Final Report for ISE532 Course on Facility Layout

Implementing Job Shop Lean in a Custom Print Shop

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An IE Student's Guidebook for Facility Assessment and Redesign Using Jobshop Lean Best Practices

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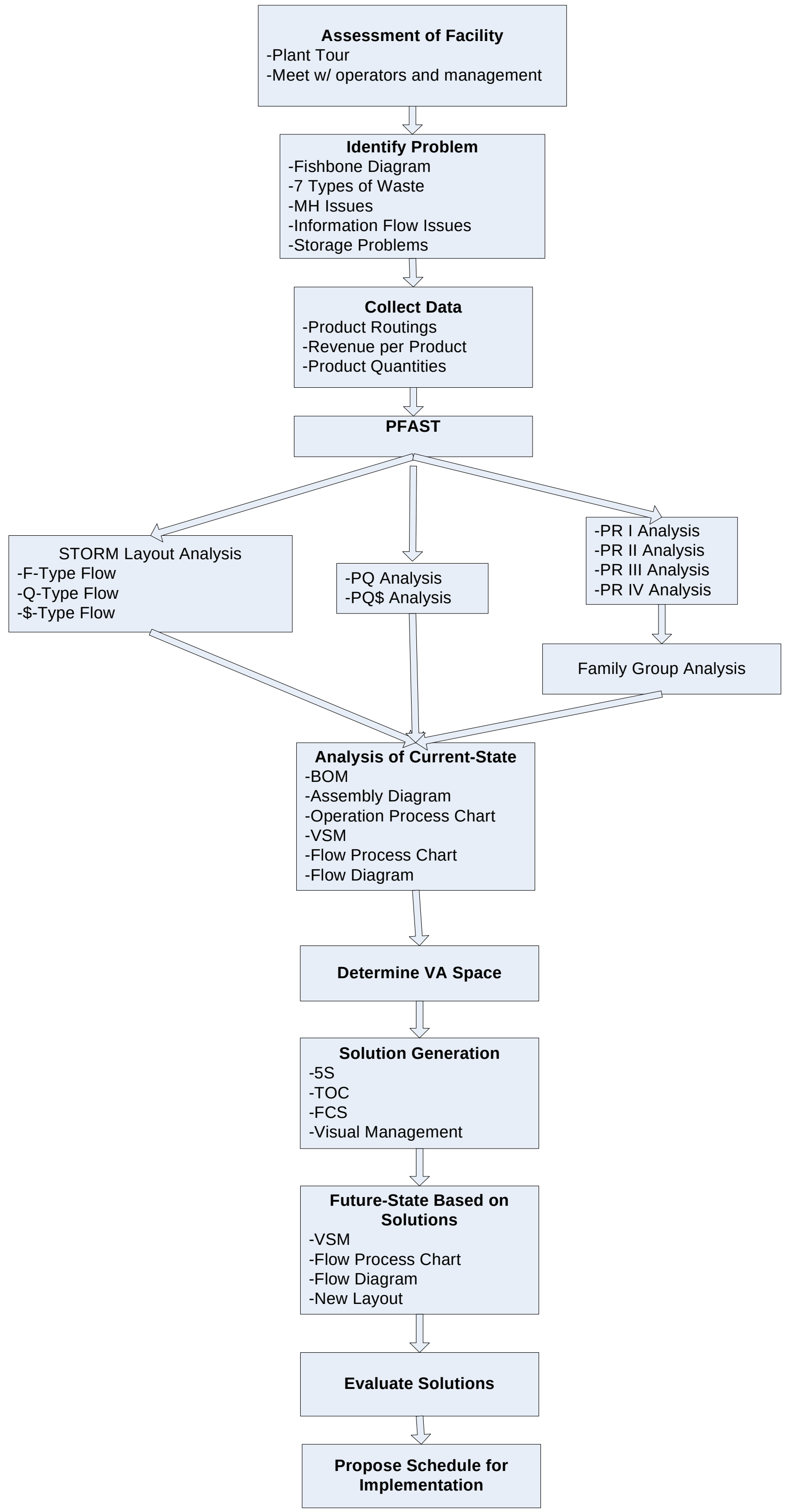


1.0 Project Overview

The project discussed in this document was the primary focus of a Facility Design class within the Industrial and Systems Engineering Program at The Ohio State University. The goal of the class was to learn and apply principles and practices in the design and analysis of process flows, facility layouts, and material handling systems for production, service, and storage systems. The following document describes in detail the steps performed by the project team to deliver potential business results to the assigned company. After the initial analysis the team continued working with UniPrint to implement its solutions. This document has been created to serve as a guidebook that will demonstrate how to successfully evaluate a facility through the use of Lean Manufacturing, Theory of Constraints, and other Industrial Engineering techniques.

1.1 Company Overview

UniPrint, formerly known as OSU Document & Printing Services, is a full service printing facility managed and operated by Ohio State University employees. The company was founded in 1929 with its purpose being “[t]o support the needs and enhance the mission of the university.” In order to successfully recruit and retain students, The Ohio State University must distribute materials such as internal university information, research findings, scholarly reports, and many other documents to its business partners. To enhance these efforts, UniPrint exists to support the communication functions of the university.

Some of the items produced by UniPrint are: official Ohio State business cards and stationary, course packets, graduation announcements, black-and-white copying, color copying, envelopes, postcards, note cards, invitations, posters, books, programs, pocket folders, forms, large format and oversize printing, periodicals, newsletters, and pamphlets. The facility creates these items by using the following finishing and binding processes: cutting and trimming, folding, collating, round cornering, perforating and scoring, binding, die cutting, foil stamping, and other specialty finishes.

In 2005, UniPrint averaged 6.5 million dollars in sales with a projected 7.25 million dollars in 2006, an 11.25 percent increase in sales. The company services approximately 12,000 jobs per year at its facility consisting of 100 or more different types of products.

In order to operate consistently with its strategy, UniPrint has focused its efforts on quality, service, and flexibility. Since it is a non-profit business, its main purpose is to serve the university as a whole and to meet the specific needs of various departments. Such customization requires extensive proofing and process-adjusting in order to produce high-quality documents aligned with the university standards. Due to the nature of its priorities and the significant variations in customers' daily requirements, UniPrint's facility layout is designed to operate as a job shop suitable for flexibility and customization. Some of the primary customers are Admissions, Buckeye Athletics, OSU Medical Center, College of Humanities Literacy program, and Fisher College of Business.

1.2 Our Relationship with the Company

To initiate the project, the team contacted Jeff Dible, Plant Manager and scheduled a planning meeting at UniPrint's facility. He provided the team with a tour of the facility and described the basic printing processes. After the initial meeting, weekly meetings at the facility were scheduled to ensure that the project would be completed in the time frame. The team was permitted to visit the facility unaccompanied by Jeff and took advantage of these opportunities to interface with the operators and understand the challenges that are faced by the current layout.

1.3 Current Facility Layout

The facility contains many large, immoveable presses. The facility was built without anticipating future business growth. Many of the presses are located in isolated rooms, making it difficult for products to flow from one station to the next. These design problems will be addressed throughout this document. Please refer to Figure 1-1 to view the current facility layout.

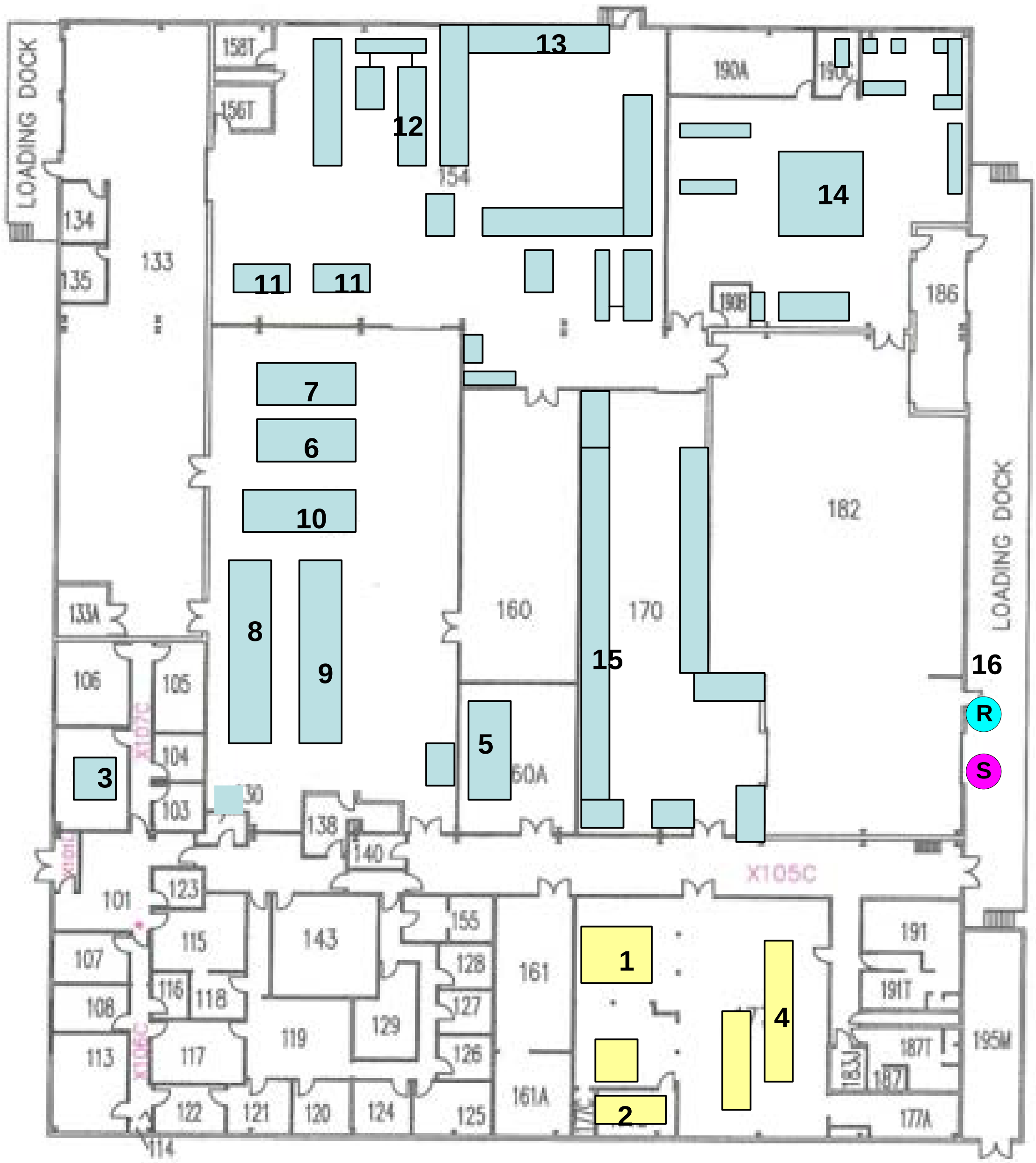


Fig. 1-1. Facility layout for UniPrint's Kenny Road printing facility with the major machines labeled. (See legend in Table 1-1 for machine descriptions.)

TABLE 1-1

MACHINE LEGENDS FOR CURRENT FACILITY LAYOUT

Machine Number	Machine Name	Description
1	Production Planning	Taking a customer order and turning it into a format that can be printed. This involves several employees and computer software. The employees ensure that wording is correct and that the colors will not bleed so that the image is accurately formatted.
2	Prepress	From the image created in production planning, a proof is created that can be sent to the customer for approval.
3	Proofing Approval Process	The created proof is physically sent to the customer for approval to print the job.
4	Plating	For jobs that must be printed on the 6, 5, or 2-color press, plates are created to hang on the printer to transfer the images onto the paper. After the plates are created, they are hung in the press room.
5	Digital Press	Small jobs are run on the digital press. Jobs are sent digitally to the press and production is monitored by an operator.
6	Duplicating	Creates a copy of the original image.
7	Envelope Press	Used for printing envelopes.
8	6-color Press	Allows for up to six colors to be used during printing. The production is monitored by an operator and an assistant.
9	5-color Press	Allows for up to five colors to be used during printing. The production is monitored by an operator and an assistant.
10	2-color Press	Allows for up to two colors to be used during printing.
11	Cutting	This facility has two cutters. An operator manually loads the machine and is then able to start the cutter; he must then manually maneuver the prints to complete the necessary cuts.
12	Folding	The folding machine can make up to four folds in order to create booklets and pamphlets. The machine requires additional attachments to complete more than one fold.
13	Saddle Binding	After Folding, some jobs are then taken to the Saddle Stitching machine to bind the booklets. Multiple booklets can be collated and assembled, then bound with stitching; the edges are then trimmed to complete the Saddle Binding process.
14	Addressing	This group of machines allows for items to be labeled and sent to the recipients.
15	Shipping	Finished goods and raw materials are all stored in the Shipping location. Activity is monitored by one operator.
16	Outside Vendors (DHL, etc.)	Vendors bring raw and packaging materials or deliver finished goods.

