OPTIMIZING A PRODUCTION SYSTEM FOR REFURBISHMENT OF DISK DRIVES

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Alexander Kafantis, Chad LaBove, Jacqueline Lynch
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Sponsoring Organization:
CNE Direct
Project Advisor:
Walter Towner, Ph.D.

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Abstract

CNE Direct is an immensely successful company that provides refurbished electronics to both the business and consumer markets. Through their in-house systems, they use proprietary methods to refurbish hard disk drives that have the potential for resale, and destroy those that do not. In order to keep up with the demand of their drives, CNE recently quintupled their size which increased their capacity considerably. However, they still have not reached their goal of 24/7 operation and the company wishes to consider lean manufacturing principles to increase their throughput.

The goal of the MQP was to assist CNE Direct in their aim of increasing their monthly throughput. The rationale for this project was to find a way for CNE Direct to optimize their production process through our research and application of various design and manufacturing methodologies. We conducted background research on the company's current system, studied multiple process optimization options, and recommended the ones we believed fit the company's needs. The methods used were an axiomatic design decomposition, value stream mapping, schedule optimization, and process modeling. The results we discovered through these methods were the detection of couplings in the production process, incompatibility of one-piece flow with the existing batch scheduling system, and finally, validation of CNE Direct's current process model. Our ultimate conclusion is that the most effective way for CNE Direct to increase throughput is to add capacity to their existing system.

Acknowledgements

We would like to thank our advisor, Professor Walter Towner, for his supervision and guidace throughout our project. He constantly steered us in the right direction and made the MQP an enjoyable and enlightening experience.

Additionally, we would like to thank CNE Direct for allowing us to take an inside look at their refurbishment process. In particular, we would like to thank Nicole Simmon (VP of Production and Development), Josh Galacar (Testing Support Specialist), and Myles Murray (QA and Testing Manager) for their support and contributions to this project. We would like to give special thanks the Ed Latham (President and CEO) for giving us the opportunity to work with CNE Direct on this MQP.

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Chapter 1 - Introduction

CNE Direct is a premier provider of refurbished electronics for both business and consumer markets. Their primary product is refurbished hard disk drives (HDDs), which they purchase from companies such as cable TV providers in order to refurbish and resell. These drives generally come from used digital video recorders (DVRs) which have become commonplace in homes today. CNE Direct's unique refurbishment process not only ensures one of the lowest return rates in the industry but also provides a product which is free of leftover data, providing peace of mind for both sides of their customer base - providers and end users.

CNE Direct was founded in 2002 and focuses on responsibility to the environment; the company is certified by Sustainable Electronics Recycling International (SERI) as R2 recyclers. R2 certification holds the highest standards in environmentally friendly reuse and recycling of electronics. Sustainability is so important to CNE Direct that the company also audits its partners in all stages of their supply chain to guarantee that they are also R2 certified and strives to forge and maintain partnerships with local businesses whenever possible. CNE Direct has also founded their charity Drives for Water in partnership with Charity: Water to provide clean drinking water to citizens of developing nations.[1] CNE Direct is committed to contributing a portion of their revenue to Drives for Water in order to further give back to the planet.

In order to assess and refurbish HDDs, CNE Direct relies on a technology called Self-Monitoring, Analysis, and Reporting Technology, also known as SMART. SMART is a diagnostic system which allows a drive to report various data related to its operation to its host

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[1] (Charity: Water 2014)

system in an effort to anticipate failures before they actually occur.[2] This technology helps foresee predictable errors such as mechanical wear of moving parts and storage surfaces, which can lead to data loss and account for about 60% of all drive failures.[3] This functionality is critical because unlike many other products, hard drives cannot be directly observed in operation and require highly expensive clean rooms and trained staff to perform costly manual maintenance. SMART also allows the host system to request a drive to perform some basic maintenance operations on itself, such as short and long extended self-tests and full surface scans. In addition to using SMART, CNE Direct also completes a data sanitization of all HDDs which is in compliance with the National Institute of Standards and Technology.[4]

CNE Direct uses SMART technology to determine which hard drives can be refurbished even during the refurbishment process itself. Using this system, CNE Direct can ensure it is producing reliable drives which will perform to CNE Direct's quality standards. This is partially because their processes exceeds industry standards for drive reconditioning as well as data destruction for both drives that can be resold, and those which must be destroyed before recycling.

The company has already done considerable work to get the most out of their resources, optimizing materials flow in their facility and maintaining a flexible staff which can easily be retrained to work elsewhere in the process. They are also in the process of developing and implementing a custom software solution which will enable them to track individual drives in their system, making an unparalleled level of information available to the customer and allowing

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[2] (Samsung Electronics 2014)

[3] (Seagate Technology PLC 2014)

[4] (Kissel, et al. 2006)

for more accurate, computer-automated forecasts of supply and demand. Because the company wishes to achieve a leaner production line and increase their throughput, lean manufacturing principles can aid them greatly in achieving these goals, especially as they make the transition from their current system to their proposed, more advanced system.

1.1 Objective

Using a variety of process optimization techniques, our project aimed to assist CNE Direct in improving monthly throughput of their hard drive refurbishment process. Our ultimate goal is to use these tools to make informed recommendations to the CNE Direct staff in an effort to increase their throughput and verify whether their current process is efficient and effective as possible.

1.2 State-of-the-Art

Axiomatic design is a design methodology and framework which can be used to break complex processes into smaller elements based on the design's functional requirements. It also incorporates the use of matrices in order to design robust, adaptive systems.[5] Axiomatic design was first developed by Dr. Suh Nam Pyo, a member of MIT's department of mechanical engineering. It is considered by many to address the shortcomings of Taguchi methods, another tool used by businesses to increase the quality of the goods they produce. The method received its name from the two axioms which it incorporates: the independence axiom and the information axiom. The independence axiom states that one must maintain the independence of the system's functional requirements, while the information axiom states that the information content of the design should be minimized. Using axiomatic design, systems can be broken down into functional requirements (FRs), design parameters (DPs), and process variables (PVs). By

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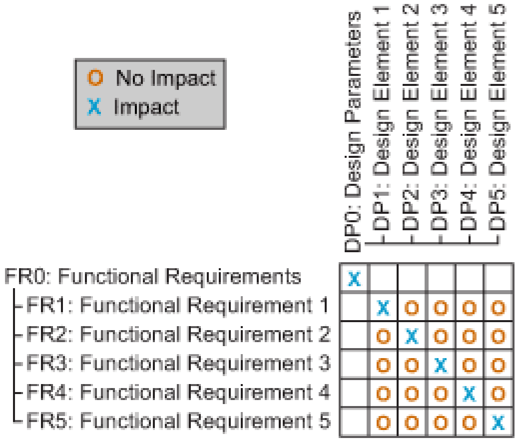
[5] (Suh 2001)

decomposing a system into these three parameters and identifying FR and DP relationships, or "couplings" in a matrix, a system can be reconfigured in ways which satisfy both axioms. Couplings occur in a design when adjusting a specific DP to better satisfy its corresponding FR affects other FRs as well. Of all possible designs which satisfy the Independence Axiom, the one which *best* satisfies the Information Axiom is the best design overall.[6]



	DP0: Design Parameters	DP1: Design Element 1	DP2: Design Element 2	DP3: Design Element 3	DP4: Design Element 4	DP5: Design Element 5
FR0: Functional Requirements	X					
FR1: Functional Requirement 1		X	O	O	O	O
FR2: Functional Requirement 2		O	X	O	O	O
FR3: Functional Requirement 3		O	O	X	O	O
FR4: Functional Requirement 4		O	O	O	X	O
FR5: Functional Requirement 5		O	O	O	O	X

FIGURE 1: EXAMPLE OF AN AXIOMATIC DESIGN DECOMPOSITION (HAMILTON 2014)

The Axiomatic Design process involves four domains of design, the first of which is understanding the customer needs. This initial step in the process essentially requires identifying what one wants to achieve in using the design. From there, designers identify how they want to achieve those goals through defining the functional requirements and the necessary design parameters to achieve them. Finally, process variables are defined as parts (either physical or conceptual) of the design parameters. Once the process is successfully mapped, the FRs are visually compared to their corresponding DPs in a matrix like the one above in order to make the impact of various couplings easier to understand and ultimately resolve. Generally, couplings are identified as crosses where the affected FR and DP intersect on the matrix. Couplings below the

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[6] (Suh 2001)

intentional couplings (those between the similarly numbered FRs and DPs) indicate a specific order of operations is necessary to avoid interference, while a coupling above the intentional couplings indicates a deeper interaction which requires a rework of the system to eliminate the problem or a modification to reduce its impact if necessary.

