costs that are difficult to attribute to a specific item. The sum of all COGS, inbound transportation, and OCNIS are subtracted from Gross Trade Sales to yield Gross Profit.

### 4.4.2 Tableau

Summing the profits and losses from each category is important and necessary, but that information is stagnant and only provides high-level information. Therefore, the main objective of this cost modeling project was to develop an easy-to-use tool to deep-dive into any cost or revenue-generating element. To achieve that goal, interactive visual representations and simulation models of supply chain design options were designed using Tableau business intelligence (BI) data visualization software. Tableau is a powerful tool that enabled the creation of interactive visualizations to communicate the cost analysis. The tool was designed so that anyone within the organization can be given access to drill-down into the data. [10] Other BI and visualization software packages are available, but as Gartner advises, Tableau is a leader in the field. Additionally, other departments within JJVC use

Tableau, so the knowledge transfer was easy and there was minimal additional licensing costs. Figure 4-14 identifies other BI packages available on the market. Some of the displayed software packages may better match another organization's needs and cost restrictions.

Figure 4-14: Analytics and Business Intelligence Platforms [11]

The back-end features within Tableau allowed the team to integrate "silos" of information from multiple sources. Each organization department uses difference source systems, but Tableau is able to read and automatically update the integration of these data sources. For the *Cost to Make*, which, the main source systems are electronic device history records (eDHR) and manufacturing execution system software (MES). The *Cost to Serve* stores data on SAP BI and an internal warehouse management system. The *Cost to Sell* also uses SAP BI as well as IBM Cognos TM1 software.

Management and other key decision-makers now have the ability to analyze multiple key financial metrics across the entire value chain. The Tableau dashboards were created with the end users in mind, and a few examples are shown and explained below. A Tableau version of the waterfall chart displayed earlier is shown in Figure 4-15. The user now has the ability to sum cost categories down to very granular levels: A feature that adds a large benefit for JJVC users is that he or she can easily access the filter shelf (shown on the left side). This allows anyone with this tool to drill-down to a specific region, country, platform, brand, beauty type, and pack size. Summary statistics are also shown in the upper right side. Additionally, the top and bottom gross margin performers are highlighted on the lower right side, which will help managers and analysts decide where to focus.

Figure 4-15: Waterfall Dashboard on Tableau

Figure 4-16 is a view of the countries where JJVC sells contact lenses. Not shown in the figure is the filter bar that also allows the user to drill-down to certain elements, such as pack size, brand, or time. The graph automatically updates as the filters are selected, giving the user insight into trends and patterns on an easy-to-interpret global dashboard.