2.0 Preliminary Assessment: Problem Identification

2.1 Introduction

Like manufacturing companies that compete in the global marketplace, it is necessary for organizations in the document and printing industry such as UniPrint to develop and implement Lean principles in order to eliminate waste and maintain a profitable business. Because each order is customized to meet the needs of its business partners at Ohio State, UniPrint must have flexible operations in order to produce a finished document that conforms to the exact specifications of the customers' order proofs. Therefore, the company operates as a job shop and faces the challenge of successfully producing over 100 types of documents that vary in size, color, and content. Such challenges have caused UniPrint to encounter issues with production scheduling; high levels of raw material, work-in-process and finished goods inventory; and extensive lead times for its products. The project team assessed UniPrint's current operations in order to identify key improvement opportunities and conducted the necessary analyses to generate useful solutions and recommendations.

2.2 Problem Statement

After observing UniPrint's current-state and performing in-depth assessments of the facility, the project team identified several elements of the system that need adjustment. During the initial facility walk-through, the project team determined that the Shipping department is in an infeasible location which contributes to a poor overall facility layout. Consequently, operators perform unnecessary material handling in order to transfer finished product to the Shipping area; this directly increases the job's overall processing time. Additionally, UniPrint practices what is referred to as "push" production, meaning that new jobs are released to the shop floor before current jobs are completed. This causes a high level of work-in-process (WIP) inventory to collect in front of each workstation which leads to increased processing times and shipment delays. Furthermore, the company does not currently have a standard scheduling method or a reliable information system within the facility. Since a Finite Capacity Scheduling system is not in place, the flow of raw materials and current jobs is not continuous and no synchronization exists between workstations. This further causes raw material and WIP inventory to accumulate throughout the facility; it also leads to a poorly prioritized job schedule at each workstation. Therefore, UniPrint has large amounts of waste that are occupying valuable floor space throughout the facility and are tying up the company's financial resources.

The following sections discuss in detail the project team's assessments and identify the specific problem areas to be addressed within the UniPrint facility.

2.3 Preliminary Findings

2.3.1 Fishbone Diagram

In order to determine the root cause(s) of UniPrint's high inventory levels and other operational issues, the project team constructed cause and effect, or fishbone, diagrams to assist in categorizing the many potential causes of such issues. After performing the fishbone analysis, the project team determined the root causes of UniPrint's high inventory levels: push production and an infeasible shipping location. By organizing the factors branching from each "bone", the project team observed that UniPrint's practice of push production was a root cause of high inventory levels throughout the manufacturing process. This Fishbone Diagram is provided in appendix A-1. The primary factor stemming from the "Materials" bone was that raw materials are ordered before new jobs are ready to be scheduled for production. The project team discovered that raw materials may sit in the Receiving area of the warehouse for six or more months before the corresponding job is ready to begin its first production process. This is because materials are ordered as soon as a new job is received in the system; however, the due date may be several months in the future. Several factors within the "Methods" and "Man" categories further alluded to the idea that push production is the root cause of high inventory levels. One such factor is that each UniPrint supervisor creates a separate production schedule for his assigned workstation. Although one workstation may be able to efficiently run and finish a particular job during the work day, the subsequent workstation may not have the capacity to begin that job during the same shift. The continuous pushing of new orders into the system causes bottlenecks early in the production system, which creates downstream workstations to accumulate WIP and fail to complete jobs on time.

The second overall root cause of high inventory levels throughout the UniPrint facility was a poor location of the Shipping department. This Fishbone Diagram is also included in appendix A-1. The main factors within the "Methods" and "Materials" categories were that the Shipping department is located over 150 feet from the production floor and that finished goods inventory has been stored on the warehouse's vertical racks for over two years. Because the Shipping area is such a long distance from the final production workstation, orders must be moved from the shop floor in large batches. The completed orders are then stored directly on the warehouse floor since the vertical storage racks are occupied by older finished goods inventory. Since these orders occupy the floor space in the warehouse and the layout of the room is not designed to accommodate traffic flow, it becomes rather difficult for the Shipping operator to access the necessary materials. Additionally, UniPrint does not currently have a standard process in place (such as an "Earliest Due Date" arrangement) to organize raw materials or finished goods. Pallets are placed in an ad-hoc fashion on the warehouse floor, as the operators have limited space to maneuver fork lifts and cannot place materials on the vertical storage racks. These constraints can cause the operator to spend up to fifteen minutes of non-value added time maneuvering finished goods in the warehouse to locate the next order to be shipped or a pallet of raw materials to be delivered to the shop floor. The primary factor within the "Measurements" category was that orders are completed one week or more before the scheduled due date, but are not immediately shipped to the customers. Since UniPrint does not have a Finite Capacity Scheduling (FCS) system in place, orders may be completed too early by the operators in order to utilize their workstations. Furthermore, job orders that are released prematurely into the system result in high levels of WIP between workstations. These high WIP levels along with the lack of communication between workstations cause an increase in lead times, un-prioritized job scheduling and processing, an increase in finished goods inventory levels, and an increase in the probability of missing due dates. While some orders are in fact completed before the due date, the disorganization of materials in the warehouse as well as the lack of a formal inventory information system causes some orders to be misplaced for days at a time and to ultimately be delivered to the customer after the promised date. The primary factor within the "Man" category was that UniPrint does not efficiently process its

Shipping and Receiving orders. The facility currently has a single operator in charge of both departments. If the operator is delivering raw materials to the production floor, no one is available to attend to vendors who are delivering new raw material orders or to couriers who are picking up completed customer orders. This causes delays in both cases and can further increase order lead times. Additionally, the operator is responsible not only for the transfer of raw materials and finished goods but also for the processing of purchase orders and bills of lading. Currently, UniPrint uses two different computer databases for the purchase order and billing processes. The purchase order number that is generated by the Purchasing & Sales department is incompatible with the database for the Master Production Schedule (MPS). The operator must mentally be aware of the specific rules to follow in order to translate the number into the required job number format in the MPS system. He must also physically write this job number on the raw materials pallet; when the job is complete, he must then manually create a Bill of Lading and ship ticket with this job number and color-code the tickets according to his perceived shipment priority. Since the operator is responsible for successfully remembering and executing these specialized tasks, UniPrint's production and delivery systems are highly susceptible to human error. Any error caused by the operator can directly result in a delay in the production process and/or a missed shipment.

By creating two Fishbone Diagrams, the project team was able to identify the primary issues associated with UniPrint's excessive inventory levels, production scheduling and logistics, and the facility's overall operations. These diagrams also aided the team in understanding the root causes of these two issues. A Checklist for Assessment is included in appendix A-2 to supplement the Fishbone Diagrams and to further explain the layout-related problems discovered by the project team. In order to gather more information about these causes and their effects on UniPrint's production system, the project team continued its assessments by using additional Industrial Engineering tools. The following section will discuss the team's plan of identifying and eliminating the seven types of waste, which is a renowned process associated with Lean Manufacturing.

2.3.2 Seven Types of Waste

One of the fundamental methods for practicing Lean in the workplace is the identification and elimination of the Seven Types of Waste. The Seven Types of Wastes are direct causes of non-value added time and unprofitable activity in the manufacturing process. It is therefore necessary for companies such as UniPrint to actively seek out these types of waste and form a solid continuous improvement program. The Seven Types of Waste include: (1) Overproduction (2) Useless Motion/Conveyance (3) Waste in Production Processes (4) Queuing (5) Scrap and Rework (6) Excessive Inventory and (7) Transportation and Handling. By performing an in-depth walk-through of the facility and observing the current production process, the project team was able to identify several opportunity areas for UniPrint to eliminate excessive waste and become a leaner document printing company.

Within the Processing Department, the first workstation in the UniPrint facility, the project team identified three types of waste: Scrap and Rework (or Correction), Processing, and Useless Motion. During this process, customer order proofs are created and are then sent back to the customer for final approval. This leads to waste from correction, because proofing is necessary to ensure that the customer's order is accurate. Figure 2-1 below shows a sample proof that was created for one of UniPrint's customers.

Fig. 2-1: Picture of sample proof created for customer. Generating proofs can lead to Correction waste due to order inaccuracies.

However, the front desk at UniPrint is not immediately signaled when orders are ready to be sent to the customer for the final proof adjustments, thus increasing the non-value added time of the order's overall processing time. Each customer order also has a physical job ticket associated with it, which is manually transported to each workstation by the operators. For example, the operator must carry the proof a distance of 115 feet from the Pre-Press/Proofing area to the Press room. If the ticket does not contain all of the necessary information for the order or if it does not specify the product's exact location, the operators will perform unnecessary motion when walking around to locate the product or to inquire about the omitted information at the Customer Service desk (a distance of 178 feet). Figures 2-2 through 2-4 respectively display a sample job ticket, the location of the Customer Service desk, and the 115 foot long hallway operators must walk down to access the desk.

Fig. 2-2: Sample job ticket created for each customer order.

Fig. 2-3: Customer Service desk located at the front of UniPrint's facility.

Fig. 2-4: Picture of hallway between Customer Service desk and Processing department. This displays the 115 foot distance traveled by operators to access order information.

Finally, the department creates Processing waste because the printer used to create proofs has an efficiency level of 50%. This waste is caused by a frequent number of paper jams, which ultimately extends the job's processing time. In order to eliminate these instances of waste in the Processing Department, the project team's goals are to: minimize material handling distances; institute attainable Quality Control goals; and integrate all material, people and information flows throughout the department.

The second workstation to be assessed by the project team was the Digital Press area. While this process has an efficient electronic system that sends orders directly to the operator, the order's proof ticket still must be manually brought to the Digital Press room. This type of waste, Useless Motion, involves the operator walking the proof a distance of 145 feet; this results in an increase in the lead time for the order. Moreover, the Digital Press department is located 70 feet away from the Bindery workstation, which is the next workstation in the manufacturing process. This further increases the amount of useless motion performed by the operator and, consequently, the lead time of the product. In order to eliminate wasted motion performed in the Digital Press department, the team expects to minimize material handling distances and possibly integrate the job ticket into the current electronic system.

The Pre-Press workstation, which creates plates to process conventional order proofs from the Processing Department, was the next workstation to be assessed by the project team. Pre-Press electronically sends orders to the plating machine for off-set printing. A separate plate must be created for each color used in the printing process. These plates are created immediately after the proofing process is complete rather than following a just-in-time (JIT) scheduling system. This causes Overproduction waste, since the plates may be produced before the next workstation is capable of receiving them for further processing. Figure 2-5 shows how plates remain in queue due to overproduction.

Fig. 2-5: Plates in queue on hanging rack in Press Room.

After the plates are created, the Press Room operator must manually transport them a distance of 115 feet to the Press Room to begin the actual printing process. As a result, the Pre-Press operation creates waste in the form of non-value added motion performed by the worker. By minimizing material handling distances, implementing a JIT scheduling system to eliminate queuing delays, and possibly assigning a separate worker to retrieve the plates for the Press operator, UniPrint can achieve a more consistent and lean process flow.

The next workstation in the production process is the Press Room, which is responsible for the actual printing of the job orders (unless they are assigned to the Digital Press). Upon assessment of this workstation, the project team identified six of the seven types of waste. Currently, UniPrint produces 2 percent more prints for each order. These additional prints serve as a buffer in case some of the prints are defective. If there are no defective prints present, then the paper becomes scrap and accumulates in trash bins on the shop floor. This waste from overproduction increases the amount of raw materials that are needed and reduces operating efficiency. Figure 2-6 shows a large scrap bin containing unused prints that sits on the shop floor.

Fig. 2-6: Large amounts of scrap accumulate on shop floor due to Overproduction waste.