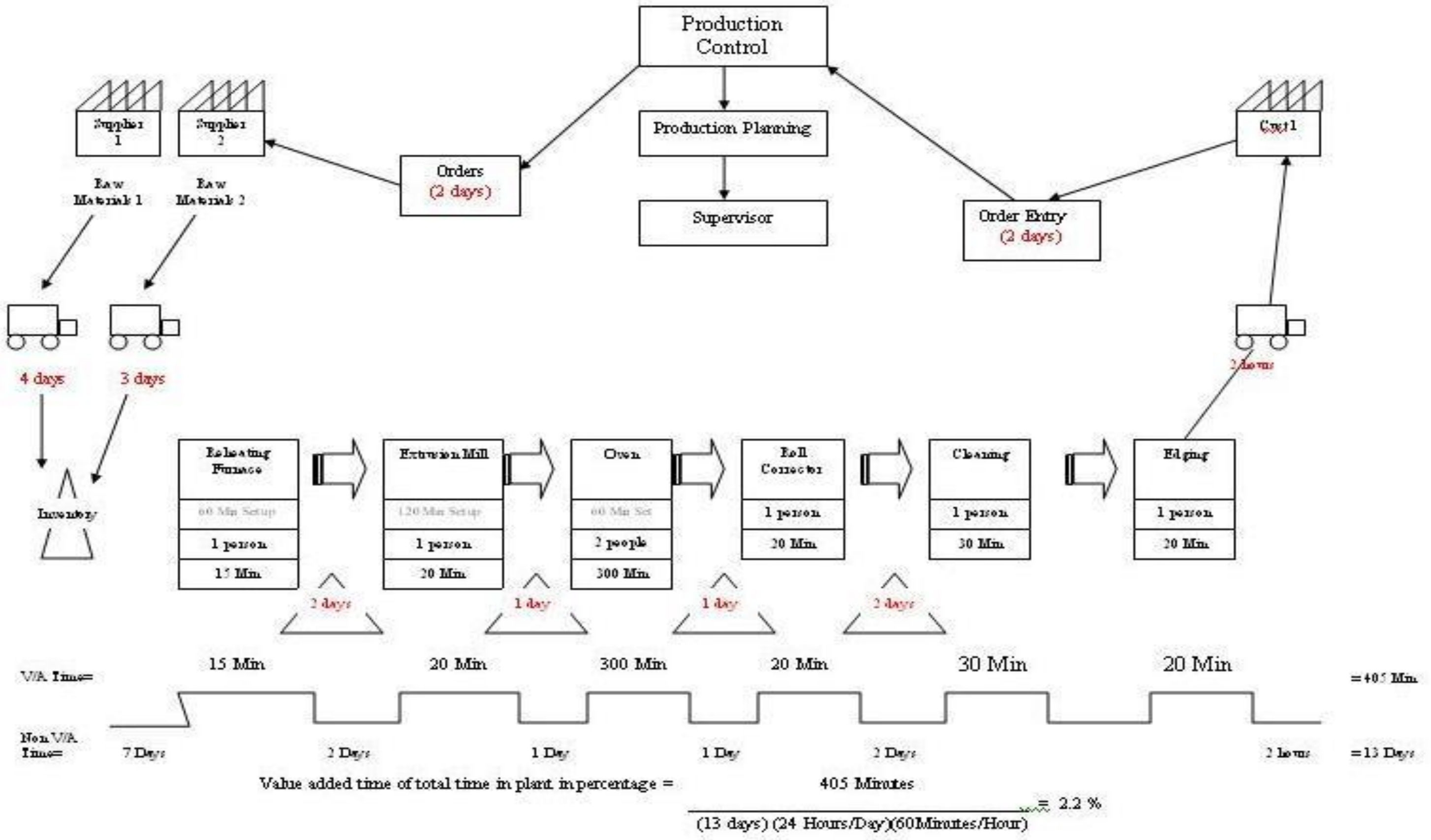

FIGURE 2: EXAMPLE OF A VALUE STREAM MAP (LEANMANUFACTURE.NET 2009)

Value stream mapping is another lean tool which involves creating a flowchart representing the flow of materials and information in a process. A value stream map highlights these flows and displays areas where non-value-added time can be eliminated by rearranging these flows within the process and potentially eliminating unnecessary steps from the process.[7] Generally, two flowcharts are created during mapping: a map of the process' current state and

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[7] (Jabobs and Chase 2013)

one or more maps of the process' potential future state, with intent that the future state map makes recommendations as to how to reduce non value added time. It would also show exactly how much can be gained from making the recommended changes, allowing for calculations of potential throughput increases due to the recommended changes.

One-piece (or single-piece) flow is a demand flow methodology which focuses on processing individual pieces in the system as a single unit in an effort to reduce downtime, ensure higher quality standards, minimize inventory, and improve production throughput. It supports other production philosophies including, but not limited to, just-in-time manufacturing.[8] The main idea behind the philosophy is "make one, move one;" the practice of using work stations to perform a single task (or step in a process) at a time on one piece of inventory. One-piece flow is advantageous in manufacturing because it allows for easy adaptability and scalability based on a number of factors, including demand, inventory mix, and order urgency.

Simulation modeling uses a spreadsheet program in order to simulate the potential outcome of a situation based on mathematical formulas and real-world data. Ideally, a simulation should allow for various parameters to be changed at will and still produce an accurate estimate of the desired data without requiring any reconfiguration. Simulation modeling was used throughout this project at multiple stages of development and research to test different design and scheduling methods for feasibility.

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[8] (Jabobs and Chase 2013)

Chapter 2 - Approach

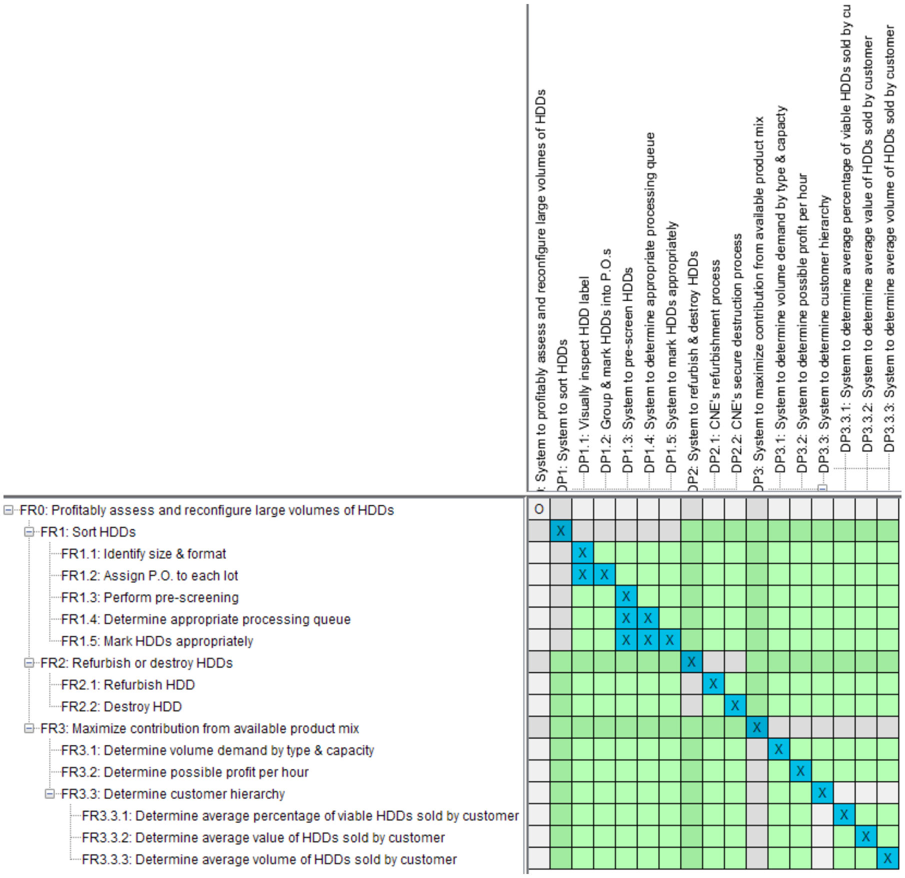
By using a combination of axiomatic design, value stream mapping, and other lean manufacturing and process simulation methods, we aim to assist CNE Direct in increasing the throughput of their drive refurbishment operation. We hope that by examining their processes from a new perspective, the use of these tools will reveal areas in which CNE Direct will be able to better take advantage of their existing resources and potentially remove unneeded steps or resources in order to run a leaner operation.

The use of an axiomatic design decomposition is intended to help reveal steps of the refurbishment process which are coupled, or otherwise dependent on one another. In doing so, we can use axiomatic design principles to minimize these dependencies and create a more robust process which can easily be reconfigured or adapted to CNE Direct's changing infrastructure. The use of axiomatic design is also intended to remove and reduce redundancies, unnecessary procedures, and additional time and effort which are unnecessary to the refurbishment process.

Through value stream mapping, we aim to reduce non-value-added time in the process by analyzing uptime, cycle and load times at each step in the process. By minimizing the time inventory spends in the process without gaining value, we can increase throughput and take better advantage of CNE's existing resources.

We also aim to test the effectiveness of CNE Direct's current production schedule in an effort to minimize non-value-added time and potentially make the schedule more adaptable as well. Depending on our findings from our other research, we may also have additional goals in designing new schedules for production. We can use a simulation involving spreadsheet software in order to compare CNE Direct's potential and current throughputs with the potential maximum throughputs of the schedules we design and decide whether or not they are worth considering. The simulation can then be used to test the feasibility of any other changes we would like to test before recommending them to CNE Direct.

2.1 Axiomatic design decomposition



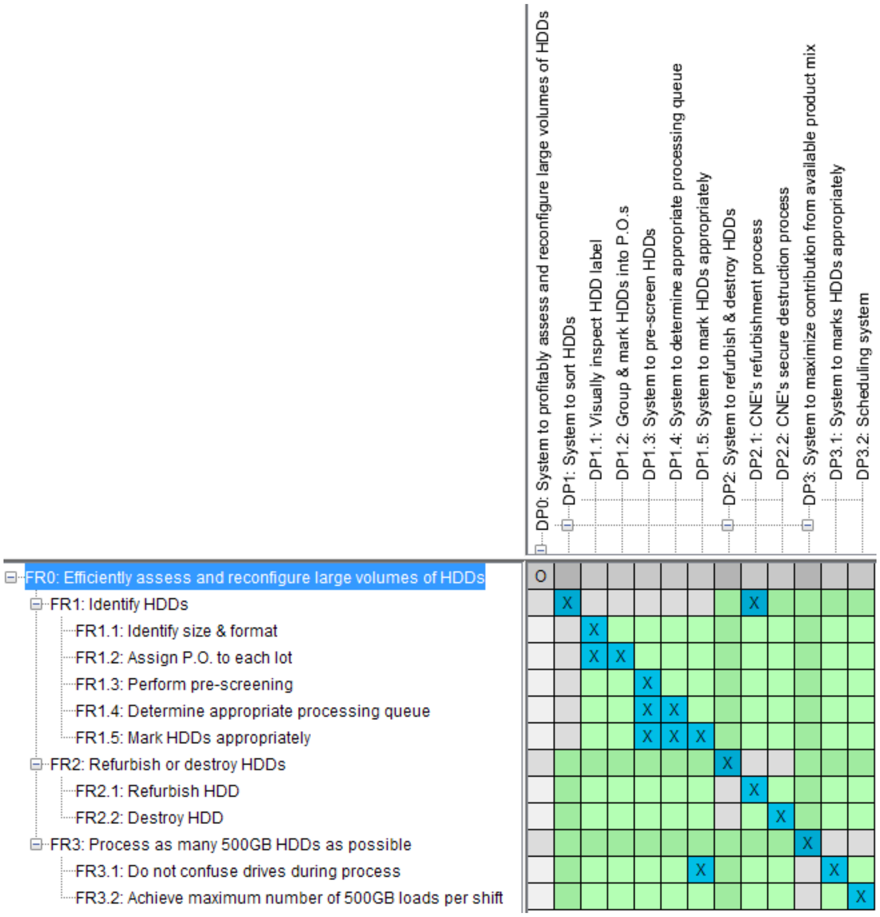
	: System to profitably assess and reconfigure large volumes of HDDs	DP1: System to sort HDDs	DP1.1: Visually inspect HDD label	DP1.2: Group & mark HDDs into P.O.s	DP1.3: System to pre-screen HDDs	DP1.4: System to determine appropriate processing queue	DP1.5: System to mark HDDs appropriately	DP2: System to refurbish & destroy HDDs	DP2.1: CNE's refurbishment process	DP2.2: CNE's secure destruction process	DP3: System to maximize contribution from available product mix	DP3.1: System to determine volume demand by type & capacty	DP3.2: System to determine possible profit per hour	DP3.3: System to determine customer hierarchy	DP3.3.1: System to determine average percentage of viable HDDs sold by cu	DP3.3.2: System to determine average value of HDDs sold by customer	DP3.3.3: System to determine average volume of HDDs sold by customer
FR0: Profitably assess and reconfigure large volumes of HDDs	O																
FR1: Sort HDDs		X															
FR1.1: Identify size & format			X														
FR1.2: Assign P.O. to each lot			X	X													
FR1.3: Perform pre-screening					X												
FR1.4: Determine appropriate processing queue					X	X											
FR1.5: Mark HDDs appropriately					X	X	X										
FR2: Refurbish or destroy HDDs								X									
FR2.1: Refurbish HDD									X								
FR2.2: Destroy HDD										X							
FR3: Maximize contribution from available product mix											X						
FR3.1: Determine volume demand by type & capacity												X					
FR3.2: Determine possible profit per hour													X				
FR3.3: Determine customer hierarchy														X			
FR3.3.1: Determine average percentage of viable HDDs sold by customer															X		
FR3.3.2: Determine average value of HDDs sold by customer																X	
FR3.3.3: Determine average volume of HDDs sold by customer																	X