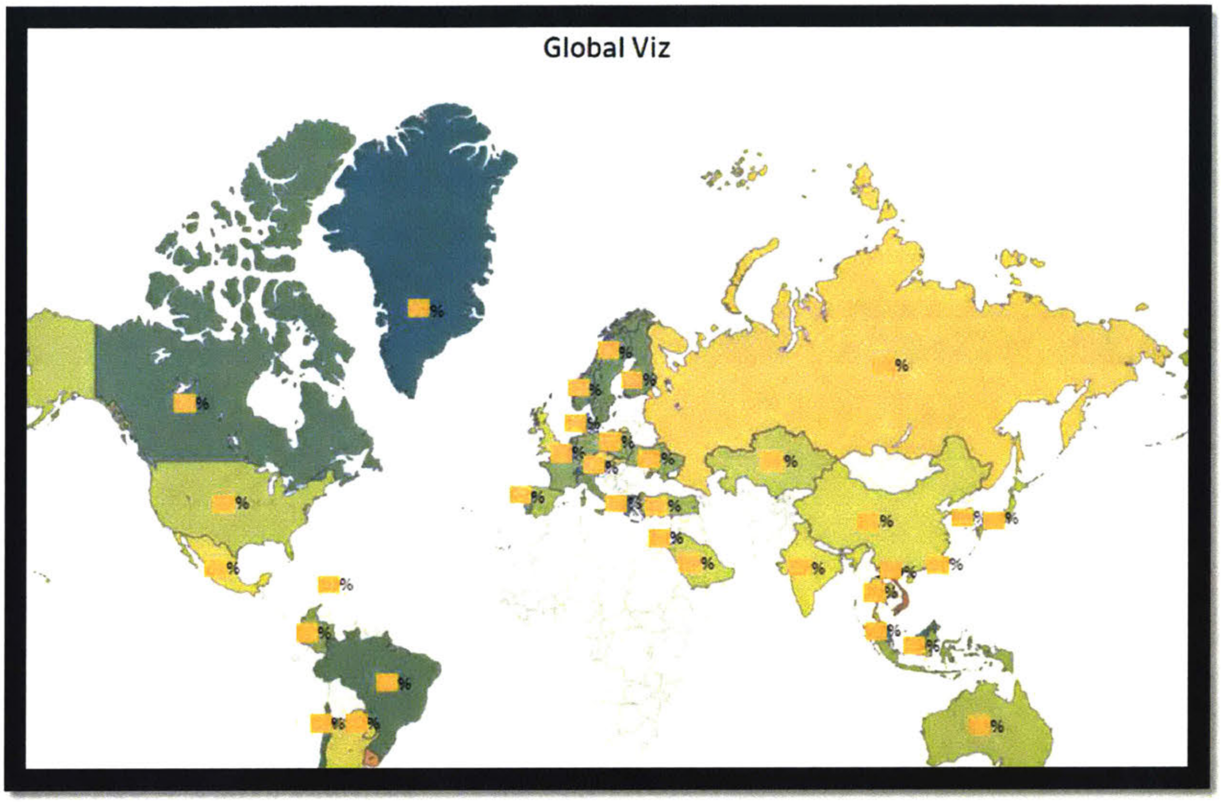

Figure 4-16: Gross Margin Breakdown by Country (All Brands)

As discussed in the fleet flexibility optimization sections, each of the manufacturing lines has constraints that limit the machine's ability to produce certain SKUs. One of the impacts of these constraints is the requirement to repackage certain SKUs. For example, a customer may want prescriptions in a 90-pack, but the manufacturing lines running are only arranged to make 30 packs. Therefore to fill the customer's order, the 30-packs are sent to the distribution center, the lenses are removed from the box and combined with lenses from two other 30-packs, and then those 90 lenses are packaged into a 90-pack box. Repackaging machines have been installed in the Jacksonville distribution center to expedite the process, but costs are stilled incurred. Figure 4-17 allows management to quantify the effect of repackaging. Not only does this dashboard raise awareness to the issue, but it also allows management to accurately understand the financial impact when calculating net present value or payback periods for projects that will mitigate the issue.