Waste is also experienced in the form of scrap and rework. Samples are taken during an order's printing process to ensure the prints are correct and of the desired quality. If any defects are found, the necessary changes are made to the printer settings and those defective prints are scrapped. Figure 2-7 shows the sampling workstation in the Press Room.

Fig. 2-7: Sampling workstation in Press Room where operators check for defective prints.

The third type of waste discovered within the Press workstation was excessive transportation. Press Room operators must retrieve paper via a fork lift from the Receiving area, which is a distance of 211 feet away from the press machines. After orders have completed the printing process, they are moved a distance of 67 feet to the

Bindery Department. Excessive inventory was the fourth and perhaps the largest form of waste found within the Press Room. Raw materials, which consist of pallets of paper, are delivered daily to the Press Room. These materials can sit on the shop floor up to twelve hours before the job is ready to be run on the presses. Figures 2-8 and 2-9 on the following page show the excessive inventory occupying the Press Room floor.

Figs. 2-8 and 2-9: Excessive raw material and WIP inventory stored on Press Room floor.

WIP exists on the Press Room floor because jobs are completed before the Bindery Department, the next workstation in the production process, is able to receive additional work. This creates waste due to queuing in the process, the fifth form of waste within the Press Room. Jobs should be scheduled according to just-in-time principles. In other words, the Press Room should only produce new jobs so that they are finished just in time to replenish orders for the subsequent workstation (the Bindery Department). Figure 2-10 shows jobs that are in queue and waiting to be transferred to the Bindery Department.

Fig. 2-10: Jobs in queue on Press floor waiting to be transferred to Bindery department.

The sixth and final type of waste in the Press Room results from excessive operator motion. During the printing process, the operator must sit and bend in difficult positions when cleaning and setting up the press machines. The set-up time (including non-value added operator motion) is approximately fifteen minutes per color. Additionally, the operator must gather the necessary supplies for the set-up process. While the cleaning supplies are stored directly adjacent to the machine, inks and plates are located 30 feet away from the 5-color press and 80 feet away from the 6-color press. Due to the clutter on the Press Room floor, the operator wastes valuable time maneuvering through the area to retrieve these materials, thus increasing the lead time for job orders. In order to eliminate the large amounts of waste in the Press Room, the following actions should be taken by UniPrint's supervisors: implement JIT scheduling, minimize the amount of material in the work area, minimize material handling distances, and set attainable quality control goals.

The project team continued its waste assessment in the Bindery Department, which is the workstation that follows the press processes. Four types of waste were identified: transportation, queuing, excessive inventory, and useless operator motion. WIP inventory accumulates before the Cutting and Saddle Stitch processes because a JIT scheduling system is not in place; this WIP remains in the system for up to two hours. Figures 2-11 and 2-12 depict the amount of WIP that can accumulate on the production floor in the Bindery Department.

Figs. 2-11 and 2-12: WIP inventory accumulates before machines and clutters the work area because no FCS system is in place.

WIP also occurs when machines break down, which can delay processing anywhere from five minutes up to four hours. UniPrint's operations are highly susceptible to machine breakdowns, as no preventive maintenance program is in place at this time. Another type of waste, queuing, occurs when jobs are waiting to be packaged and transported to the Shipping Department. Figure 2-13 shows the excessive number of booklets that are waiting to be packaged in the Bindery Department.

Fig. 2-13: Thousands of "Keep Books" occupy up to 500 square feet of the production floor in the Bindery department.

Operator motion is a significant portion of the waste in the Bindery. One primary cause of this useless motion is that fork lifts are needed to transport jobs, and these fork lifts are not stored in a designated area. Therefore, operators spend up to five minutes locating the fork lift and retrieving the necessary job. Figures 2-14, 2-15 and 2-16 show the long distances orders are transported to and from the Bindery, the inconvenient location of material handling equipment, and the effort required by an operator to transport these orders, respectively.

Fig. 2-14: Operators must transport orders over large distances with little to no line of sight between workstations.

Fig. 2-15: Material handling equipment does not have a centralized storage area.

Fig. 2-16: Operators spend non-value added time locating and retrieving material handling equipment.

This leads into the fourth type of waste identified in the Bindery Department: excessive transportation. After jobs are finished in the Bindery, they are transported a distance of 170 feet to the Shipping Department. While this distance may not seem to result in a large amount of wasted motion or time, UniPrint produces over 12,000 jobs per year. By summing the wasted time over all of these jobs, one can see how this non-value added time exponentially increases! The Bindery Department can eliminate its waste by implementing a JIT scheduling system, setting easily attainable quality control and preventive maintenance measures, and assigning a centralized location for material handling equipment.

The Receiving/Shipping Department is the final workstation in the production process. After assessing the warehouse area, the project team identified three types of waste. The first type was a result of wasted intellect (or correction). During the receiving process, raw material orders that were placed with the Purchasing department are pulled up on the computer to be reviewed. The operator then checks the accuracy of each raw material order with its corresponding ticket; this process takes between ten and fifteen minutes. If the purchase order contains any errors, the operator must, if possible, make the necessary corrections; if the order is completely incorrect, he must create an entirely new order and further delay production. Excessive inventory is a major cause of waste within this department. Since raw materials are sometimes ordered up to five months in advance, inventory levels become extremely large. Additionally, the vertical storage racks in the warehouse are occupied by outdated orders that have never been shipped to the customer. This results in raw materials and finished goods having to be stored directly on the warehouse floor and creates maneuverability issues for the workers. Not only does the excessive inventory reduce the line of sight through the warehouse, but it also translates into non-value added time that workers spend moving pallets around to access necessary material. Figures 2-17, 2-18, and 2-19 show the excessive amount of inventory stored in the Shipping and Receiving department.

Figs. 2-17 and 2-18: Because raw materials are ordered up to five months in advance and vertical storage is occupied, excessive inventory is stored directly on the warehouse floor.

Fig. 2-19: Outdated finished goods inventory occupy vertical storage racks, causing current orders to be stored on the warehouse floor.

Transportation/logistics was identified as the third type of waste within the Receiving/Shipping department. Since all receiving and shipping flows through the same dock, transportation issues arise. Figure 2-20 shows the narrow doorway that all Receiving and Shipping transactions must flow through.

Fig. 2-20: All Receiving and Shipping deliveries occur through this narrow doorway.

Furthermore, one worker is responsible for both operations; if he is away from the area, truck drivers must wait for him to return to receive the necessary paperwork for receiving or delivering materials. In order to eliminate these types of waste within the department, the following actions must be taken: the Shipping area should be placed in proper relation to internal flow, materials should be removed from the warehouse floor, outdated materials should be cleared from vertical storage, and raw materials should be ordered by JIT scheduling.

By assessing the current operations at UniPrint, the project team successfully identified several forms of waste throughout the facility. The seven types of waste described in this section are generally caused by variability within the production system; variability causes downstream operations to experience delays in the arrival of work, otherwise known as a lack of continuous flow. Since UniPrint does not have a continuous process flow due to a variable product mix and lack of a FCS system, the company has high amounts of each of the seven types of waste. In order to become a lean document and printing business, UniPrint must implement a continuous improvement program and engage in the relentless pursuit and elimination of waste. The project team will perform in-depth assessments and develop a formal plan to aid UniPrint in eliminating waste and operating as a lean and efficient business.

2.3.3 Material Handling-Related Problems

As discussed in the previous section, transportation and material handling is a major cause of waste in manufacturing facilities. While some material handling is necessary to transport product within and between workstations, excessive handling can lead to the following issues: increases in lead times and overhead costs, discontinuous flow throughout the production line, and wasted manpower from retrieving and operating material handling equipment. Therefore, developing and implementing an efficient manual materials handling process is essential in achieving a lean manufacturing system. The project team observed and assessed UniPrint’s current material handling processes and identified several key opportunities for improvement. The following section will provide details on the facility’s material handling-related problems including associated costs, causes of discontinuous flow, lack of process standardization, and high levels of non-value added work.

Since UniPrint produces orders that consist of thousands of sheets of paper or similar materials, several types of material handling equipment are used to transport these heavy and bulky orders between workstations. The following table provides the types and quantity of material handling equipment as well as the associated cost of purchasing this equipment.

TABLE 2-1

ANALYSIS OF MATERIAL HANDLING EQUIPMENT COSTS

Equipment Type	Number of Units	Unit Cost	Total Cost
Pallet Jack	8	$315	$2,520
Fork Truck	2	$7,500	$15,000
Wood Platform Dolly	24	$25	$600
Scissor Lift Pallet Jack	1	$600	$600
			$18,720

In order to further assess the costs associated with material handling, the project team closely observed the production process of a Saddle Stitch job. The material handling processes associated with this Saddle Stitch job are summarized in the Material Handling Planning Chart provided in appendix A-3. An example of a Saddle Stitch job is a program booklet for athletic events, which is a type of booklet that requires the separate pages to be stitched together. The following table shows the material handling costs for a Saddle Stitch job that were quantified by the project team.

TABLE 2-2

ANALYSIS OF COSTS ASSOCIATED WITH MATERIAL HANDLING FOR A SADDLE STITCH JOB

Process	Labor Costs per Hour	Number of Hours	Units of Material Moved	Material Costs per Unit	Total Cost
Plating	$20.60	0.08	10 plates	$17.20/plate	$173.72
Press	$19.87	0.17	23,000 sheets	$0.07/sheet	$1,613.31
Bindery	$18.80	0.17	23,000 sheets	$0.07/sheet	$1,613.13
					$3,400.16

As indicated by the above tables, UniPrint currently has over $20,000 of overhead resources tied up in its material handling processes. One Saddle Stitch job contributes to $3,400 of material handling costs along with the variable costs associated with equipment use. Since UniPrint services approximately 12,000 jobs per year, one can recognize that excessive material handling can exponentially increase the company's overhead costs.

In addition to the excessive costs associated with transporting products, UniPrint's current material handling method causes discontinuous process flows throughout the facility. In a lean manufacturing system, the optimal state to achieve is continuous or one-piece flow. Continuous flow means that items are processed and moved directly to the next process one piece at a time. Each processing step completes its work just before the next process needs the item and the transfer batch is of size one. This is also known as one-piece flow and "make one, move one". However, one-piece flow is not optimal for UniPrint because one job consists of thousands of sheets of paper; thus, jobs are transferred as one large batch using available material handling equipment. Since these jobs are transferred in batches, finished product must wait for the entire batch to complete. The next workstation in the process must also wait for this batch to arrive in order to continue production. Moreover, no Finite Capacity Scheduling (FCS) system is in place and raw material is prematurely ordered. This leads to jobs being processed too early, causing WIP to accumulate between workstations. Therefore, the flow of products is not continuous throughout the facility.

When assessing current material handling methods, several different principles should be considered. The Standardization, Work, Space Utilization, and System Principles provide guidance and perspective to manufacturing and design engineers when planning and implementing material handling systems. The project team focused on these four principles when evaluating UniPrint’s current-state operations and discovered specific violations of these principles. The Standardization Principle requires less variety and customization in the material handling methods and equipment employed in the facility. In UniPrint’s current production system, jobs that have completed a process are not immediately transported to the next workstation; they are not even directly delivered to the workstation itself, as operators often leave jobs on the shop floor in the general vicinity of that station’s machines. Another violation of this principle is the lack of a designated material handler on the production floor. As a result, machine operators must leave their workstations to either retrieve raw materials or deliver jobs in the form of WIP to the next machine in the process. This can increase the lead times (caused by the increase in non-value added transportation time) as well as delay completion times for the company’s job orders. The Work Principle evaluates the work associated with material flow, where work is the volume of material moved per unit of time multiplied by the distance moved. For each job, UniPrint’s operators must exert a high level of work to transport a 3’x4’x5’ skid of raw material a distance of 211 feet from the Receiving Department to the Press Room. Since the goal for an efficient material handling system is to minimize the amount of work, the current-state system is in clear violation of this principle. Furthermore, this transportation of materials increases the jobs’ lead times, prevents operators from performing value-added tasks associated with the actual order processing, and increases the chances of damaging the materials and/or inflicting injuries upon the operators.