FIGURE 3: INITIAL DECOMPOSITION

The early stages of the project involved learning what axiomatic design is, how to implement axiomatic design, and how to decompose an existing process into a design matrix. We began building a simple list of functional requirements and their applicable design parameters in word processing software. Then, we constructed a simple matrix in a spreadsheet program. The next iteration of our decomposition was done in Acclaro's DFSS software, a custom solution designed for creating axiomatic design matrices and decompositions. This allowed for easier editing and refinement of the couplings present in the matrix - a necessary feature once collaboration on the matrix began with CNE Direct.

We made a conscious decision to leave simple descriptions of the functional requirements under FR2, the drive refurbishment process, as CNE Direct uses a confidential method which produces much lower rates of failure after sale than their competitors, and this process would not be modifiable by our group. For this reason, there was no need to decompose this process further than it is shown now, allowing us to focus our attention on the other aspects of CNE Direct's process.

Our initial FR3 was to maximize the contribution from the available product mix. We created some simple sub FRs as a best guess of how CNE Direct decided which drives to refurbish. The system we created involved prioritizing drives for processing by demand, potential profit per hour, and customer loyalty. Customer loyalty was split into three sub FRs (3.3.1, 3.3.2, and 3.3.3) for determining the average value and volume of HDDs sold by each customer as well as the average percentage of drives sold by the customer which became viable drives for resale.

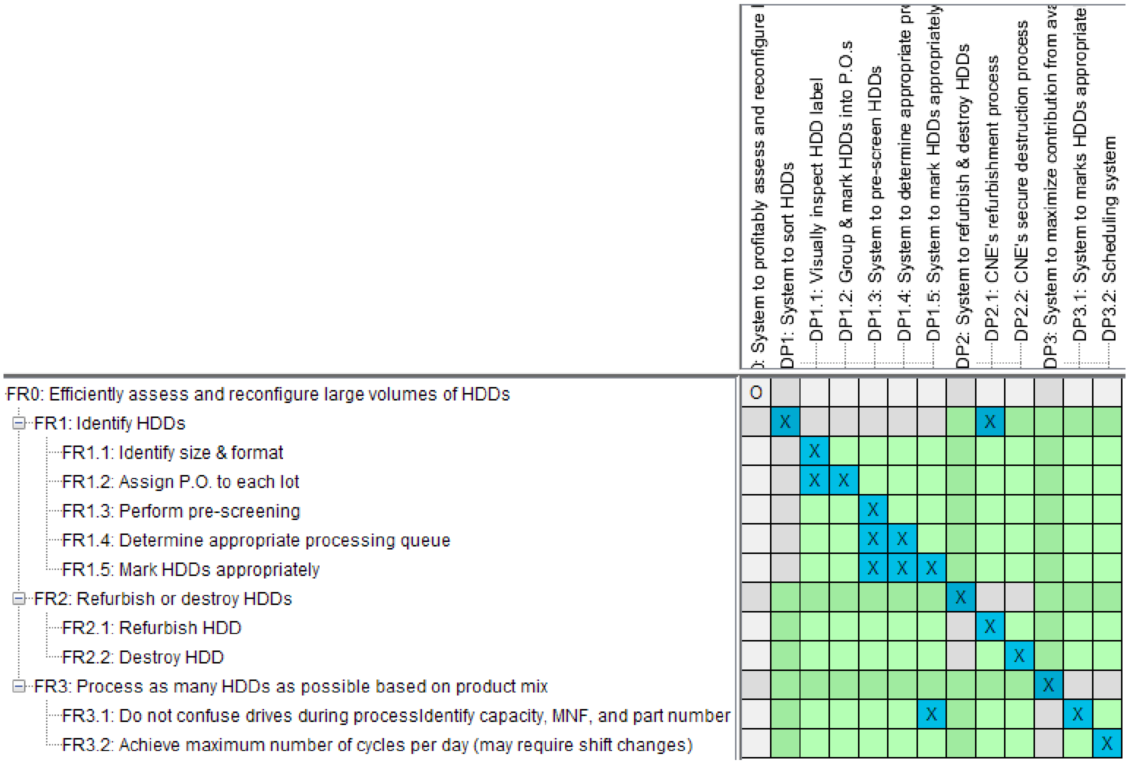


	DP0: System to profitably assess and reconfigure large volumes of HDDs	DP1: System to sort HDDs	DP1.1: Visually inspect HDD label	DP1.2: Group & mark HDDs into P.O.s	DP1.3: System to pre-screen HDDs	DP1.4: System to determine appropriate processing queue	DP1.5: System to mark HDDs appropriately	DP2: System to refurbish & destroy HDDs	DP2.1: CNE's refurbishment process	DP2.2: CNE's secure destruction process	DP3: System to maximize contribution from available product mix	DP3.1: System to marks HDDs appropriately	DP3.2: Scheduling system
FR0: Efficiently assess and reconfigure large volumes of HDDs	O												
FR1: Identify HDDs		X							X				
FR1.1: Identify size & format			X										
FR1.2: Assign P.O. to each lot			X	X									
FR1.3: Perform pre-screening					X								
FR1.4: Determine appropriate processing queue					X	X							
FR1.5: Mark HDDs appropriately					X	X	X						
FR2: Refurbish or destroy HDDs								X					
FR2.1: Refurbish HDD									X				
FR2.2: Destroy HDD										X			
FR3: Process as many 500GB HDDs as possible											X		
FR3.1: Do not confuse drives during process							X					X	
FR3.2: Achieve maximum number of 500GB loads per shift													X

FIGURE 4: SECOND DECOMPOSITION

After discussion with CNE Direct about this initial decomposition, we were surprised to find that they use a much simpler method to prioritize drives which doesn't take customer history into account. The strategy the company uses is much simpler; CNE Direct makes an effort to process as many of their highest demand drives as possible, fitting drives of lower demand in where convenient for scheduling purposes. Upon revisiting our decomposition to make these changes, we found additional couplings in the system, mostly within their top-level FR and only requiring obedience to proper order of operations to correct. Examples of these couplings are present under FR1. For instance, assigning PO numbers to each lot is only negatively affected by identifying the size and format if the former is performed before the latter.

After our first discussion with CNE Direct, we found that there is a crucial interaction between the refurbishment process and the need to identify HDDs in the process. This coupling arose because CNE Direct identifies drives at each step in the process to ensure the correct operations are performed on them. This means that if a drive is not identified properly or becomes misplaced, the entire system will be affected. Because it would not be wise to recommend that CNE Direct be less thorough in their quality control standards, we instead opted to recommend ways to minimize the impact a misidentified or unidentified drive would have on the refurbishment process. We found that the software solution CNE Direct plans to implement will be the perfect solution; by identifying drives by their factory-assigned barcodes with a handheld scanner, the process of identifying drives and their histories in the process will require minimal labor and downtime.



	: System to profitably assess and reconfigure l	DP1: System to sort HDDs	DP1.1: Visually inspect HDD label	DP1.2: Group & mark HDDs into P.O.s	DP1.3: System to pre-screen HDDs	DP1.4: System to determine appropriate pr	DP1.5: System to mark HDDs appropriately	DP2: System to refurbish & destroy HDDs	DP2.1: CNE's refurbishment process	DP2.2: CNE's secure destruction process	DP3: System to maximize contribution from ava	DP3.1: System to marks HDDs appropriate	DP3.2: Scheduling system
FR0: Efficiently assess and reconfigure large volumes of HDDs	O												
FR1: Identify HDDs		X							X				
FR1.1: Identify size & format			X										
FR1.2: Assign P.O. to each lot			X	X									
FR1.3: Perform pre-screening					X								
FR1.4: Determine appropriate processing queue					X	X							
FR1.5: Mark HDDs appropriately					X	X	X						
FR2: Refurbish or destroy HDDs								X					
FR2.1: Refurbish HDD									X				
FR2.2: Destroy HDD										X			
FR3: Process as many HDDs as possible based on product mix											X		
FR3.1: Do not confuse drives during processIdentify capacity, MNF, and part number							X					X	
FR3.2: Achieve maximum number of cycles per day (may require shift changes)													X

FIGURE 5: FINAL DECOMPOSITION

Further modifications to our decomposition involved changes in wording for the FRs and DPs, but the matrix of the decomposition remained the same for our final iteration. The most important thing we found from our design decomposition is that CNE Direct has already created a very robust and independent system for processing hard drives. Despite our scrutiny, we were only able to find one crucial interaction which could cause problems in the system, and CNE Direct is already in the process of minimizing the impact of this interaction.