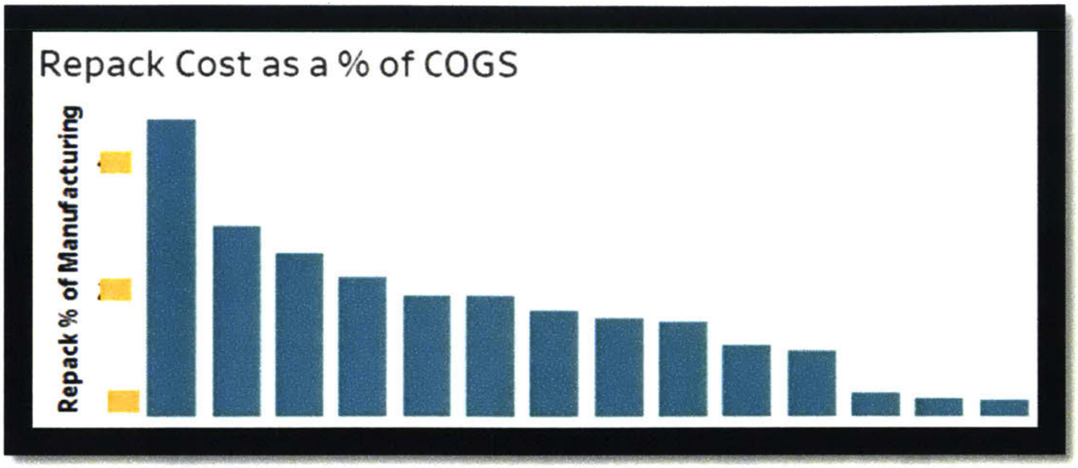

Figure 4-17: Repackaging Costs Dashboard[8]

Dx's are used to attract new contact lens wearers or to try to switch current users to a new brand, whereas Rx's are the lenses actually sold. Fore New Product Introductions (NPI), the ratio of Rx:Dx will be extremely low initially due to the high percentage of contacts that must be marketed. Figure 4-18 shows a screenshot of the dashboard created to visualize this ratio. This dashboard is most valuable when using it to trend the shift over time to predict when Dx's will flatline as it matures in the market. That length of time can be used as a baseline to predict future NPI rollout profitability over a time horizon. The colors are grouped by platform, so management can use the NPI's same cluster to estimate the Rx:Dx ratio over the new brand's lifecycle.

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[8] The x-axis is hidden to censor proprietary brand and package size data.

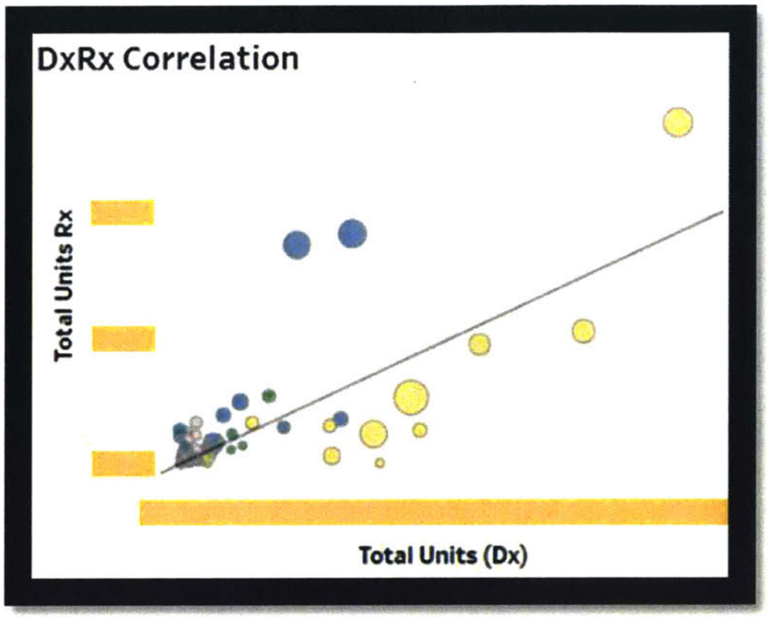

Figure 4-18: Comparing Number of Sold Lenses to Marketing Activity

Figure 4-19 is the last example this paper will provide. The ratio of ASP to COGS can be used to determine when to phase out a brand. When multiple years of data are collected, the brand's data-point will shift left over time, indicating that an NPI is needed recapture the former gross margins. As with the other dashboards, this one can also be filtered to concentrate on specific brands or geographies, etc.