A third material handling principle, Space Utilization, involves quantifying the amount of cubic space occupied by materials along with the non-value added motion and time associated with material handling. Since vertical storage racks in UniPrint’s

Shipping & Receiving warehouse are occupied by scrap and outdated job orders, raw material clutters the area and results in the non-value added operator motion from maneuvering material handling equipment to access pallets of paper. In order to quantify the actual cost of this non-value added motion, the following sample calculation is provided:

- Average time spent accessing and retrieving material: Five minutes per job
- Average number of jobs: Five per day
- Number of working days per year: 250
- Operator hourly rate: $20 per hour
- Yearly non-value added time:

  (5min./job)*(1hr./60min.)*(5 jobs/day)*(250 days/yr) = 104.17 hours per year

- Costs associated with wasted operator motion:

  ($20/hr.)*(104.17hrs./yr.) = $2,083.33 per year

Therefore, UniPrint incurs over two thousand dollars in labor costs every year simply from accessing raw materials in the warehouse. Performing this calculation for each material handling process in the current system would show that the company has a significant portion of its overhead tied up in costs associated with wasted motion.

In addition to the wasted operator motion, the excessive raw material and WIP between workstations delays the transport of material because of the lack of line-of-sight throughout the facility. Currently, over $90,000 worth of raw material and finished goods inventory occupy the warehouse floor. This is obviously a significant amount of overhead costs and further alludes to the violation of the Space Utilization principle.

The fourth and final material handling principle studied by the project team was the System Principle, which involves assessing the interaction of the manufacturing tasks that form the overall process. One major issue with the current system is the large travel distances between workstations. Pallet jacks or fork trucks must be used to transport pallets of paper from the Receiving Department to the Press Room, a distance of 211 feet. Since jobs are transported as one large batch, wood platform dollies must be used to transport the jobs from the Press Room to the Bindery Department, a distance of 67 feet. Additional issues include the lack of a FCS system and line-of-sight between workstations. Operators and supervisors must search for current job orders in the computer system to track their statuses. Furthermore, no communication exists between workstations and operators are unaware of when to release jobs or when to begin new ones. Supervisors instead perform “go-see” scheduling, which means that they must manually walk to the upstream workstation and visually detect if it is ready to receive new jobs. This is an indicator of push production and inefficient order tracking within the facility.

In order to summarize the amount of wasted motion and time associated with material handling, the following section describes the type of waste within each work center along with the corresponding times and costs.

- **Shipping**: Operators must maneuver material handling equipment around raw material stored on the warehouse floor, which results in wasted motion and time. This material could be stored on the vertical racks if outdated finished goods were removed.
- **Prepress:** Job tickets sometimes lack all of the necessary information about where the electronic file is stored on the computer. As a result, operators waste time searching for the files when they could be performing value-added activities such as processing additional electronic orders.
- **Bindery:** WIP inventory is stored on the shop floor, causing excessive movement between the Folder and Saddle Stitch operations. Implementing a more efficient pull production system could eliminate the WIP between workstations.
- **Press:** Operators must maneuver material handling equipment around WIP inventory in order to transport jobs between workstations. They must also manually retrieve ink from storage racks located across the room. Implementing a pull system and storing raw material adjacent to the presses would eliminate wasted motion and time for the Press Room operators.

TABLE 2-3

ANALYSIS OF ANNUAL COSTS ASSOCIATED WITH WASTED MOTION AND TIME FROM MATERIAL HANDLING

Operation	Wasted Time per Job (minutes)	Minutes per Hour	Average Number of Jobs per Day	Working Days per Year	Operator Hourly Rate	Total Wasted Time (hours)	Total Cost
Shipping	5.00	60	5	250	$20	104	$2,083.33
Prepress	5.00	60	10/person	250	$20*(5 operators)	1041.67	$20,833.33
Bindery	0.15	60	8	250	$20*(3 operators)	15	$300.00
Press (MH equipment)	0.15	60	4	250	$20*(2 operators)	6	$100.00
Press (Retrieving ink)	0.589	60	4	250	$20*(2 operators)	20	$392.67
						1186.67 hours per year	$23,709.33 per year

After assessing the current material handling process, the project team identified the total amount of wasted time and money associated with violations of the material handling principles explained in this section. The design of a facility's material handling system is an important component of the overall process' efficiency. In order to achieve a lean future-state process, further assessments will need to be performed and a standardized material handling method must be integrated into UniPrint's production system.

2.3.4 Information Flow-Related Problems

When learning about the many different lean manufacturing concepts in the classroom and hands-on in the industry, some common misconceptions tend to arise. Often times lean is simply thought of as the just-in-time (JIT) method. However, lean manufacturing encompasses several different concepts. One crucial tool that is often overlooked is an electronic information system. A floor information system can help companies such as UniPrint become leaner by effectively identifying issues within the production system, creating accurate and feasible schedules, tracking orders through the system, and achieving synchronization between workstations. The project team evaluated UniPrint's current information flow and identified several improvement areas which will be discussed in this section.

Perhaps the most significant information flow-related issue is that UniPrint has no visual displays on the production floor for flow time, costs, schedules, or quality of work. Rather than using a visual management system such as a magnetic whiteboard to display the current production schedule, area supervisors print the five month order forecast and schedule work for their respective areas based on the orders' due dates. The shop floor does have one LED counter over the cutting machine that displays the number of completed pieces, but this counter is difficult to see from other areas. Another issue involves the speed of information flow regarding machine breakdowns, schedule changes, material handling requests, and job instructions. Currently, schedule changes are communicated by the area supervisors using an inefficient word-of-mouth method. These supervisors meet an average of ten minutes before every production shift to finalize the daily requirements. They must then walk a distance of 150 feet from the front office to the Press Room and an additional 100 feet to the Bindery Department in order to provide job schedules and instructions to operators; the operators must also walk these same distances to clarify information as needed. Since the current-state production system does not provide a material handling signaling process, operators cannot communicate that a fork truck or pallet jack is needed to retrieve materials or deliver job orders. Therefore, they must walk an average distance of 50 feet to other workstations in order to locate and retrieve the necessary equipment.

The third major issue related to UniPrint's information flow is that the production departments use a completely different computer system than the Purchasing department, which causes inconsistencies in the generated purchase orders as well as a discontinuous flow of electronic information. Currently, the purchase order numbers generated within Purchasing are in an unrecognizable format for the Receiving department's computer system. The Receiving supervisor must manually input the purchase order number in another format for each new job. If the number is entered incorrectly, the corresponding raw material order will be lost for that job. This can directly result in a delay in receipt of raw materials and therefore delay the production of critical orders.

Finally, the current-state information system is a root cause of the inefficient methods of communication between operators to synchronize and prioritize work plans. Jobs remain idle as WIP inventory between machines for three to twelve hours simply because operators cannot effectively signal the upstream workstations that they have completed their processes. Since each area has its own production schedule, no synchronization is in place between workstations. This further leads to the build-up of WIP inventory on the shop floor. As many as twenty-five jobs are either being processed or are idle on the shop floor during a given work day. Because of the lack of one overall prioritized work plan, low priority jobs may occupy a workstation when a job with an earlier due date should have been scheduled first. In order to eliminate these significant issues within the facility, UniPrint would greatly benefit from implementing an electronic information system that would allow for easy accessibility by all operators and an efficient order scheduling and tracking process. The project team will further evaluate the current system and research alternative information technology solutions that provide real-time performance measurements and offer an effective method of communication between personnel.

2.3.5 Storage-Related Problems

As explained in the section regarding the Seven Types of Waste, excessive inventory and material handling prevent companies such as UniPrint from achieving and operating a lean manufacturing system. In push production, new orders are released into the system before downstream operations are ready to receive additional work. This leads to the build-up of work-in-process (WIP) inventory between workstations. Additionally, parts are typically produced in large batches that require the use of material handling equipment to transport these parts between workstations. As a result, push production can lead to significant storage-related issues. Large batches in queue between workstations as well as the material handling equipment required to transport them can occupy hundreds of square feet of the production floor. This not only clutters the work area, but it also prevents companies from using the area for purposes that add value to the business. The project team continued its assessment of UniPrint's current operations and identified opportunities for the company to further eliminate waste and efficiently utilize storage areas within the facility.

The first step taken by the project team to identify UniPrint's storage-related problems was to quantify the amount of WIP stored in each container type on the shop floor. The team then measured the distances each container is transported between workstations and performed evaluations of the overall effectiveness of each storage container. Below is a table summarizing the information collected by the project team.

TABLE 2-4

ANALYSIS OF STORAGE CONTAINERS

Container	WIP Levels	Distances	Effectiveness
Wooden three-sided carts (15)	Store batches of 11,000 Keep Books after Saddle Stitch process directly on the shop floor; cart dimensions are 3’x1.5’x4’ and occupy 100 sq. ft. in Bindery Department	Carts are transported a distance of 169 feet from Bindery to Shipping Department	Carts can be manually transported to Shipping but occupy 100 sq. ft. of floor space
Wooden Skids	Store raw material orders (up to 20,000 sheets of paper) on warehouse floor; skid dimensions are 3’x4’ and occupy 300 sq. ft. in Receiving area	Skids are transported using pallet jacks or fork trucks a distance of 211 feet to Press Room	Must be moved using MH equipment due to weight, volume and long travel distance; stored on skids because ordered in bulk
Wooden Platform Dollies (24)	Used in Press Room to transport up to 6,000 sheets of paper to Bindery; dolly dimensions are 26”x40” and occupy 10 sq. ft. of floor space in Press Room	Dollies are wheeled to Cutter (distance of 67 feet) or Folder (distance of 100 feet)	Dollies can be manually transported to Bindery and are lightweight; can be put on Press to unload printed paper

Referring to Table 2-4, it can be seen that UniPrint has several hundred feet of its facility occupied by storage containers that hold large batches of products. To further evaluate the storage-related issues, the project team performed an in-depth assessment of the Shipping and Receiving area. This section of the facility is the primary storage area for raw material and finished goods inventory. It is an L-shaped area at the rear of the building. Because of its infeasible location and its odd shape, the room provides no line of sight to the production area. With the Press Room located 211 feet away and the Bindery Area located 169 feet away, it is difficult for operators to visually detect when the workstations are in need of raw material or when they are ready for the Shipping supervisor to retrieve finished jobs. Another issue within the Shipping and Receiving area is that the vertical storage racks are occupied by outdated finish goods inventory, causing raw material to be stored directly on the warehouse floor. Operators have difficulty in maneuvering fork trucks around this material and spend up to fifteen minutes of non-value added time moving various pallets. Furthermore, raw material is ordered in bulk up to five months in advance which further clutters the warehouse area. During the project team's assessment, eight skids of paper products sat idle in the Receiving area and over one hundred skids of finished goods material occupied the vertical storage racks. UniPrint stores envelopes, stationary, and Keep Books for various departments at the university free of charge. Since no rental fee is in place, the facility loses over $85,000 in opportunity costs alone. In order to regain storage capacity and remove inventory from the warehouse floor, UniPrint must discard outdated inventory or send the held inventory to its customers. A rental fee could be instituted for those orders that are unable to be delivered to the university departments. Finally, a just-in-time production system should be implemented to prevent inventory from building up in the system and occupying the workspace. By removing inventory from the vertical storage racks, the Shipping and Receiving supervisor will be able to place raw material and finished goods directly on these racks. Orders can then be organized using the Earliest Due Date (EDD) scheduling principle. This will allow those raw material orders that are first needed on the production floor to be easily accessed by the operators. Organizing finished goods orders by EDD will allow the Shipping supervisor to visually determine which orders need to be pulled from storage and be prepared for delivery to the customer. Furthermore, storing the skids of raw material and packages of finished goods on vertical racks will free up the floor space in the warehouse. This will improve the line of sight from the Shipping and Receiving area to the production floor and will reduce the non-value added time associated with excessive material handling in the area. The project team will further discuss these findings with UniPrint's management and will develop strategic plans for eliminating waste, organizing products by EDD, and implementing just-in-time ordering and scheduling systems.