2.2 Value stream mapping

We created our first simple value stream map in Microsoft PowerPoint and configured it to show load and cycle times for each type of drive that CNE Direct processes. To avoid complications due to excessive information and design complexity, our next map was configured for a single type of drive. We decided to focus on the type and size of drive which creates the most profit for CNE Direct in order to focus more in depth and offer more useful solutions. The second iteration of our map was simpler, more streamlined and reworked in a new piece of software designed for the easy creation of diagrams and figures. This was a necessary step before involving CNE Direct in the map's development in order to facilitate easier editing and more professional presentation of the map.

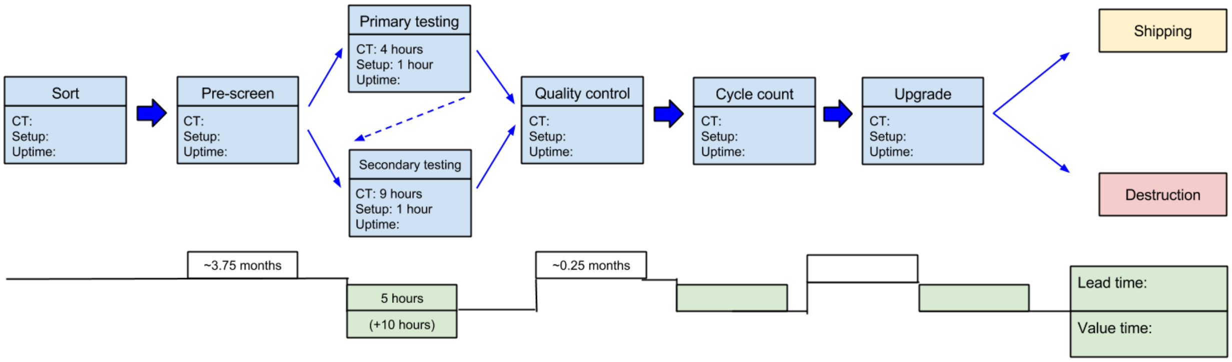


FIGURE 6: VALUE STREAM MAP

Using our new value stream map as well as data provided by CNE Direct, we were able to determine the amount of non-value-added time in the process. Non-value-added time is time a production unit spends in the process where it is not increasing in value. Some examples in CNE Direct's process are the sorting and pre-screening stations. These processes, while necessary to the system, do not actually add value to the drive, making it an example of necessary non-value-added time. Another example of non-value-added time is time spent waiting to be processed – an example of unnecessary non-value-added time; theoretically, given infinite resources, drives would never wait to move to the next step in the process. The goal is to seek to reduce necessary non-value-added time and eliminate unnecessary non-value-added time in a process to improve throughput.

After creating our value stream map, we examined it to find the greatest source of non-value-added time in CNE Direct's process. Generally, the greatest source of non-value-added time is a good target for improvement as reducing it could have the biggest possible impact on the system's overall throughput. We found that the greatest amount of non-value-added time by far in the process is time inventory spends waiting between processing stations. The time spent waiting to be processed at various stations greatly outweighs the amount of time inventory spends being processed. Because the non-value-added time in CNE Direct's refurbishment process is based on work-in-progress (WIP) inventory, we found that exploring one-piece flow concepts could help CNE Direct reduce their WIP inventory and potentially improve their monthly throughput.

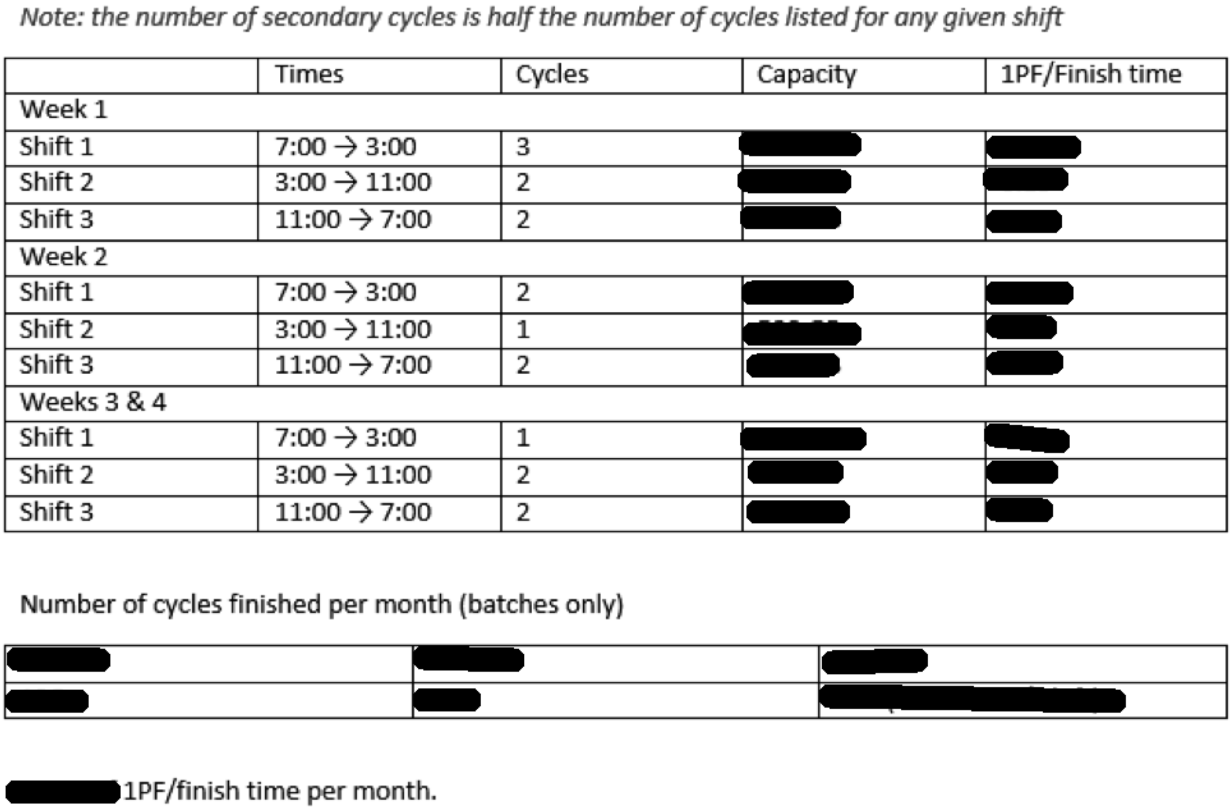
2.3 Schedule optimization

2.3.1 CNE Direct's current schedule

CNE Direct currently processes several cycles of each drive type per day. Certain drive racks are dedicated to each type of drive so all types can be processed simultaneously. Because different types of drives take different amounts of time to process, shifts are uneven and begin and end at different times for each station. While the schedule is very efficient in terms of how many drives of each type can be processed in a day, it is incompatible with a one-piece flow model of production. It also does not allow for a simple implementation of a third, overnight shift or continuous 24/7 operation without heavy modification. This schedule is not flexible enough to allow for changes in production schedule or purchase order priority. We felt that by implementing some one-piece flow concepts to CNE Direct's schedule, we could assist them in implementing more flexible operations and perhaps process more drives per month.

CNE Direct's model of production is based on purchase orders, often consisting of several of a single type of drive. The batches they schedule each day are intended to keep purchase orders (or sections of them) together in order to simplify the process of internally tracking inventory. For this reason, a true one-piece flow model is not practical to implement in their facility – it would drastically increase the difficulty involved in fulfilling purchase orders correctly, completely, and in a timely manner. As such, our group has developed a basic model of operation we call the hybrid one-piece flow system. Essentially, we propose a combination of solid shifts processing a single type of drive at a time, followed by one-piece flow operations for the remainder of shifts in order to prevent lost time while eliminating uneven shifts. Under this system, all shifts can begin and end at a single time and are very flexible in terms of which drives can be processed during the shift. An added benefit of the system is that even under several schedule proposals, it is easy to implement a third shift to cover overnight operations, as well, while maintaining consistent and even shift times across the schedule. The following is an explanation of each of our proposals for the hybrid one-piece flow operation.

2.3.2 Hybrid one-piece flow proposal 1



Note: the number of secondary cycles is half the number of cycles listed for any given shift

	Times	Cycles	Capacity	1PF/Finish time
Week 1				
Shift 1	7:00 → 3:00	3	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00	2	[redacted]	[redacted]
Week 2				
Shift 1	7:00 → 3:00	2	[redacted]	[redacted]
Shift 2	3:00 → 11:00	1	[redacted]	[redacted]
Shift 3	11:00 → 7:00	2	[redacted]	[redacted]
Weeks 3 & 4				
Shift 1	7:00 → 3:00	1	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00	2	[redacted]	[redacted]

Number of cycles finished per month (batches only)

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted] 1PF/finish time per month.

FIGURE 7: HYBRID MODEL 1

The first hybrid model our group proposed operates on a weekly basis. Two eight hour shifts, with an optional overnight third shift (also eight hours), are offered with the same shift run each day of the particular week. The goal is to pack as many cycles of a particular drive into a single eight hour shift and use any remaining time which could not be used for a complete cycle as finishing time as well as one-piece flow time. The intent with this model is to allow CNE Direct to continue to use shifts in order to make fulfilling purchase orders as easy as the previous model, while preventing lost time and continuing to offer the flexibility of a one-piece flow model. For example, the first shift of the first week calls for three cycles of A drives to be processed. Three cycles of A drives only takes seven and a half hours, leaving half an hour at the end of the shift. Our model suggests this half hour can be used both to finish any leftover drives that have not yet finished processing as well as allow for the injection of other drives into the system before the second shift begins. This would allow for quick processing of leftover drives, drives which had been misplaced in the system and needed to finish processing, or the fulfillment of an urgent, smaller order.