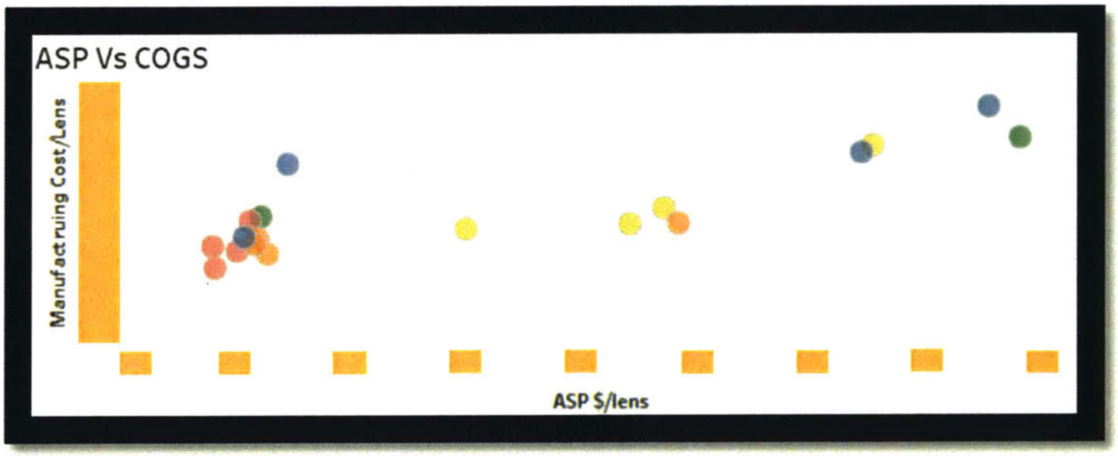

Figure 4-19: Comparing Average Selling Price to COGS

The collection of dashboard examples shown above are only a fraction of those created in the entire TDC model. While the dashboards created provide tremendous insights for JJVC's managers, the tool can be continuously improved. Tableau is developer-friendly, so engineers and analysts within JJVC should be able to create and change the worksheets and dashboards with minimal additional training.

# 5 Conclusion and Learnings

The Total Delivered Cost model offers essential benefits and capabilities for product managers, value stream analysts, and other key stakeholders. The model creates insights by highlighting profitability trends as JJVC grows and the data become more complex. This supports supply chain data management as JJVC continues to roll-out new brands and SKUs, purchase new manufacturing lines, and serve more customers in more territories. This model is scalable and will be a useful tool as the company adds 50 percent more SKUs to its product offering in addition to customized packaging. The commercial team will now be able to better forecast NPI costs as JJVC begins to enter new markets around the globe. The sales channels are evolving rapidly, driven in large part by direct-to-consumer options for customers. The TDC model will enable management to keep a pulse on the profitability of JJVC's new subscription offering and any new e-commerce initiatives. Moving forward, the TDC model will be enhanced by commercial and supply chain projects. For example, JJVC's marketing team recently started tracking consumer experience metrics; those results can be linked to this model's data sources for improved channel strategy decisions. Other departments will also begin to adopt this model.

The cost model will help the production planning and capital purchasing teams when calculating the return on future projects. Even large and sophisticated companies such as J&J are using manual processes (i.e. Excel planning input files), meaning that there is still significant opportunity to implement technology that has been adapted by other industrial companies. With the increase in accessibility to machine learning, JJVC will be able to invest in software to further optimize the scheduling process. When an easier-to-use optimization tool is implemented, the capital planning team will be able to create forecasts with a higher degree of certainty. Inventory planning can also set ideal inventory levels for each brand. However, these base levels are typically set using one service level. As the optimization model continues to evolve, the net effect of changing service level at the SKU level will be calculable. Some SKUs within each brand have a very low demand and are referred to as "tail-end SKUs", meaning they are only used by consumers with either very high positive or very low negative correction factors. While there are many business reasons that JJVC wants to continue providing for these tail-end users, it comes with a higher cost per lens to due shorter production batches. The actual cost of providing to these customers can now be better understood.

The global need for vision correction is projected to increase over at least the next several years. JJVC has positioned itself to remain the leading provider of solutions for patients, but the company must continue to innovate and remain on the leading edge of technology implementation. The tools and analyses detailed in this paper should assist them on that journey.