By performing in-depth assessments of UniPrint's facility, the project team successfully identified the primary issues as being an infeasible shipping location and excessive waste caused from operating a push production system. Industrial Engineering tools and methods such as Fishbone Diagrams and the Seven Types of Waste were applied to determine the root causes of UniPrint's issues and to recognize and quantify waste throughout the facility. The team also evaluated the company's current material handling, information flow, and storage processes to pinpoint the major problems within each process. As a result of these different issues, UniPrint has excessive inventory levels, extensive lead time for its customers' orders, and high overhead costs associated with non-value added material handling time and carrying inventory over long periods of time. While UniPrint's business strategy requires the facility to maintain flexible operations and run as a job shop, several opportunity areas exist for management to adopt lean manufacturing principles. Such principles as finite capacity scheduling, just-in-time production, and continuous improvement using the Seven Types of Waste and 5S will allow document and printing services to eliminate waste in the system and maintain efficient operations. By implementing profitable solutions developed by Industrial Engineers much like the members of this project team, manufacturing companies such as UniPrint can increase customer satisfaction and become fierce competitors in the ever-increasing global marketplace.

3.0 PFAST

3.1 Job Shop Lean

Production Flow Analysis and Simplification Toolkit (PFAST) is a program used to evaluate Job Shop facilities. A Job Shop can be characterized as a company whose products all follow a different flow through the facility. The opposite of a Job Shop would be an assembly line plant where most or all products follow the same processes through the facility. There are many examples of Job Shops, with one being the UniPrint company. UniPrint constantly receives job orders that are unique from other jobs in the system. One customer might request an eight-page brochure using the duplicating machine and the saddle stitch machine, but another customer, also requesting an eight-page brochure, might require it to be processed using the 2-color press and prefect binding. Although both customers are requesting the same eight-page product, the final results are achieved using significantly different processes.

3.1.1 Product Flow

PFAST analyzes the product flow through a facility. This program is especially important and useful in the evaluation of a Job Shop. PFAST is a program that shows three different types of flow through a given facility: quantity, dollar, and job flow. Each of these flow types will be discussed in the next three sub-sections of this document.

3.1.2 Quantity Flow

Quantity flow is the flow of every product moving through a facility. The flow patterns for all jobs and the quantity of products within the specific job is counted and documented as the quantity flow. This information is useful because it shows how the set of machines or processes within the facility are used during the year or a specified time period during which the production activity is documented and analyzed. The information gathered from the quantity flow analysis shows which machines or processes should be closely located to one another within the facility. One goal for a facility re-design project is to reduce the travel distances between machines and processes. Where a great amount of quantity flow exists between machines and processes, the travel distances should obviously be minimized to reduce non-value added transportation and handling times.

Referring to the project data, Job 1 occurred 330 times during the year. The product flow for Job 1 is Prepress to Plating to Duplicating to Shipping. The quantity flow analysis takes into account the groups of flow between each of the previously-stated processes. Each job following this same flow would represent a quantity of 330 to be included in the total quantity flow for UniPrint. This process is repeated for all 5,364 products created by this same product flow at UniPrint during the year.

3.1.3 Dollar Flow

The flow of revenue through a facility is analyzed using Dollar flow. This type of flow takes into account all products created in a facility and their stated revenues for a specified time period. The dollar flow is an important type of flow to be analyzed because companies are driven by sales, and they like to know where their money is moving throughout the supply chain. As with revenue flow, the dollar flow can dictate the desirable location of machines and processes within a facility. Again, high dollar flow machines and processes should be located such that the travel distance is minimal. Facility re-design projects can also use this dollar flow to determine the optimal locations for machines and processes.

Referring to the project data, Job 1 accounts for $78,000 of the total revenue. This product moves through the facility from Prepress to Plating to Duplicating to Shipping. The $78,000 would be added to each of the sets of process and with other similar jobs created at UniPrint. The groups of processes with the higher dollar flows should be analyzed for future process improvements or facility re-designs.

3.1.4 Job Flow

The final flow analyzed by PFAST is the actual movement of jobs through a facility. This type of flow does not take into account the quantity of products included in each job. Because the amounts of products within the jobs are not included in this type of flow, this information given from PFAST might seem skewed to the reader of the chart. Therefore, this type of product flow is not as informative as the quantity flow or the dollar flow. For this project, the movements of the 104 different jobs throughout the facility were tracked in order to understand the various product routings.

3.1.5 Purpose of PFAST

PFAST was created to simplify Job Shop problems. PFAST visually displays the product flow of jobs moving through a facility. The program shows the quantity, revenue, and jobs moving through the facility using different graphs and tables. Examples of these graphs and tables are shown in following sub-sections of this document. The graphs and tables can help the user focus on essential process improvements.

One technique for focusing on essential process improvements is the "80/20 rule." The main idea behind the 80/20 rule originated with the wealth of humans concept. The rule states that 80 percent of the wealth is held by only 20 percent of the population. This rule can also be applied in industry, where 80 percent of the total revenue is brought into a company by 20 percent of the jobs. When using PFAST, users should begin by focusing on the 20 percent of the jobs that account for 80 percent of the revenue. This will help the user focus on the more important jobs to the company.

PFAST was created by professors from The Ohio State University. These professors recognized the need for a program that could simplify Job Shop projects. The program is currently used in courses at The Ohio State University. Undergraduate and graduate students use the program in Facility Design courses such as ISE532 and ISE758. The students are taught how to input data and read the tables and graphs in both of these courses. PFAST is not only used for academic purposes, but is also used by manufacturing companies for real-world situations. Because of the different requirements for course curricula and industrial projects, two versions of the program have been developed - a student demo version and a larger, professional version for the manufacturing industry. The versions differ in the amount of data that can be input into the computer program. With the student demo version of PFAST, only 50 separate jobs can be input and only 50 machines or processes can be used. Any larger amount of jobs or processes must be analyzed using the professional version of the program. This version allows the user to input an unlimited amount of jobs and processes.

PFAST was a primary data analysis tool for the project team in evaluating UniPrint's manufacturing processes. PFAST was able to track all of the jobs moving through UniPrint's facility using a multitude of tables, graphs, and charts. Examples of each of these figures will be discussed later in this section. Because of the Job Shop characteristics of the UniPrint facility, PFAST was able to visually prove that the facility is in fact a Job Shop. The information provided by PFAST allows users to focus on particular jobs and processes for future process improvements in the facility. The following sub-section describes how to use the program to analyze a company's current-state operations in order to begin addressing facility layout-related issues.

3.2 UniPrint Analysis using PFAST

UniPrint manufactures 64 different types of products in its facility. A product is considered to be the overall service provided to the customer. A job is the specific product that is tailored to meet the exact specifications of each customer order. Based on these specifications, jobs can typically use different presses for the actual printing processes. At UniPrint, 23 of the 64 products can be processed on multiple machines. Because of this versatility, UniPrint's products are manufactured using a total of 104 different product routings. The following list in table 3-1 shows all of the products created at UniPrint, and an asterisk indicates the amount of routes a product can take within the facility. For example, Product 14 and Product 15 both create a 1-Color 2-Page Flyer. These can be produced using either the Duplicator or the Digital Press.

TABLE 3-1

PRODUCTS MANUFACTURED AT UNIPRINT

1	Firm Bid Letterhead	32	3-Color 6-Page Brochure	64-67	Case-bound Book ****
2	Firm Bid Envelopes	33	6-Color 6-Page Brochure	68-71	Gatefold Brochure****
3	Firm Bid Mailing Labels	34	1-Color 8-Page Brochure	72	Bindery Work Only
4	Specialty Envelope	35	2-Color 8-Page Brochure	73	Stock Work Only
5	Specialty Letterhead	36	3-Color 8-Page Brochure	74	NCR Form
6	Pre-Press Work Only	37	4-Color 8-Page Brochure	75	Tab Cut Pieces
7	Labels	38	1-Color 12-Page Brochure	76-77	Postcards/Bookmarks/Cards **
8	Web-Newsprint	39	2-Color 12-Page Brochure	78	Rolodex Cards
9	Pocket Folders	40	3-Color 12-Page Brochure	79	Laminated Pieces
10	Firm Bid Business Cards	41	4-Color 12-Page Brochure	80	Imprinting Work
11	Specialty Business Cards	42	1-Color 16-Page Brochure	81	Forms
12-13	Certificates **	43	2-Color 16-Page Brochure	82	Miscellaneous Duplicating
14-15	1-Color 2-Page Flyer **	44	3-Color 16-Page Brochure	83-86	Loose-leaf Book ****
16-17	2-Color 2-Page Flyer **	45	4-Color 16-Page Brochure	87-90	Newsletter ****
18-19	3-Color 2-Page Flyer **	46	1-Color Saddle Stitched Book	91-94	Programs/Directories ****
20-21	4-Color 2-Page Flyer **	47	2-Color Saddle Stitched Book	95	Tickets/Coupons/Badges
22-23	1-Color 4-Page Flyer **	48-49	3-Color Saddle Stitched Book **	96-97	Invitations/Notecards **
24-25	2-Color 4-Page Flyer **	50-51	4-Color Saddle Stitched Book **	98	Pads
26-27	3-Color 4-Page Flyer **	52-53	5-Color Saddle Stitched Book **	99-103	Special Jobs-Die Cut, Etc. ****
28-29	4-Color 4-Page Flyer **	54-55	Poster **	104	Magnets
30	1-Color 6-Page Brochure	56-59	Spiral Bound Book ****		
31	2-Color 6-Page Brochure	60-63	Perfect Bound Book ****		

Figure 3-1 shows how each product moves through the UniPrint facility. The information shown on the table is taken directly from the Excel sheets exported from PFAST. The “No.” column entry indicates the product number, the “Part” column entry is the description of the product, the “Quantity” column entry is the amount of jobs created within each product during the year, the “Revenue” entry is the amount of revenue earned by the product during the year, and the “Routing” entry represents how the product flows through the facility. The numbers shown in the Routing column will be discussed later in this section of the document.