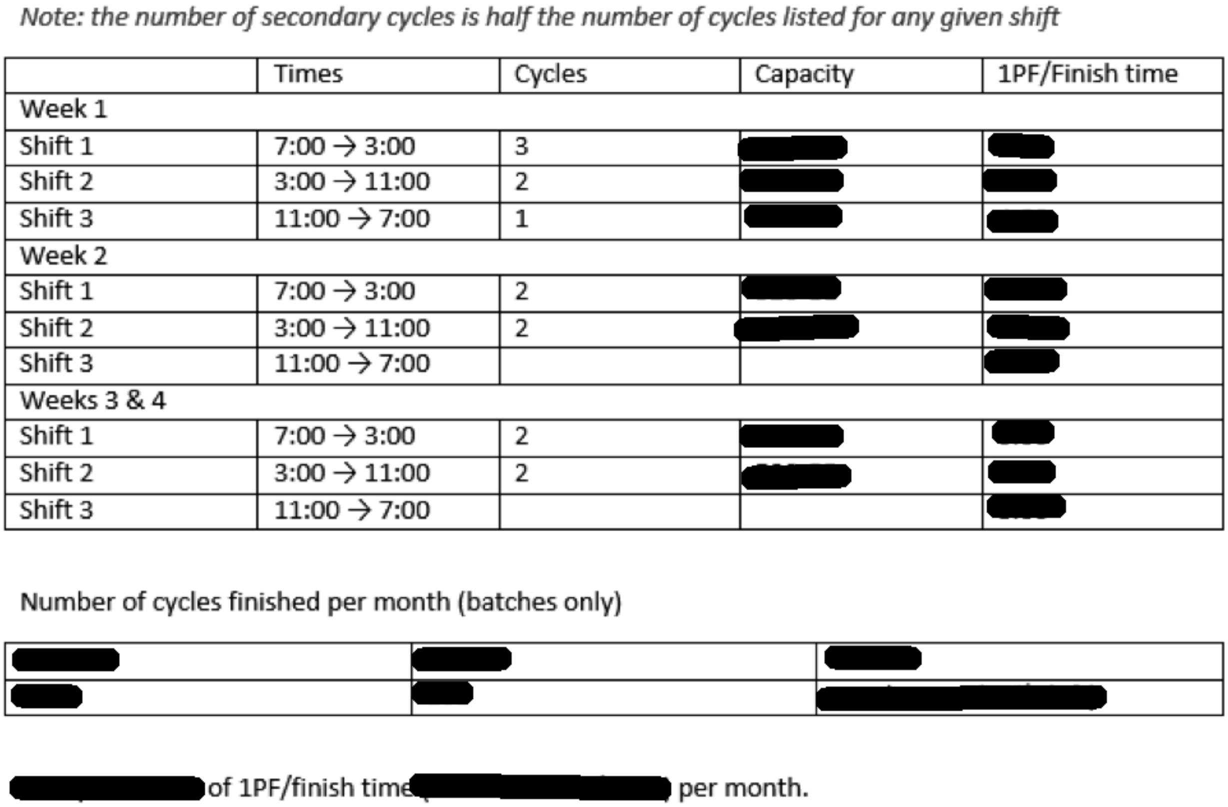
The first week of the first model focuses on the drives with the least demand, A and B drives. The first shift calls for three cycles of A drives with a half hour of one-piece flow / finish time. The second shift allows for two cycles of B drives with fifteen minutes left over for one-piece flow / finish time. Adding the third overnight shift allows CNE Direct an additional two cycles of C drives, but no additional one-piece flow / finish time.

The second week begins to shift focus to CNE Direct's highest demanded product, the C hard drives. This week allows for two cycles of B drives with fifteen minutes of one-piece flow / finish time, followed by a single shift of C drives with four hours of one-piece flow / finish time. Adding the third shift grants the ability to add an additional two cycles of C drives, but not any additional one-piece flow / finish time.

The third and fourth weeks of the first proposal are the same. The first shift is designated for a single cycle of C drives with four hours of one-piece flow / finish time, while the second and third shifts are dedicated solely to two cycles of C drives apiece with no one-piece flow / finish time.

This first proposal was explicitly designed to retain CNE Direct's batch-based schedule as much as possible while moving to the new hybrid model. It also focused on making the schedule as complete as possible without the third shift, making it truly optional. To find he theoretical maximum capacity of the system, we used data provided by CNE Direct and some simple math. Knowing the capacity of each drive rack and how many are available as well as the amount of time to process each drive type via the primary and secondary processes, we could calculate the maximum number of drives the schedule could process each week. In total, this proposal allows for 126 cycles of A drives, 168 cycles of B drives, and 252 cycles of C drives (504 cycles with the additional third shift in place) per month. As the focus is mostly on rigid scheduling and less on one-piece flow / finish time, it only allows for thirteen hours per month. Seeing this as a potential shortcoming, we decided to address this factor in our next proposal and allow for more one-piece flow/finish time and improved flexibility in the amount of one-piece flow / finish time available per month.

2.3.3 Hybrid one-piece flow proposal 2



Note: the number of secondary cycles is half the number of cycles listed for any given shift

	Times	Cycles	Capacity	1PF/Finish time
Week 1				
Shift 1	7:00 → 3:00	3	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00	1	[redacted]	[redacted]
Week 2				
Shift 1	7:00 → 3:00	2	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00			[redacted]
Weeks 3 & 4				
Shift 1	7:00 → 3:00	2	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00			[redacted]

Number of cycles finished per month (batches only)

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted] of 1PF/finish time [redacted] per month.

FIGURE 8: HYBRID MODEL 2

Our second model operates similarly to the first in that it operates on a weekly basis and consists of two shifts with an optional third which runs overnight. It also works by fitting as many cycles as appropriate into a shift and filling in additional time with one-piece flow / finish time. However, our second model focuses more on flexibility in terms of how many one-piece flow / finish hours they desire per month.

The first week of the second proposed model is identical to the first week of the first model, except the third shift only consists of a single C cycle with four hours of one-piece flow / finish time available. Though fewer C drives can be processed with this change, our aim was ultimately to increase the amount of one-piece flow / finish time available in a month, which the change satisfies.

The second week is, again, similar to the second week of the first model, however two cycles of C drives are run during the second shift while the third shift is devoted entirely to one-piece flow / finish time. We continued to make the additional shift entirely devoted to one-piece flow / finish time in the third and fourth weeks, as well, allowing for high flexibility of operations. The added benefit of this unscheduled shift is the ability to run entire cycles of a single drive type while still leaving time for one-piece flow / finishing operations.

During weeks three and four, both first and second shifts process two cycles of C drives with no one-piece flow / finish time. This deficit is made up for during the third shift, which is entirely devoted to freedom of operation.

Compared to the first proposed model, this second model offers greater flexibility in the amount of one-piece flow / finish time in a month via the overnight shift while maintaining a less variable monthly output of C cycles. Using the same process we did to calculate the theoretical maximum capacity of our first model, we were able to again find the theoretical maximum capacity of this new model. In total, the second model is capable of 126 cycles of A drives, 168 cycles of B drives, and 420 cycles of C drives, with seven hours of one-piece flow / finish time per month. Adding the overnight shift increases the number of C cycles to 462 while bringing the one-piece flow / finish time per month to 203 hours. With these changes, CNE Direct also has the flexibility to more easily determine whether the third shift is needed on a week-by-week basis rather than a month-by-month basis, as its purpose is the same in every week of production but the first.

2.4 Process modeling

In order to better understand how these processes compared to the existing process CNE Direct currently employs to refurbish HDDs, we created a mathematical model of the current process' maximum capacity, current average capacity (an estimation that was marked as example data), as well as the theoretical maximum capacities of models one and two, in two and three shift configurations. From these starting figures we were able to use data provided by CNE Direct as well as some other example data to estimate the maximum profit and drives processed per month for every permutation of every schedule. We used this data further in order to calculate the estimated interest and return on investment for the implementation of the custom scanning and software system that CNE Direct is considering depending on which schedule they use moving forward.

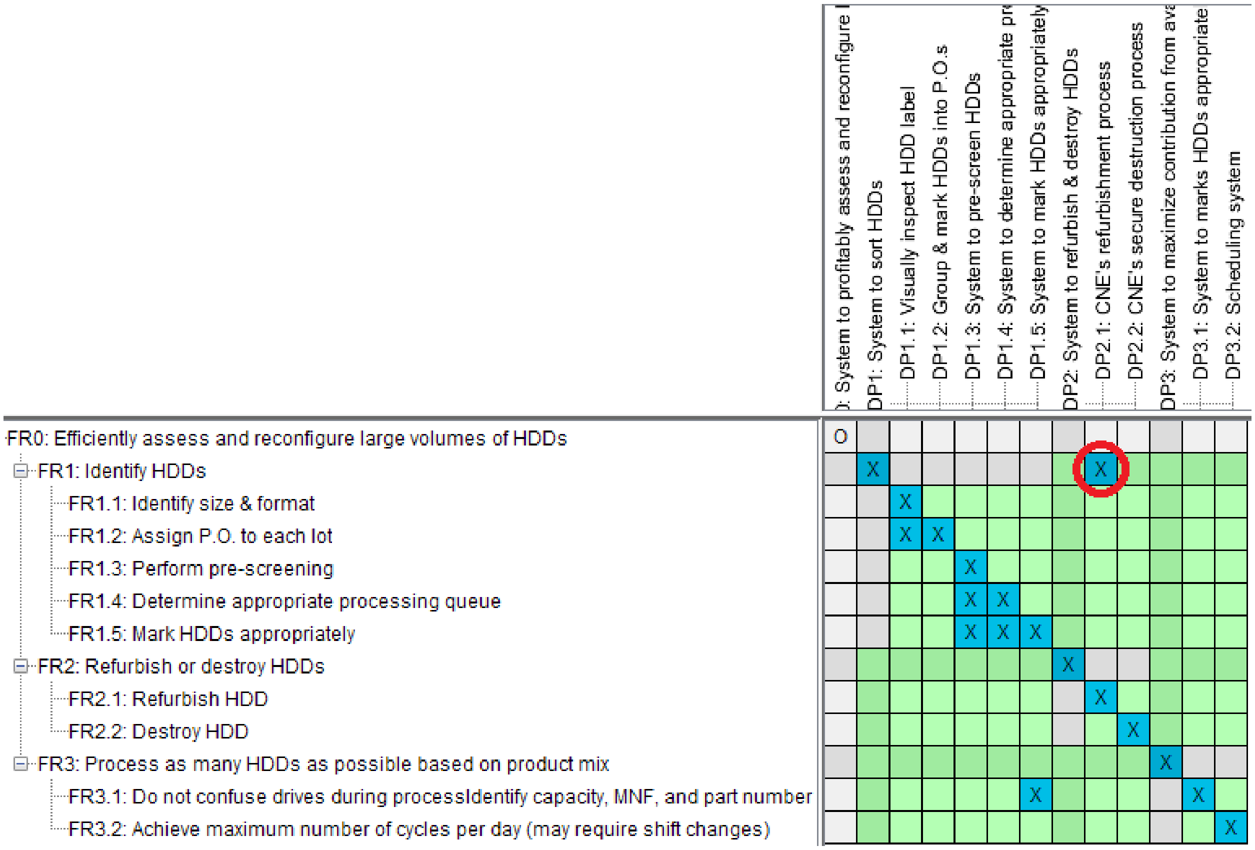
Much of the simulation uses simple arithmetic to calculate figures. For instance, to find the output of a certain drive capacity under a certain schedule type, the number of drives per cycle is multiplied by the number of cycles performed in a month under that schedule. To estimate the potential profit, the number of drives produced in a month is multiplied by the profit for that drive capacity. Each figure in the simulation is linked to other cells in the simulation so that changing one number will affect any other figures which rely on it appropriately. Using simple math and the ability to link and copy formulas from one set of data to another, we were able to estimate our desired figures, even with the use of example data. In addition, our use of referenced cells and formulas rather than static data means that CNE Direct will be able to compare schedules or assess their investment in custom software using their own data or at a later date.