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# 7 Appendix

Table 7-1: Glossary, Definitions, and Abbreviations

| **Acronym/ Abbreviation** | **Definition** |
|---|---|
| 2GT, 3GT, 4GT… | 2nd, 3rd, etc. Generation Technology (type of manufacturing line) |
| 5S | Sort, Simplify, Shine, Standardize, Sustain |
| ALI | Automatic Lens Inspection |
| ANSI | American National Standards Institute |
| ASP | Average Selling Price |
| BC | Base Curve (of the contact lens) |
| BI | Business Intelligence software (e.g. Tableau) |
| BLOT | Jacksonville Lot (3GT) |
| BOM | Bill of Materials |
| BSI | British Standards Institute |
| BUM | Business Unit Manager |
| CAPA | Corrective Action / Preventative Action |
| CBT | Computer-Based Training |
| CC | Change Control |
| CE | Conformité Européenne: mandatory conformity marking for products in the European Union. |
| CFR | Codification of Regulation |
| CI | Cause Investigation |
| CI | Change Implementation |
| CLOT | Clinical Lot |
| CMMS | Computerized Maintenance Management System |
| CP-ACT | CAPA Activity |
| CP-EFF | CAPA Effectiveness Check |
| CPP | Critical Process Parameter |
| CR | Change Request |
| CTQ | Critical to Quality |
| DC | Document Control |
| DCS | Distribution Computer System |
| DHR | Device History Record |
| DI | De-Ionized Water |
| DLOT | Engineering/Experimental lot (destruction lot) |
| DMAIC | Process Excellence Program (Six Sigma) - Define, Measure, Analyze, Improve, Control |
| DOS | Days of Supply (inventory) |
| ECP | Eye Care Professional (i.e. Ophthalmologist) |
| EDHR | Electronic Device History Record |
| EGOP | Environmental General Operating Procedure |
| FC | Front Curve (of contact lens) |
| FDA | Food and Drug Administration |
| FMEA | Failure Mode Effects Analysis |

| **Acronym/ Abbreviation** | **Definition** |
|---|---|
| FOD | Facility Operations Department |
| GCC | Global Change Control |
| HECP | Hazardous Energy Control Procedures |
| HMI | Human - Machine Interface |
| HR | Human Resource |
| HYD | Hydration |
| IDP | Internal Departmental Procedures |
| IG | Information Guide |
| IMM | Injection Molding Machine |
| IPA | Isopropyl Alcohol |
| IPC | Intrinsic Process Capability |
| IQ | Initial Qualification |
| ISO | International Organization for Standards |
| ITS | Information Technology System |
| JJVC | J&J Vision Care (Vistakon) |
| JLOT | Jacksonville Lot (production) |
| JSA | Job safety Analysis |
| JTA | Job Training Aid |
| Kaizen | Process Excellence Program |
| KPI | Key Performance Indicators |
| LEL | Lower Explosion Limit |
| LET | Line Engineer Tech |
| LF | Lens Fabrication |
| LPS | Lenses per shift |
| LTS | Lot Tracking System |
| MDD | Medical Diagnostic & Devices |
| MES | Manufacturing Execution System |
| METL | Manufacturing Engineering Team Lead |
| MI | Manufacturing Intelligence |
| MOC | Method of Change |
| MP | Manufacturing Procedures |
| MSDS | Material Safety Data Sheet |
| NC | Non Conformance |
| OE | Operational Engineer |
| OEE | Overall Equipment Effectiveness |
| OGSM | Objectives, Goals, Strategies, Measurements |
| OPP | Operational Performance to Plan |
| OQ | Operational Qualification |
| OSG | Operations Support Group |
| PE | Process Engineer |
| PETL | Process Engineering Team Lead |
| PIT | Package Integrity Test |
| PLC | Programmable Logic Computer |