No.	Part	Quantity	Revenue	Routing
1	1	330	78211	2->4->6->15
2	10	235	24732	2->5->11->15
3	100	4	3705	1->2->3->4->10->11->15
4	101	3	3705	1->2->3->4->9->11->15
5	102	3	3705	1->2->3->4->8->11->15
6	103	3	3705	1->2->3->5->11->15
7	104	3	2167	1->2->3->5->11->15
8	11	319	45632	1->2->3->5->11->15
9	12	19	17639	1->2->3->4->6->11->15
10	13	19	17639	1->2->3->5->11->15
11	14	50	37837	1->2->3->4->6->11->15
12	15	49	37837	1->2->3->5->11->15
13	16	71	41943	1->2->3->4->6->11->15
14	17	71	41943	1->2->3->5->11->15
15	18	2	2184	1->2->3->4->8->11->15
16	19	2	2184	1->2->3->5->11->15
17	2	299	67881	2->4->7->15
18	20	39	31984	1->2->3->4->8->11->15
19	21	39	31984	1->2->3->5->11->15
20	22	19	9543	1->2->3->4->6->11->12->15
21	23	18	9543	1->2->3->5->11->12->15
22	24	37	41646	1->2->3->4->6->11->12->15
23	25	37	41646	1->2->3->5->11->12->15
24	26	1	621	1->2->3->4->8->11->12
25	27	0	621	1->2->3->5->11->12->15
26	28	41	69098	1->2->3->4->8->11->12->15
27	29	41	69098	1->2->3->5->11->12->15
28	3	95	14767	2->4->6->11->15
29	30	19	12904	1->2->3->4->10->11->12->15
30	31	82	111766	1->2->3->4->10->11->12->15
31	32	3	4989	1->2->3->4->9->11->12->15
32	33	124	180958	1->2->3->4->9->11->12->15
33	34	20	32978	1->2->3->4->10->11->12->15
34	35	34	49585	1->2->3->4->10->11->12->15
35	36	10	39667	1->2->3->4->9->11->12->15
36	37	70	154434	1->2->3->4->9->11->12->15
37	38	6	6349	1->2->3->4->10->11->12->15
38	39	20	42260	1->2->3->4->10->11->12->15
39	4	483	286305	1->2->3->4->7->15
40	40	4	9366	1->2->3->4->9->11->12->15
41	41	32	85901	1->2->3->4->9->11->12->15
42	42	6	6554	1->2->3->4->10->11->12->15
43	43	1	996	1->2->3->4->10->11->12->15
44	44	3	20516	1->2->3->4->9->11->12->15
45	45	1	3001	1->2->3->4->9->11->12->15
46	46	94	343457	1->2->3->4->10->11->12->13->15
47	47	97	340709	1->2->3->4->10->11->12->13->15
48	48	7	13771	1->2->3->4->9->11->12->13->15
49	49	7	13771	1->2->3->4->8->11->12->13->15
50	5	287	140529	1->2->3->4->6->15
51	50	94	512287	1->2->3->4->9->11->12->13->15
52	51	94	512287	1->2->3->4->8->11->12->13->15
53	52	16	134804	1->2->3->4->9->11->12->13->15
54	53	15	134804	1->2->3->4->8->11->12->13->15
55	54	47	56571	1->2->3->4->9->11->15
56	55	47	56571	1->2->3->4->8->11->15
57	56	3	22983	1->2->3->4->10->11->16->15
58	57	3	22983	1->2->3->4->9->11->16->15
59	58	3	22983	1->2->3->4->8->11->16->15
60	59	3	22983	1->2->3->5->11->16->15
61	6	16	14205	2->3
62	60	13	119277	1->2->3->4->10->11->16->15
63	61	13	119277	1->2->3->4->9->11->16->15
64	62	13	119277	1->2->3->4->8->11->16->15
65	63	12	119277	1->2->3->5->11->16->15
66	64	1	15946	1->2->3->4->10->11->16->15
67	65	0	15946	1->2->3->4->9->11->16->15
68	66	0	15946	1->2->3->4->8->11->16->15
69	67	0	15946	1->2->3->5->11->16->15
70	68	1	3731	1->2->3->4->10->11->15
71	69	1	3731	1->2->3->4->9->11->15
72	7	122	73239	1->2->3->4->6->11->15
73	70	1	3731	1->2->3->4->8->11->15
74	71	1	3731	1->2->3->5->11->15
75	72	140	142691	1->11->12->13->15
76	73	70	3698	15
77	74	191	81820	1->2->3->4->6->11->15
78	75	12	28438	1->2->3->4->6->11->15
79	76	207	167756	1->2->3->4->8->11->15
80	77	206	167756	1->2->3->5->11->15
81	78	3	6296	1->2->3->5->11->16->15
82	79	5	2188	1->2->3->5->11->16->15
83	8	1	9847	1->2->3->16->15
84	80	6	640	1->2->3->4->6->15
85	81	149	44756	1->2->3->4->6->11->15
86	82	67	33334	1->2->3->4->6->11->15
87	83	3	17479	1->2->3->4->10->11->15
88	84	3	17479	1->2->3->4->9->11->15
89	85	3	17479	1->2->3->4->8->11->15
90	86	2	17479	1->2->3->5->11->15
91	87	13	25765	1->2->3->4->10->11->12->15
92	88	12	25765	1->2->3->4->9->11->12->15
93	89	13	25765	1->2->3->4->8->11->12->15
94	9	56	149043	1->2->3->4->8->16->15
95	90	12	25765	1->2->3->5->11->12->15
96	91	10	22289	1->2->3->4->10->11->12->13->15
97	92	10	22289	1->2->3->4->9->11->12->13->15
98	93	10	22289	1->2->3->4->8->11->12->13->15
99	94	9	22289	1->2->3->5->11->12->13->15
100	95	39	21207	1->2->3->5->11->15
101	96	105	94848	1->2->3->4->8->11->12->15
102	97	105	94848	1->2->3->5->11->12->15
103	98	114	38736	1->2->3->5->11->15
104	99	10	13816	1->2->3->5->11->15

Fig. 3-1. Product routings within UniPrint.

3.2.1 Machines and Processes

Figure 3-2 shows the 16 machines and processes used to complete jobs at UniPrint. The processes include: Production Planning, Proofing Approval, Addressing, Shipping, and Outside Sources. Production Planning is the step during which customers order a product and determine the format of their final work order. Prepress is the process that creates a rough version of the final job. The Proofing Approval process is another step that requires customer involvement. During Proofing Approval, the customer must examine and approve the initial version of the job created in Prepress. Addressing is a process performed on only a select number of jobs at UniPrint. If customers request that their products be shipped to different locations, the finished goods are labeled with the corresponding addresses and prepared for delivery during this process. Shipping is the process where completed jobs are transported to the customer. The Outside Source process is performed when UniPrint must send finished jobs to another company to add a detail that is not performed in-house. An example of outside sourcing might involve adding transparent film to an envelope window.

Process #	Process Name	
1	Production Planning	Green
2	Prepress	Yellow
3	Proofing Approval Process	Green
4	Plating	Red
5	Digital Press	
6	Duplicating	
7	Envelope Press	
8	6 Color Press	
9	5 Color Press	
10	2 Color Press	
11	Cutting	Yellow
12	Folding	
13	Saddle Binding	Red
14	Addressing	Yellow
15	Shipping	
16	Outside Sources	Red

Fig. 3-2. Machines and processes at UniPrint.

The machines shown in figure 3-2 include: Plating, Digital Press, Duplicator, Envelope Press, 6-Color Press, 5-Color Press, 2-Color Press, Cutter, Folder, and Saddle Stitch Binding. The Plating machine creates the plates used by the different presses. Each of the plates created for a job account for a set of pages and colors used in the printing process. For example, a job that is printed with two colors will need two plates from the Plating machine. The Digital Press is the only press at UniPrint that does not require plates for the printing process. It instead uses electronic information that is transmitted from the computer system to the machine. The Envelope, Duplicating, 2-Color, 5-Color, and 6-Color presses all operate in similar ways. Plates are placed onto the presses with varying amounts of ink; paper is loaded into the machines; and the jobs are processed based on the customers' final proof. The Cutter is a machine that cuts large sheets of paper into the smaller pages used in books and other products. The Folding machine takes the smaller pieces of paper and folds them into shapes based on customer requirements. The Saddle Stitch Binder is a machine that takes all of the pages included in the finished job and binds them together to form a book, program, or other similar products.

All of the machines in figure 3-2 have been assigned three different colors: red, yellow, and green. The red color signifies that the process or work center is a monument. A machine is labeled as a monument when it is rather difficult to move to another location in the facility; it is also considered a monument if it would be too expensive to purchase another machine for co-location. In the UniPrint example, all of the presses are considered to be monuments. Each press occupies approximately 200 square feet and is too heavy to move to another location. The presses also have a location constraint; they must be located in interior rooms to reduce their exposure to humidity and similar environmental conditions. These machines are also quite expensive; therefore, purchasing additional machines is not an option. Another factor in deciding the monument labels has to do with the three unions within the UniPrint facility. Members of the unions are limited to working on only press work, only bindery work, or only shipping/receiving work; this limits the movement of some machines and processes.

The yellow color signifies that the process or work center can be moved if necessary. Costs may still be incurred from moving the process or work center, but justifications would be given before relocation occurred. In the UniPrint example, the Prepress, Cutters, Folders, Addressing, and Shipping processes were considered to be flexible. The current location for Prepress is a small room connected to the Production Planning location. The machine is fairly small and could therefore be moved to another location in the facility. This machine, however, must be located in a room with a de-humidifier or in a humidity-free environment. After talking with the Maintenance Manager at UniPrint, the project team was able to label the Cutters and Folders with a yellow color. The movement of these machines would cost about $20,000. Moving these machines, however, is limited to the Bindery room because of union regulations. The Addressing process within UniPrint is a separate entity to the company. The product flows examined for the UniPrint project did not pass through the Addressing department. Therefore, the company could relocate Addressing within the facility or possibly outsource the process. The Shipping process is also considered to have a flexible location because the facility currently has an unused dock to which Shipping could be relocated.

Finally, the green color indicates that the process is extremely flexible and can be easily relocated. The cost to move the process is minimal, and the size of the process or machine is not a significant factor. In the UniPrint example, the Production Planning and Proofing Approval processes were the only processes considered to be flexible. The processes only rely on computer-based work and can occur anywhere within the facility. If the company decided that more computers were needed to improve the process, it would be a small expense to implement additional resources.

3.2.2 F-Type From-To

Figures 3-3 and 3-4 show the F-Type From-To information. Figure 3-3 indicates the amount of jobs moving through each set of processes and work centers. In the UniPrint example, this information only accounts for the 104 jobs that are produced at the facility. Figure 3-4 provides a visual representation of the jobs moving through each process. When a number is large, it suggests that processes should be located near each other. In the UniPrint example, approximately 100 jobs move from Production Planning to Prepress. Since this quantity accounts for most of the jobs, these two work centers should be located near each other to reduce the travel distances within the facility. Other routings between processes, such as the Duplicator or Envelope Press to Shipping, only account for 2 and 3 jobs, respectively. This indicates that locating these processes near each other would not significantly impact travel distances within the facility.

	1	2	3	4	9	8	6	16	15	11	12	5	13	10	7
1		97								1					
2			98	3								1			
3				70				1				26			
4					20	19	14							18	2
9										20					
8								1		18					
6									3	11					
16									16						
15															
11								14	38		43				
12									29				13		
5										27					
13									13						
10										18					
7									2						

Fig. 3-3. f-Type From-To Chart.

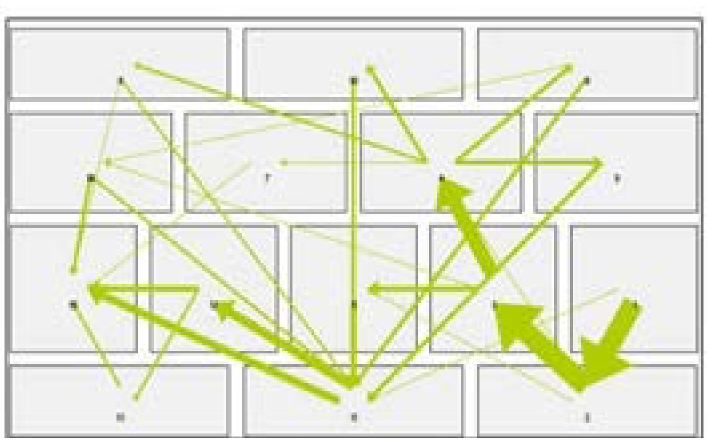


Fig. 3-4. F-Type Flow Diagram.

3.2.3 P-Q Analysis

The P-Q Analysis shows those parts or jobs that are created in the largest quantity within the facility. This information will show which jobs are runners, repeaters, or strangers regarding the frequency of production. A runner is a job that the company produces frequently. Repeaters are jobs that are produced often but not as frequent as the runners, and rare jobs (strangers) are ones that the company creates infrequently. These terms can vary among Job Shop and assembly facilities.

Because companies have different sales volumes, the terms “frequent” and “rare” in terms of quantity flow must be determined with an analysis of a company’s unique product flow. UniPrint had a total of 5,364 jobs during the previous fiscal year. One method used to determine high and low quantities is to create a box-plot using the available quantity data. A box-plot for the quantity flow at UniPrint can be seen in figure 3-5. Outliers for this data are defined by the equation Q3+(1.5*(Q3-Q2))=150.25. For the data obtained from UniPrint, high quantity jobs would be those for which the quantity is greater than 150 for an individual job. Figure 3-6 shows the distribution of high and low quantity jobs. It can be seen that about 50 percent of the jobs are higher-quantity jobs, and most of the remaining jobs can be considered lower-quantity jobs. The information shown in figure 3-6 is valuable for companies to see which products they are creating more frequently. It is also a good determinate of Job Shop environments. A Job Shop is characterized as having a higher ratio of lower quantity jobs to higher quantity jobs.

Fig. 3-5. Box-plot distribution of quantity of jobs at UniPrint.