Using the reconfigurable properties of our simulation, we were also able to test various changes to CNE Direct's system without performing the calculations again. In considering potential improvements for CNE Direct's current process, we wanted to test the additional throughput gained by replacing the pre-test stage of the process with another drive rack specific to C drives and using the primary queue racks to perform pre-test functions. We used our existing production model in order to test this change under all permutations of the process previously mentioned by increasing the number of drive bays available to process C type drives enough to count for an entire additional drive rack. Even adding this single rack in place of the pre-test station boosted CNE Direct's monthly profit by about 10%. This surprising gain also did not take into consideration the amount of time saved in the production of every drive type by skipping the time involved in performing the pre-test. While it bears repeating that some example data was used in our simulation where exact numbers were not available, we were still able to draw some crucial conclusions from this additional consideration. These conclusions are explained in detail later in this report.

Chapter 3 - Discussion

3.1 Axiomatic design

Though there are some minor interactions in CNE Direct’s process, it is otherwise a very robust design; it is easily reconfigurable and very simple to the casual observer, and this is demonstrated by our decomposition. In creating the decomposition, we were able to determine that CNE Direct’s process design itself was not creating a bottleneck or slowing down production. The main coupling in the process is between FR1 (Identify HDDs) and DP2.1 (CNE Direct’s refurbishment process). This is because drives are re-identified at each step in the process to ensure the correct operations are carried out on them. Though this does not often cause an interaction, there will be coupling in the event of a mistake; the identification of HDDs



	: System to profitably assess and reconfigure	DP1: System to sort HDDs	DP1.1: Visually inspect HDD label	DP1.2: Group & mark HDDs into P.O.s	DP1.3: System to pre-screen HDDs	DP1.4: System to determine appropriate pr	DP1.5: System to mark HDDs appropriately	DP2: System to refurbish & destroy HDDs	DP2.1: CNE's refurbishment process	DP2.2: CNE's secure destruction process	DP3: System to maximize contribution from ava	DP3.1: System to marks HDDs appropriate	DP3.2: Scheduling system
FR0: Efficiently assess and reconfigure large volumes of HDDs	O												
FR1: Identify HDDs		X							X				
FR1.1: Identify size & format			X										
FR1.2: Assign P.O. to each lot			X	X									
FR1.3: Perform pre-screening					X								
FR1.4: Determine appropriate processing queue					X	X							
FR1.5: Mark HDDs appropriately					X	X	X						
FR2: Refurbish or destroy HDDs								X					
FR2.1: Refurbish HDD									X				
FR2.2: Destroy HDD										X			
FR3: Process as many HDDs as possible based on product mix											X		
FR3.1: Do not confuse drives during processIdentify capacity, MNF, and part number							X					X	
FR3.2: Achieve maximum number of cycles per day (may require shift changes)													X

Figure 9: Highlight of the process' critical interaction

will be affected during the refurbishment process. In order to maintain quality, however, this precaution cannot be removed.

The risk of coupling can be reduced greatly with the use of CNE Direct's custom software solution. The software will allow drives to be scanned at every step in the process rather than verified by hand; reducing the margin for human error and making the root of the problem more identifiable. Through the axiomatic design decomposition, we found that for CNE Direct to effectively achieve FR0, they must prioritize minimizing the processing time for drives, then the sequencing of the drives, and finally optimizing labor.

FR0: Make Money by Refurbishing Hard Disk Drives
FR1: Minimize Processing Time of Drives
FR2: Optimize Sequencing of Drives (scheduling, prioritizing by profitability)
FR3: Optimize Labor (physical loading, unloading, packing, etc)

	DP1	DP2	DP3
FR1	X	X	X
FR2	X	X	
FR3	X		

For this reason, priority must be placed on FR1: Minimizing Processing Time of Drives, before the other two, because this affects all the other functional requirements and design parameters. Next should be optimizing the sequence of drives, and lastly the labor and physical movement in the system. If this is done out of order, then process ends where it started.

	DP1	DP2	DP3
FR1	X		
FR2	X	X	
FR3	X	X	X

We are aiming for this model in which priority lies with minimizing processing time, secondly sequencing types of drives, and lastly all other physical processes. This is all in order to reach FR0: Maximizing Profit through Refurbishing the Drives.

FR0: Make Money by Refurbishing Hard Disk Drives

FR1: Optimizing Labor and other Physical Processes

FR2: Optimize Sequencing of Drives (scheduling, prioritizing by profitability)

FR3: Minimize Processing Time of Drives *if possible*

3.2 Value stream map

Through the development of our value stream map, we were able to determine that the most non-value-added time in the system occurs in between processing steps, which take considerably less time than the waiting periods between them. This is a good indication that improving the system's throughput would drastically reduce the amount of inventory in progress rather than outstripping the supply of incoming drives. Though our value stream map turned out to be a small portion of our project, it was important in that it led us to attempt to incorporate one-piece flow into our proposed schedules later on.

3.3 Scheduling changes and simulations

The most important things we learned through our simulations were that our proposed schedules were not nearly as capable at their maximum capacities as the theoretical maximum capacity of CNE Direct's current system. While the one-piece flow / finish time could make up for otherwise non-value-added time, the equal, non-staggered, shorter shift times are not as useful for batch operations, which make up the majority of CNE's orders and are what truly drive their profits. This is still true if three shifts are used in either proposed scheduling model. Though our models allow for easy reconfiguration and are more flexible, CNE Direct's current scheduling model has the advantage of having been implemented and modified over years of experience; it does not need to be reconfigured regularly and overnight operations can be implemented in the existing system more simply and without hiring additional staff by scheduling a batch at the end of the day's final shift. This, along with our findings from the addition of resources in the system, led us to the conclusion that the best way to improve CNE Direct's throughput is to add capacity to the existing system. This conclusion is complicated by the fact that CNE Direct's supply and demand vary greatly from month to month, making the investment in additional equipment a risky one.

In addition to testing the schedule models, we were also able to test the difference made by removing the pre-test station and replacing it with another drive rack dedicated to C drives. While the results were promising, in discussion with CNE Direct it was explained that the pre-test station is not actually a bottleneck when the process is running; it is fast enough to process another batch while the current batch is running. It was further explained that the pre-test station performs some necessary sorting functions not previously understood by our team. Because it was only a factor in throughput when the operation first started, it is not worth removing. However, our findings are verification that improving capacity would yield a significant gain in throughput.

3.4 Cost-Benefit Analysis

Along with our scheduling simulations, we performed a cost-benefit analysis on potential investments for CNE Direct. Using example data, we were able to determine whether or not the investments were feasible. We used a simple return on investment (ROI) formula including interest to determine how long it would take CNE Direct to earn back each individual investment. The formula included CNE Direct's actual and potential outputs as well as our hybrid models' outputs to ascertain the time to return on investment for each scenario. We were excited to find that under most circumstances, CNE Direct would be able to pay for their proposed investments in less than a year. This means that their primary concern in considering these changes and additions is whether they will be helpful or necessary in the future, given the wild fluctuations of CNE Direct's supply and demand of drives.

Chapter 4 - Conclusion

During our time with CNE Direct, we used many different analytical tools to find ways to improve the throughput of their drive refurbishment system. In our work we tested the robustness of their process, searched for process bottlenecks, considered additional manufacturing philosophies, and attempted to streamline their existing process.