| **Acronym/ Abbreviation** | **Definition** |
|---|---|
| PM | Preventative Maintenance |
| POC | Point of Contact |
| POP | Point of Production |
| PP | Primary Package |
| PPE | Personal Protective Equipment |
| PPF | Preprinted Foil |
| PPI | Primary Package Inspection |
| PQ | Process Qualification |
| PR | Product Release |
| PSM | Process Safety Management |
| PT | Process Technician |
| PTL | Process Team Lead |
| QA | Quality Assurance |
| QC | Quality Control |
| QOTRM | Quality Operations Technical Resource Manual |
| QP | Quality Procedure |
| QSR | Quality Standard Regulation |
| QUMAS | JJVC Quality and Compliance Management Software Document Repository |
| R&D | Research and Development |
| RCI | Root Cause Investigation |
| R-Spec | Raw material specification |
| RTS | Resource Tracking System |
| SFG | Standard Finished Goods Audit |
| SGOP | Safety General Operating Procedures |
| SKU | Stock Keeping Unit |
| SME | Subject Matter Expert |
| SOC | Standard of Conduct |
| SOP | Standard Operating Procedure |
| SPC | Statistical Process Chart |
| SPN | Shift Production Numbers |
| TAM | Tokyo Automated Machine (3GT) |
| TM | Test Method |
| Toric | Astigmatic |
| TR | Technical Report |
| TVCI | The Vision Care Institute |
| UPC | Universal Product Code |
| VAL | Validation Procedure |
| VOC | Voice of the Credo |
| VSPL | Value Stream Production Lead |
| WWID | World Wide I.D. |

Table 7-2: JJVC Contact Lens Portfolio[9]

| Category | DD/RU[10] | Marketing Family | Brand Family | Brand |
|---|---|---|---|---|
| Astigmatism | DD | 1-Day Moist | 1-Day Moist for Astigmatism | **1-Day Moist for Astigmatism** |
| Astigmatism | DD | Oasys 1-Day | Oasys 1-Day Astigmatism | **Oasys 1-Day Astigmatism** |
| Astigmatism | RU | Acuvue Advance | Acuvue Advance for Astigmatism | **Acuvue Advance for Astigmatism** |
| Astigmatism | RU | Acuvue Oasys | Acuvue Oasys for Astigmatism | **Acuvue Oasys for Astigmatism** |
| Astigmatism | RU | Acuvue | Acuvue Astigmatism | **Vita Astigmatism** |
| Beauty | DD | 1-Day Acuvue Define | 1-Day Acuvue Define | **1-Day Acuvue Define Accent** |
| Beauty | DD | 1-Day Acuvue Define | 1-Day Acuvue Define | **1-Day Acuvue Define Natural Shine** |
| Beauty | DD | 1-Day Acuvue Define | 1-Day Acuvue Define | **1-Day Acuvue Define Vivid** |
| Beauty | DD | 1-Day Define w Lacreon | 1-Day Define Rejuvenation | **1-Day Define Accent Rej** |
| Beauty | DD | 1-Day Define w Lacreon | 1-Day Define Rejuvenation | **1-Day Define Natural Shine A Rej** |
| Beauty | DD | 1-Day Define w Lacreon | 1-Day Define Rejuvenation | **1-Day Define Vivid Rej** |
| Beauty | DD | 1-Day Define w Lacreon | 1-Day Define Spark B | **1-Day Define Shimmer** |
| Beauty | DD | 1-Day Define w Lacreon | 1-Day Define Spark B | **1-Day Define Sparkle** |
| Beauty | DD | 1-Day Refine w Lacreon | 1-Day Refine | **1-Day Refine Radiant Bright** |
| Beauty | DD | 1-Day Refine w Lacreon | 1-Day Refine | **1-Day Refine Radiant Charm** |
| Beauty | DD | 1-Day Refine w Lacreon | 1-Day Refine | **1-Day Refine Radiant Chic** |
| Beauty | DD | 1-Day Refine w Lacreon | 1-Day Refine | **1-Day Refine Radiant Gloss** |
| Beauty | RU | Acuvue2 Define | Acuvue2 Define | **Acuvue2 Define** |
| Presbyopia | DD | 1-Day Moist | 1-Day Moist for Presbyopia | **1-Day Moist for Presbyopia** |
| Presbyopia | DD | Oasys 1-Day | Oasys 1-Day Presbyopia | **Oasys 1-Day Presbyopia** |
| Presbyopia | RU | Acuvue Oasys | Acuvue Oasys for Presbyopia | **Acuvue Oasys for Presbyopia** |
| Spherical | DD | 1-Day Acuvue | 1-Day Acuvue | **1-Day Acuvue** |
| Spherical | DD | 1-Day Moist | 1-Day Moist | **1-Day Moist** |
| Spherical | DD | 1-Day TruEye | 1-Day TruEye | **1-Day TruEye** |
| Spherical | DD | Oasys 1-Day | Oasys 1-Day | **Oasys 1-Day** |
| Spherical | RU | Acuvue | Acuvue | **Acuvue** |
| Spherical | RU | Acuvue Advance | Acuvue Advance | **Acuvue Advance** |
| Spherical | RU | Acuvue Advance Plus | Acuvue Advance Plus | **Acuvue Advance Plus** |
| Spherical | RU | Acuvue Clear | Acuvue Clear | **Acuvue Clear** |
| Spherical | RU | Acuvue Oasys | Acuvue Oasys | **Acuvue Oasys** |
| Spherical | RU | Acuvue Oasys | Acuvue Oasys Bandage | **Acuvue Oasys Bandage** |
| Spherical | RU | Acuvue Vita | Acuvue Vita | **Acuvue Vita** |
| Spherical | RU | Acuvue2 | Acuvue2 | **Acuvue2** |