Part	Quantity	Agg. Qty	Agg. Qty %
4	483	483	9
1	330	813	15
11	319	1132	21
2	299	1431	26
5	287	1718	32
10	235	1953	36
76	207	2160	40
77	206	2366	44
74	191	2557	47
81	149	2706	50
72	140	2846	53
33	124	2970	55
7	122	3092	57
98	114	3206	59
96	105	3311	61
97	105	3416	63
47	97	3513	65
3	95	3608	67
46	94	3702	69
50	94	3796	70
51	94	3890	72
31	82	3972	74
16	71	4043	75
17	71	4114	76
37	70	4184	78
73	70	4254	79
82	67	4321	80
9	56	4377	81
14	50	4427	82
15	49	4476	83
54	47	4523	84
55	47	4570	85
28	41	4611	86
29	41	4652	86
20	39	4691	87
21	39	4730	88
95	39	4769	88
24	37	4806	89
25	37	4843	90
35	34	4877	90
41	32	4909	91
34	20	4929	91
39	20	4949	92
12	19	4968	92
13	19	4987	93
22	19	5006	93
30	19	5025	93
23	18	5043	94
52	16	5059	94
6	16	5075	94
53	15	5090	94
60	13	5103	95
61	13	5116	95
62	13	5129	95
87	13	5142	95
89	13	5155	96
63	12	5167	96
75	12	5179	96
88	12	5191	96
90	12	5203	97
36	10	5213	97
91	10	5223	97
92	10	5233	97
93	10	5243	97
99	10	5253	97
94	9	5262	98
48	7	5269	98
49	7	5276	98
38	6	5282	98
42	6	5288	98
80	6	5294	98
79	5	5299	98
100	4	5303	98
40	4	5307	98
101	3	5310	99
102	3	5313	99
103	3	5316	99
104	3	5319	99
32	3	5322	99
44	3	5325	99
56	3	5328	99
57	3	5331	99
58	3	5334	99
59	3	5337	99
78	3	5340	99
83	3	5343	99
84	3	5346	99
85	3	5349	99
18	2	5351	99
19	2	5353	99
86	2	5355	99
26	1	5356	99
43	1	5357	99
45	1	5358	99
64	1	5359	99
68	1	5360	99
69	1	5361	99
70	1	5362	100
71	1	5363	100
8	1	5364	100
27	0	5364	100
65	0	5364	100
66	0	5364	100
67	0	5364	100

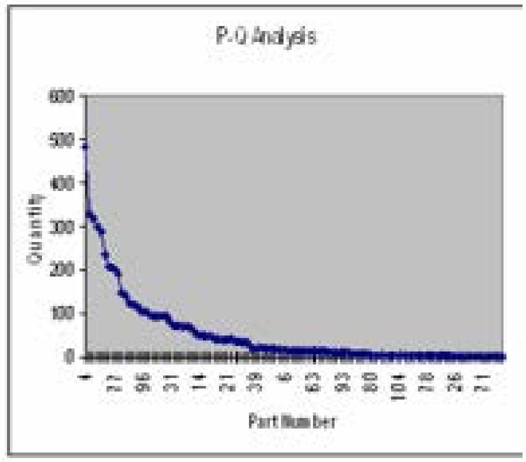


Fig. 3-6. P-Q analysis for UniPrint project.

3.2.4 Q-Type From-To

Figure 3-7 shows how the quantity of jobs moves through the UniPrint facility. The numbers in the table indicate the quantity of jobs moving between the different work centers in the facility. If a pair of work centers has a high number in the intersecting cell, then those two work centers should be located near each other to reduce the travel distance within the facility. In the UniPrint project, approximately 4,200 jobs moved from Production Planning to Prepress and then from Prepress to the Proofing Approval process. 2,252 jobs moved from Cutting to Shipping, and 1,492 jobs moved from Cutting to Folding. Because of the high volume of orders flowing between these processes, it would be beneficial to locate the Production Planning, Prepress, and the Proofing Approval processes near each other on the shop floor. The Cutting, Folding, and Shipping processes should also be closely-located. Other pairings of processes such as the 2-Color Press to Cutting, which only accounts for 427 jobs, do not necessarily need to be located immediately next to each other on the shop floor.

	1	2	3	4	6	8	13	15	11	12	5	7	9	10	16
1		4179							140						
2			4195	724							235				
3				3056							1122				1
4					1465	660						782	466	427	
6								623	832						
8									604						56
13								603							
15															
11								2252		1492					72
12							603	888							
5									1357						
7								782							
9									466						
10									427						
16								129							

Fig. 3-7. Q-Type From-To chart from UniPrint project.

Figure 3-8 provides a visual representation of how many products flow through the different processes. The thick arrows represent a larger amount of flow between processes, and the thinner arrows represent a smaller amount of flow. This information can easily be transposed onto an existing facility layout diagram. By placing the arrows on the existing layout, the user can visually see the impact of large travel distances on high volume products within the facility.

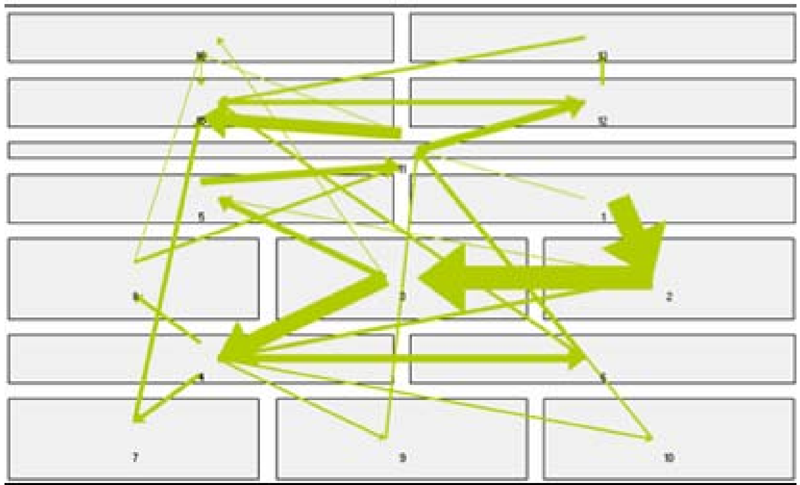


Fig. 3-8. Q-Type From-To facility diagram for UniPrint project.

3.2.5 P-Q-$ Analysis

Figures 3-10 and 3-11 show the P-Q-$ analysis for the UniPrint project. The graph and table show the distribution of the revenue and quantity of products moving through the facility. This analysis provides more in-depth information to supplement the quantity flow analysis described in the previous section. The benefit of presenting the revenue flow with the quantity flow is that the company can visualize the volume of products that contribute to the majority of its revenues.

To simplify the information contained in the graph, a company should focus on the jobs that account for 80% of both the revenue and the quantity. This will ensure that the company is structuring its process improvements around the products that are manufactured the most frequently and that generate the bulk of its sales. In the UniPrint example, 36 of the 104 total jobs account for 80.5% of the total quantity and 83.9% of the total revenue. The facility's process improvements should be planned to accommodate the production of these jobs.

As with the P-Q analysis, the terms "high" and "low" revenues need to be appropriately defined. This can be performed in a manner similar to the P-Q Analysis. The distribution of revenues can be seen in the box-plot shown in figure 3-9. The outliers for the revenue values would be any job that earns more than $140,000 for the company. Therefore, jobs with large revenue values can be characterized as being a "high revenue" job.

Fig. 3-9. Box-plot distribution of revenue at UniPrint.

Part	Revenue	Quantity	Agg. Rev	Agg. Qty	Agg. Rev %	Agg. Qty %
4	286305	483	286305	483	4	9
50	512287	94	798592	577	13	10
51	512287	94	1310879	671	21	12
1	78211	330	1389090	1001	22	18
46	343457	94	1732547	1095	28	20
47	340709	97	2073256	1192	33	22
11	45632	319	2118888	1511	34	28
5	140529	287	2259417	1798	36	33
2	67881	299	2327298	2097	37	39
76	167756	207	2495054	2304	40	43
77	167756	206	2662810	2510	43	46
10	24732	235	2687542	2745	43	51
33	180958	124	2868500	2869	46	53
74	81820	191	2950320	3060	47	57
72	142691	140	3093011	3200	50	59
37	154434	70	3247445	3270	52	61
81	44756	149	3292201	3419	53	63
9	149043	56	3441244	3475	55	64
7	73239	122	3514483	3597	57	67
96	94848	105	3609331	3702	58	69
97	94848	105	3704179	3807	60	71
31	111766	82	3815945	3889	61	72
52	134804	16	3950749	3905	64	72
53	134804	15	4085553	3920	66	73
98	38736	114	4124289	4034	66	75
60	119277	13	4243566	4047	68	75
61	119277	13	4362843	4060	70	75
62	119277	13	4482120	4073	72	75
63	119277	12	4601397	4085	74	76
3	14767	95	4616164	4180	74	77
41	85901	32	4702065	4212	76	78
16	41943	71	4744008	4283	77	79
17	41943	71	4785951	4354	77	81
28	69098	41	4855049	4395	78	81
29	69098	41	4924147	4436	79	82
82	33334	67	4957481	4503	80	83
54	56571	47	5014052	4550	81	84
55	56571	47	5070623	4597	82	85
73	3698	70	5074321	4667	82	87
14	37837	50	5112158	4717	83	87
15	37837	49	5149995	4766	83	88
35	49585	34	5199580	4800	84	89
24	41646	37	5241226	4837	85	90
25	41646	37	5282872	4874	85	90
20	31984	39	5314856	4913	86	91
21	31984	39	5346840	4952	86	92
39	42260	20	5389100	4972	87	92
95	21207	39	5410307	5011	87	93
36	39667	10	5449974	5021	88	93
34	32978	20	5482952	5041	89	94
75	28438	12	5511390	5053	89	94
87	25765	13	5537155	5066	89	94
89	25765	13	5562920	5079	90	94
88	25765	12	5588685	5091	90	94
90	25765	12	5614450	5103	91	95
12	17639	19	5632089	5122	91	95
13	17639	19	5649728	5141	91	95
91	22289	10	5672017	5151	92	96
92	22289	10	5694306	5161	92	96
93	22289	10	5716595	5171	92	96
94	22289	9	5738884	5180	93	96
30	12904	19	5751788	5199	93	96
56	22983	3	5774771	5202	93	97
57	22983	3	5797754	5205	94	97
58	22983	3	5820737	5208	94	97
59	22983	3	5843720	5211	94	97
22	9543	19	5853263	5230	95	97
6	14205	16	5867468	5246	95	97
23	9543	18	5877011	5264	95	98
44	20516	3	5897527	5267	95	98
83	17479	3	5915006	5270	96	98
84	17479	3	5932485	5273	96	98
85	17479	3	5949964	5276	96	98
86	17479	2	5967443	5278	96	98
99	13816	10	5981259	5288	97	98
64	15946	1	5997205	5289	97	98
65	15946	0	6013151	5289	97	98
66	15946	0	6029097	5289	97	98
67	15946	0	6045043	5289	98	98
48	13771	7	6058814	5296	98	98
49	13771	7	6072585	5303	98	98
40	9366	4	6081951	5307	98	98
8	9847	1	6091798	5308	98	99
42	6554	6	6098352	5314	99	99
38	6349	6	6104701	5320	99	99
78	6296	3	6110997	5323	99	99
80	640	6	6111637	5329	99	99
79	2188	5	6113825	5334	99	99
32	4989	3	6118814	5337	99	99
100	3705	4	6122519	5341	99	99
101	3705	3	6126224	5344	99	99
102	3705	3	6129929	5347	99	99
103	3705	3	6133634	5350	99	99
104	2167	3	6135801	5353	99	99
68	3731	1	6139532	5354	99	99
69	3731	1	6143263	5355	99	99
70	3731	1	6146994	5356	99	99
71	3731	1	6150725	5357	99	99
18	2184	2	6152909	5359	99	99
19	2184	2	6155093	5361	99	99
45	3001	1	6158094	5362	100	100
43	996	1	6159090	5363	100	100
26	621	1	6159711	5364	100	100
27	621	0	6160332	5364	100	100

Fig. 3-10. P-Q-$ Analysis chart for UniPrint project.

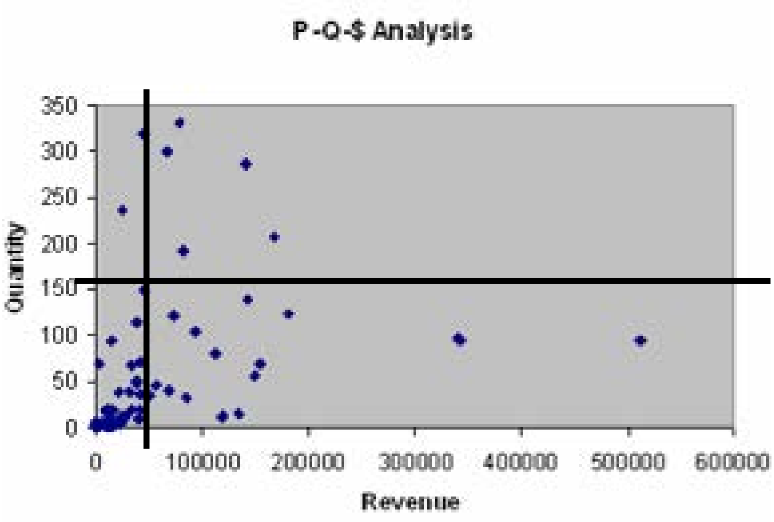


Fig. 3-11. P-Q-$ Analysis graph for UniPrint project.