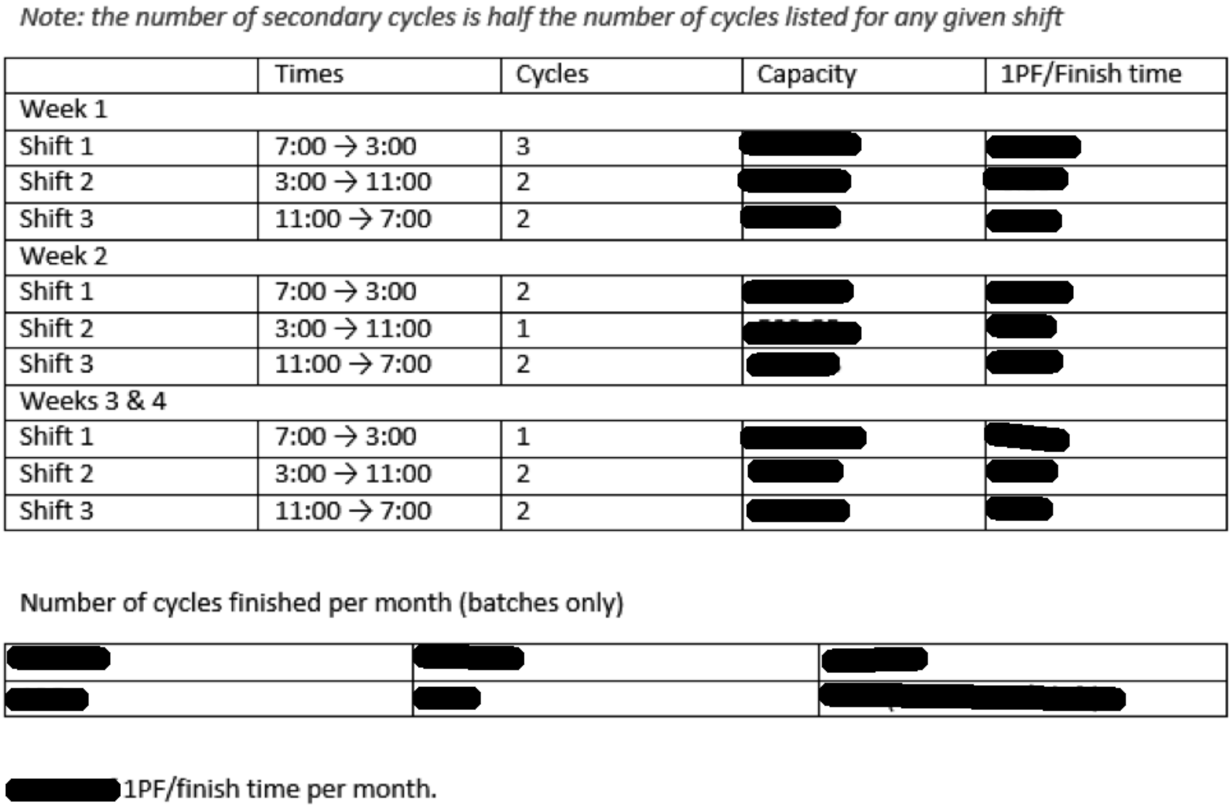
Through our use of an Axiomatic Design decomposition, we were able to verify the flexibility of their existing process and suggest ways to minimize the impact of necessary couplings arising from CNE Direct's strict quality standards. Other couplings we found can be remediated through consideration of the order of operations, which has already been done by their team. We were also able to better understand their process through our discussions with CNE Direct during the various stages of our decomposition's design. This was especially helpful as we continued our analysis of the drive refurbishment process.

With our value stream map, we continued to analyze the process and learned that the most non-value-added time spent in the system is in between processing steps. This was a strong indicator to our team that increasing the process' throughput would significantly reduce the amount of work-in-progress inventory. This led us to look into developing a system which incorporated one-piece flow principles which are known to drastically reduce inventory and work-in-progress materials.

The incompatibility between one-piece flow and CNE Direct's batch purchase order system led us to our idea for a hybrid one-piece flow system. While the models sounded good on paper, our simulations proved that they could not compete with CNE Direct's current scheduling system from a throughput standpoint, despite the advantages they offered in flexibility. This led us to find other ways of improving throughput and/or efficiency, including removal of the pre-test station and optimizing the use of human capital on the floor.

Through our efforts we have found our most important conclusion is that the most effective way CNE Direct could improve their throughput is to simply add capacity to the system. This is a testament to the amount of thought and effort put into the process design by CNE Direct, as well as the careful attention and consideration they have given it as it has reached maturity. Despite considering and researching different changes, some drastic and some small, at best we were able to make suggestions for small improvements, many of which CNE Direct has already been considering for some time. Again, this is evidence of their diligence of achieving high quality and efficiency in their system and their product.

Appendix A – Hybrid process proposal 1



Note: the number of secondary cycles is half the number of cycles listed for any given shift

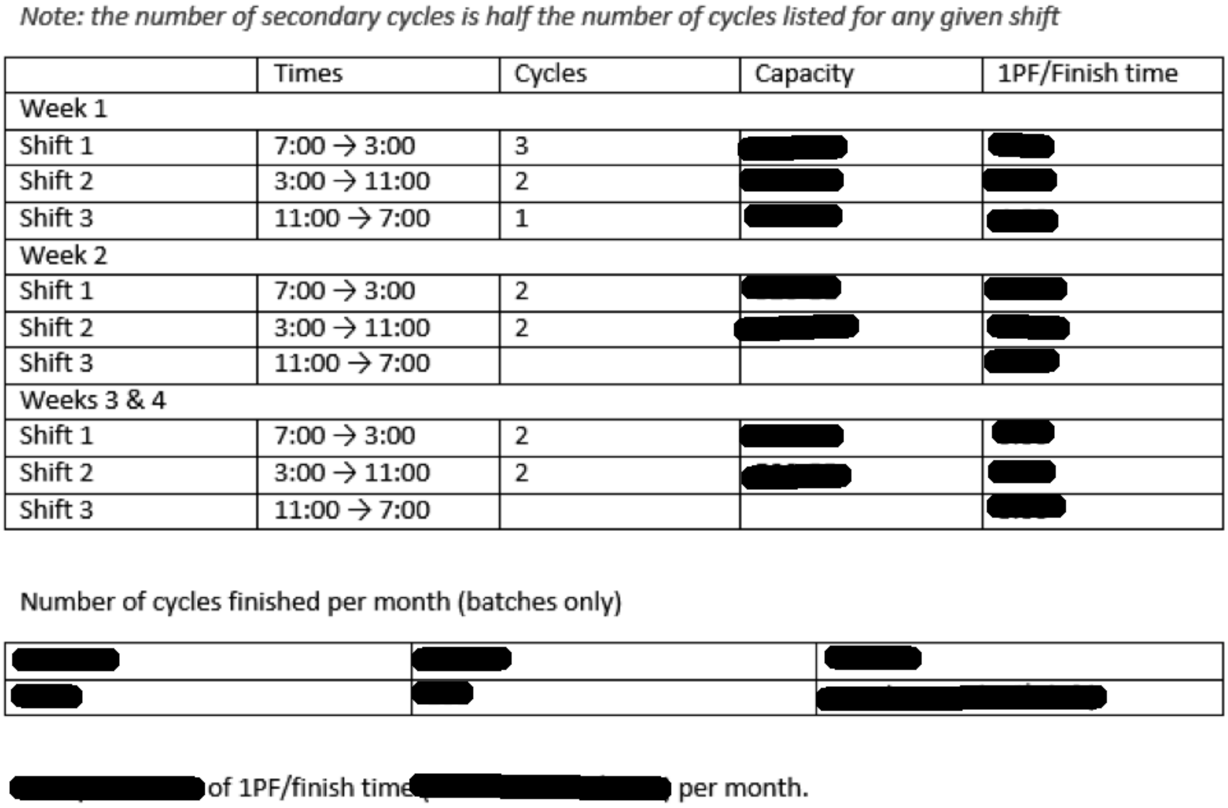
	Times	Cycles	Capacity	1PF/Finish time
Week 1				
Shift 1	7:00 → 3:00	3	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00	2	[redacted]	[redacted]
Week 2				
Shift 1	7:00 → 3:00	2	[redacted]	[redacted]
Shift 2	3:00 → 11:00	1	[redacted]	[redacted]
Shift 3	11:00 → 7:00	2	[redacted]	[redacted]
Weeks 3 & 4				
Shift 1	7:00 → 3:00	1	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00	2	[redacted]	[redacted]

Number of cycles finished per month (batches only)

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted] 1PF/finish time per month.

Appendix B – Hybrid process proposal 2



Note: the number of secondary cycles is half the number of cycles listed for any given shift

	Times	Cycles	Capacity	1PF/Finish time
Week 1				
Shift 1	7:00 → 3:00	3	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00	1	[redacted]	[redacted]
Week 2				
Shift 1	7:00 → 3:00	2	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00			[redacted]
Weeks 3 & 4				
Shift 1	7:00 → 3:00	2	[redacted]	[redacted]
Shift 2	3:00 → 11:00	2	[redacted]	[redacted]
Shift 3	11:00 → 7:00			[redacted]

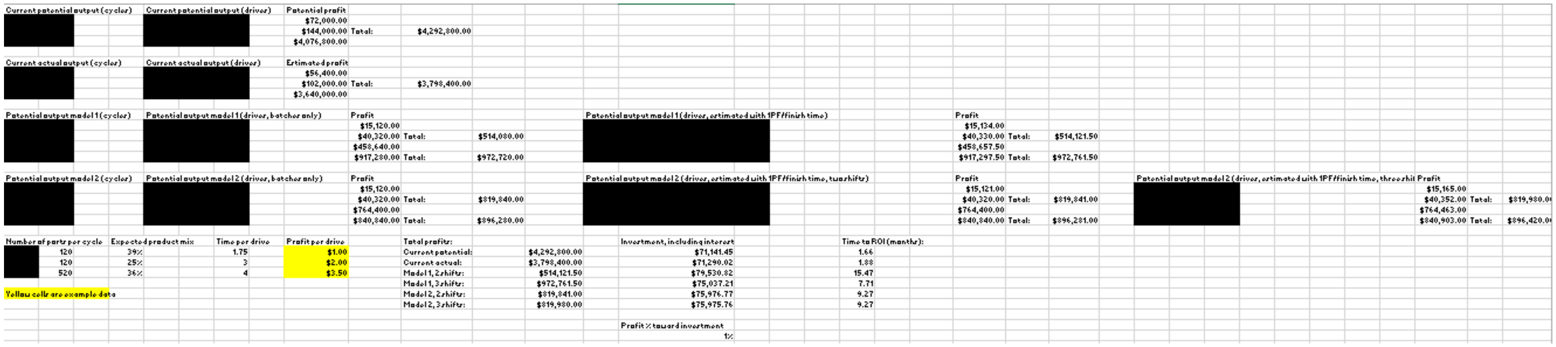
Number of cycles finished per month (batches only)

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted] of 1PF/finish time [redacted] per month.

Appendix C – Simulation model

Example data was used in this simulation where exact numbers were not available.