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[9] Includes obsolete products.

[10] DD=Daily Disposable; RU=Reusable.

Table 7-3: Example Calculation of OEE [8]

| Components | Data | Comments |
|---|---|---|
| Total available time | 24 hours | 24 hours in one day |
| Idle time | 8 hours | Not required eight hours per day |
| Scheduled downtime | | |
| No production, breaks, shift change, etc. | 0.66 hours | Meeting & shift change |
| Planned maintenance | 1.00 hours | Monthly PM |
| Total scheduled downtime | 1.66 hours | |
| Unscheduled downtime | | |
| Waiting for operator | 0.46 hours | Operator distracted, on other tasks |
| Failure or breakdowns | 0.33 hours | Mechanical drive coupling |
| Set-ups & changeover | 0.26 hours | Two mold changes |
| Tooling or part changes | 0.23 hours | Screw station bits |
| Startup & adjustment | 0.30 hours | First shift Monday |
| Input material flow | 0.50 hours | Waiting for raw materials |
| Total unscheduled downtime | 2.08 hours | |
| Total downtime (scheduled + unscheduled) | 3.74 hours | 1.66 + 2.08 = 3.74 hours |
| Uptime | 12.26 hours | (24 – 8) – 3.74 = 12.26 hours |
| Availability | 76.63% | 12.26 / (24-8) x 100 = 76.63% |
| Performance efficiency losses | (Count) | |
| Minor stops | 10 events | Machine jams |
| Reduced speed or cycle time | 100 v.167 units | Design rate: 12.5 lenses/hour |
| Performance efficiency | 59.88% | (100 / 167) x 100 = 59.88% |
| Quality & yield losses | (Count) | |
| Scrap product/output | 2 | Waste, non-salvageable |
| Defects, rework | 1 | |
| Yield/transition | 5 | Startup & adjustment related |
| Rejected units produced | 8 | 2 + 1 + 5 = 8 |
| Good units produced | 92 | 100 – 8 = 92 good lenses |
| Quality rate | 92% | (92 / 100) x 100 = 92% |
| Overall equipment effectiveness | 42.21% | 76.63 x 59.88 x 92.00 = 42.21% |