Current potential output (cycles)	Current potential output (drives)	Potential profit		
[redacted]	[redacted]	$72,000.00		
		$144,000.00	Total:	$4,292,800.00
		$4,076,800.00		

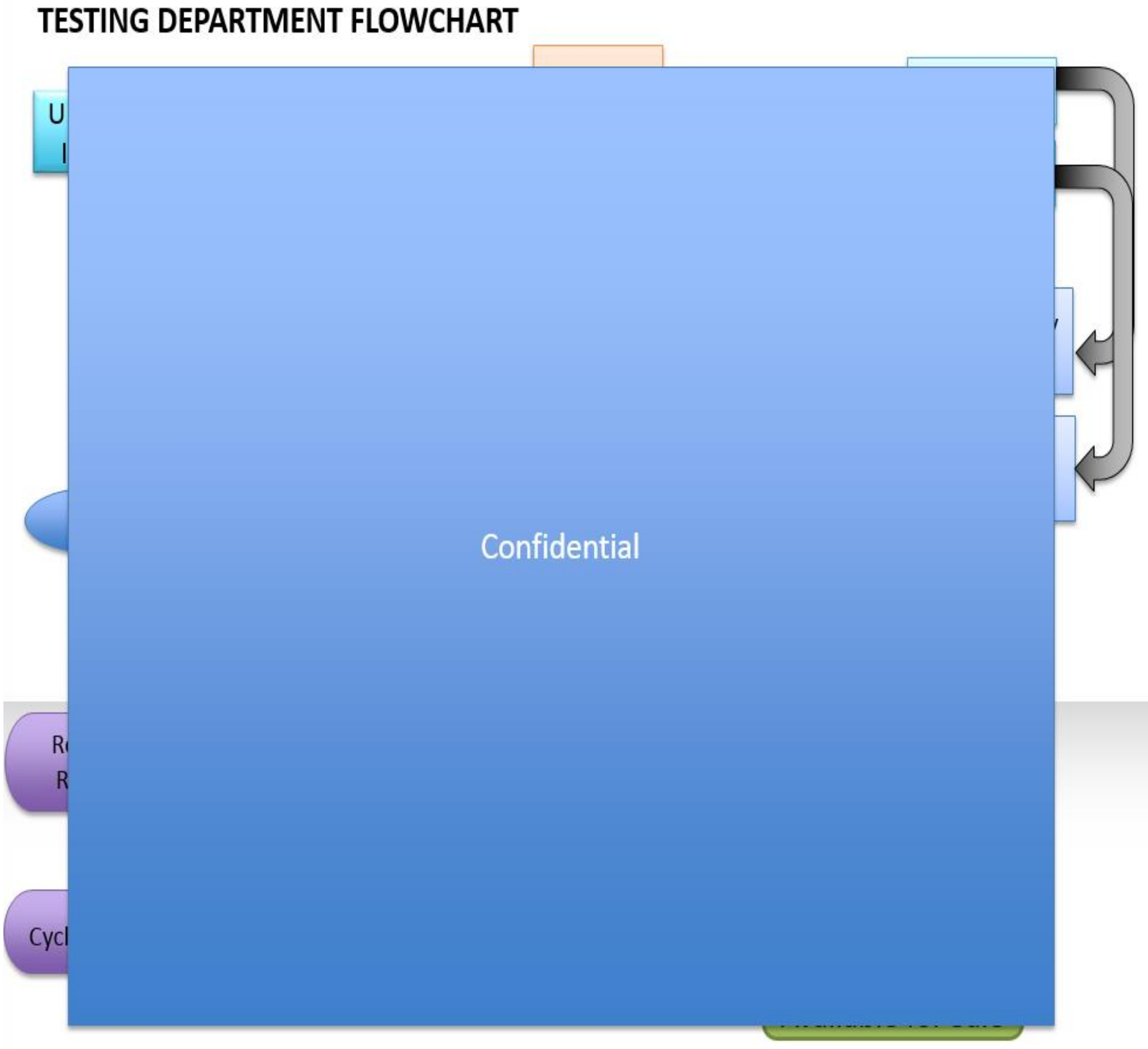
Current actual output (cycles)	Current actual output (drives)	Estimated profit		
[redacted]	[redacted]	$56,400.00		
		$102,000.00	Total:	$3,798,400.00
		$3,640,000.00		

Potential output model 1 (cycles)	Potential output model 1 (drives, batches only)	Profit			Potential output model 1 (drives, estimated with 1PF/finish time)	Profit		
[redacted]	[redacted]	$15,120.00			[redacted]	$15,134.00		
		$40,320.00	Total:	$514,080.00		$40,330.00	Total:	$514,121.50
		$458,640.00				$458,657.50		
		$917,280.00	Total:	$972,720.00		$917,297.50	Total:	$972,761.50

Potential output model 2 (cycles)	Potential output model 2 (drives, batches only)	Profit			Potential output model 2 (drives, estimated with 1PF/finish time, two shifts)	Profit			Potential output model 2 (drives, estimated with 1PF/finish time, three shi	Profit		
[redacted]	[redacted]	$15,120.00			[redacted]	$15,121.00			[redacted]	$15,165.00		
		$40,320.00	Total:	$819,840.00		$40,320.00	Total:	$819,841.00		$40,352.00	Total:	$819,980.0
		$764,400.00				$764,400.00				$764,463.00		
		$840,840.00	Total:	$896,280.00		$840,840.00	Total:	$896,281.00		$840,903.00	Total:	$896,420.0

Number of parts per cycle		Expected product mix	Time per drive	Profit per drive	Total profits:		Investment, including interest	Time to ROI (months):
[redacted]	120	39%	1.75	$1.00	Current potential:	$4,292,800.00	$71,141.45	1.66
	120	25%	3	$2.00	Current actual:	$3,798,400.00	$71,290.02	1.88
	520	36%	4	$3.50	Model 1, 2 shifts:	$514,121.50	$79,530.82	15.47
					Model 1, 3 shifts:	$972,761.50	$75,037.21	7.71
Yellow cells are example data					Model 2, 2 shifts:	$819,841.00	$75,976.77	9.27
					Model 2, 3 shifts:	$819,980.00	$75,975.76	9.27
							Profit % toward investment	
							1%	

Appendix D- Process Flowchart



Appendix E- Cell Capacity

PO	Original Quantity	Balance As of 4-16-14	Capacity	Pretest Requirement	Collection Date	ETA to CNE	Processing Month	Processing Priority	Freight Cost	CPC	Status

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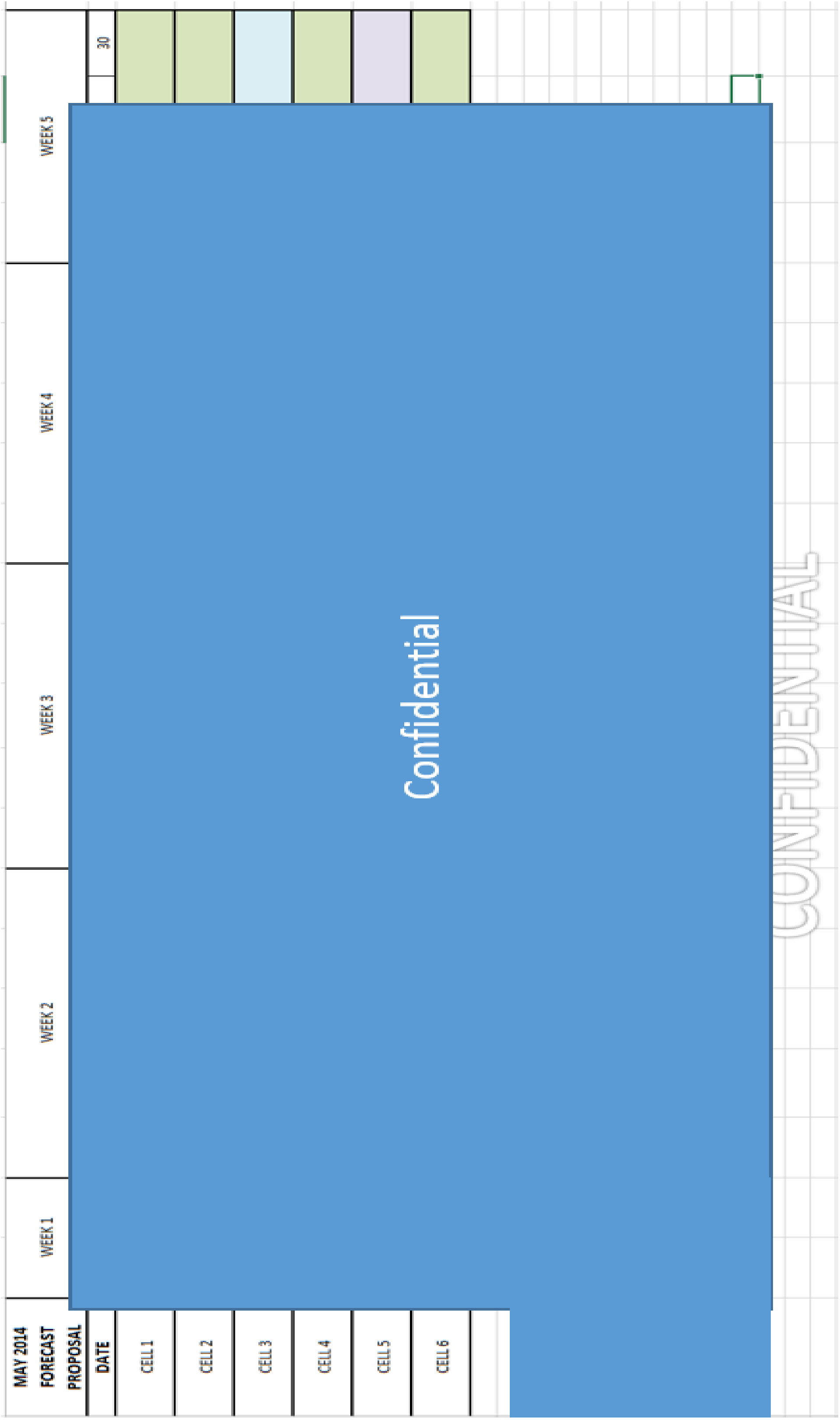
Appendix F- Scheduling Forecast



MAY 2014 FORECAST PROPOSAL	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5
DATE					30
CELL 1					
CELL 2					
CELL 3					
CELL 4					
CELL 5					
CELL 6					

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