3.2.6 $-Type From-To

The revenue flow through the different processes and work centers in UniPrint's facility can be seen on the $-Type Flow analysis (figures 3-12 and 3-13). This information shows the amount of revenue moving through the individual processes within a facility. The information on the chart in figure 3-12 is similar to that seen on the Q-Type Flow chart (figure 3-7), but is more applicable for the company. A company is interested in having its most valuable products flow efficiently through the facility; therefore, those pairs of processes experiencing the highest revenue flows should be located close to each other on the shop floor. In the UniPrint example, approximately $6 million of revenue moves from Production Planning to Prepress to the Proofing Approval process. Because this product routing accounts for most of the facility's revenue, it would be financially beneficial for these processes to be closely-located. Another product routing with high revenue flows is from Cutting to Folding, which contributes $3.5 million in revenue, and from Folding to Saddle Stitching, which contributes $2.2 million in revenue. The $-Type Flow also identifies those processes that do not experience high revenue flows between each other and do not need to be located close to each other; examples are the product routing of Proofing Approval to Outside Resources that only accounts for $10,000 of the company's revenue.

Figure 3-13 represents the amount of revenue moving through the facility with arrows of different thicknesses. As with the Q-Type flow, the thicker the arrow, the more revenue flow between two processes. This figure was mapped onto the existing UniPrint facility as seen in figure 3-14. This visualizes the distances that jobs with high revenues must travel in order to be completed. The results of this analysis can assist Industrial Engineers in performing process improvements by reducing high revenue travel distances.

	1	2	3	4	8	10	9	11	12	13	15	16	5	6	7
1		5814147						142691							
2			5828352	160859									24732		
3				4927984								9847	876316		
4					1464142	1178733	1447440							644042	354186
8								1315099				149043			
10								1178733							
9								1447440							
11									3534633		1234132	641308			
12										2237737	1296175				
13											2237737				
15															
16											800198				
5								901048							
6								424962			219380				
7											354186				

Fig. 3-12. $-Type From-To chart for UniPrint project.

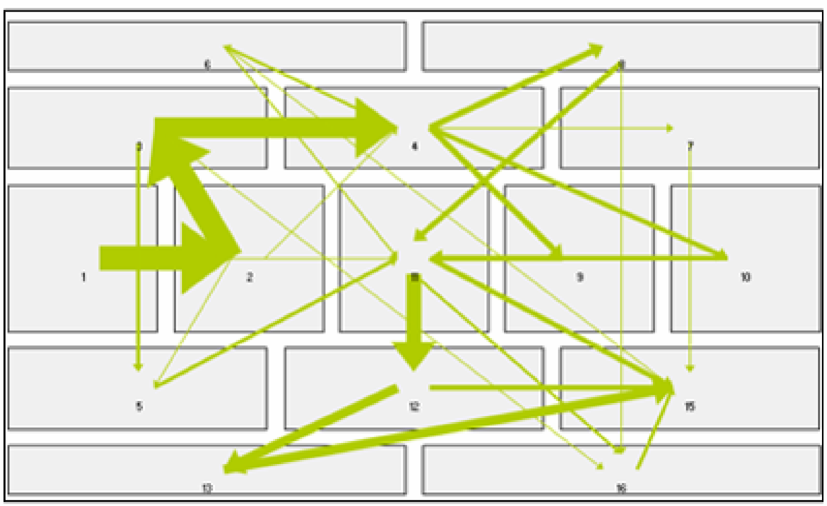


Fig. 3-13. $-Type From-To facility diagram for UniPrint project.

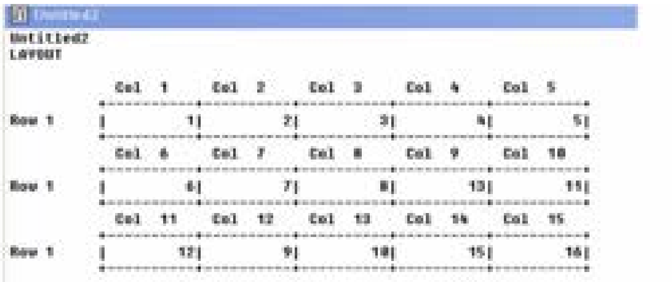
Fig. 3-14. $-Type From-To facility diagram mapped onto UniPrint's current layout.

3.2.7 Storm

Storm is a program that was used in the UniPrint project to evaluate the data received from the $-Type From-To analysis. Storm takes the $-Type From-To data obtained from PFAST and creates a facility design that optimizes the dollar flow through the facility. The user simply selects "Facility Layout" from the Module List that appears when creating a new file in Storm. The user then must define the amount of work centers to be analyzed. When asked for the dimensions, the user should select "1 down." This will ensure that the final result is in linear form. The user then must input the From-To data into the appropriate cells. After running the program, a linear facility layout will be created.

Storm was used to show the linear flow of products through the UniPrint facility. The result given by Storm is an optimal facility design that should be adopted by the company to ensure the products and revenues flow efficiently between processes. In the UniPrint project, the facility layout can be seen in figure 3-15. The linear layout, as seen in the

UniPrint example, allows the end user to maneuver the processes and work centers in order to create an appropriate layout for the facility's structure.



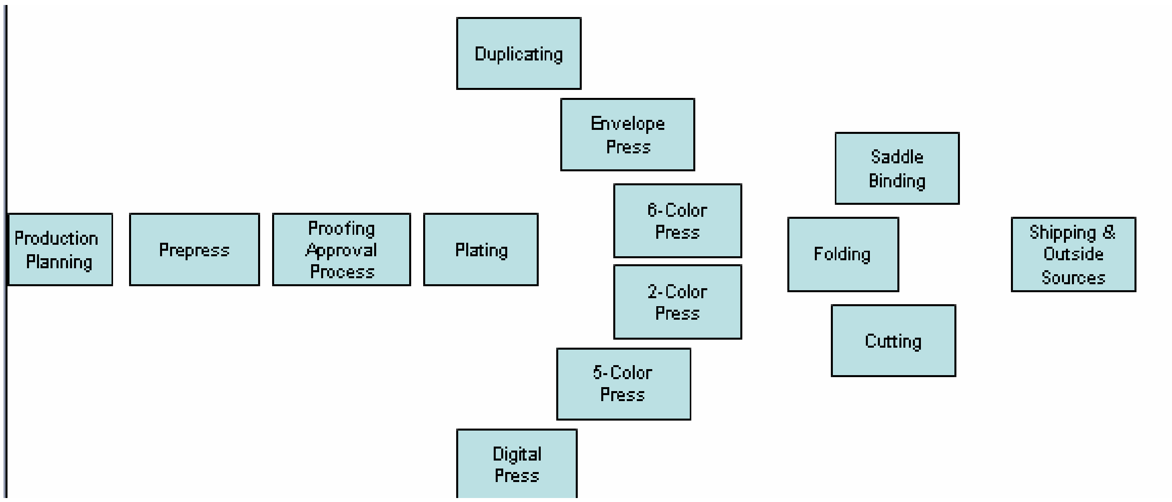


Fig. 3-15. Storm results from $-Type From-To chart for UniPrint project.

This result shows that all of the Prepress processes (Production Planning, Prepress, Proofing Approval, and Plating) should be located in the same area. The presses (6-Color, 5-Color, 2-Color, Digital, Envelope, and Duplicator) follow the Prepress operations in the production process; similarly, these machines should be located close to one another. The Cutting, Folding, and Saddle Binding processes occur after the Press work and should precede the Shipping and Outside Sourcing processes. Because the facility design created in Storm is a linear facility model, the user can now decide how to rearrange the processes and work centers to minimize travel distances throughout the facility.

An example of a facility design created for UniPrint using the Storm output can be seen in figure 3-16. This facility design has the Prepress processes in a linear pattern because most of the revenue flowed through the same steps: Production Planning, Prepress, Proofing Approval, and Plating. The press machines are placed adjacent to the

Prepress steps to form a T-shape. This design was created because all of the jobs flow through at least one of the presses. To eliminate unnecessary travel distances for the material handling equipment, employees, and the physical material, jobs should be able to move directly from the press used for the printing process to the adjacent workstation without having to maneuver around the other presses. The steps after the press vary by job; therefore, the most efficient layout allows for the placement of the Cutter, Folder, Saddle Binder, and the Shipping department in a way that will minimize travel distances between locations. A U-shaped area for these processes will allow jobs to by-pass unnecessary work centers without increasing travel distances.

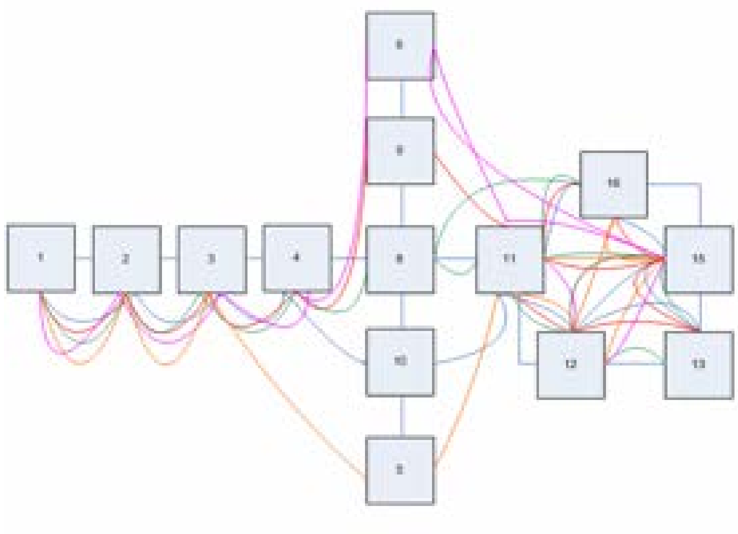


Fig. 3-16. Ideal facility layout for UniPrint project using a multi-project analysis.

3.2.8 PR Analysis Type I

PR Analysis Type I shows which work centers or processes are required to create each job. Figure 3-17 shows the UniPrint results for this type of analysis. In this table, job numbers are listed in the first column, and work center numbers are the remaining column headers. Each row in the table corresponds to a job that is created at UniPrint. Within each row, a "1" is placed in the work center cells to show which work centers that particular job must flow through in order to be completed. In the UniPrint example, it can be seen from the figure that job 1 must flow through work centers 15, 4, 2, and 6. This type of analysis aids in the creation of manufacturing cells containing similar work centers within a facility.

When groups of jobs share similar work centers, manufacturing cells can be formed. These cells will contain the processes and machines needed to complete a particular group of jobs. In some situations, it might be necessary to have multiple locations for the processes and machines; for these situations, more cells and groups can be created in the facility. A cellular layout process improvement should occur only after a thorough analysis of the machines and processes used in the facility's operations is performed. The costs and sizes of the machines and processes must be taken into consideration when creating cells. The process of assigning monuments and flexible machines and processes can be taken into consideration when determining whether a cellular layout can be achieved. If the facility currently contains several monuments, such as the UniPrint example, then a cellular layout would be too costly and undesirable for the company.

In the UniPrint example, it can be seen that many jobs require the use of the same machines and processes. The results in the PR Analysis Type I show that a cellular layout is not optimal for UniPrint's facility.

	8	13	10	9	4	15	2	3	1	11	12	5	16	6	7
73						1									
72		1				1			1	1	1				
10						1	1			1		1			
79						1	1	1	1	1		1	1		
78						1	1	1	1	1		1	1		
67						1	1	1	1	1		1	1		
63						1	1	1	1	1		1	1		
59						1	1	1	1	1		1	1		
99						1	1	1	1	1		1			
98						1	1	1	1	1		1			
95						1	1	1	1	1		1			
86						1	1	1	1	1		1			
77						1	1	1	1	1		1			
71						1	1	1	1	1		1			
21						1	1	1	1	1		1			
19						1	1	1	1	1		1			
17						1	1	1	1	1		1			
15						1	1	1	1	1		1			
13						1	1	1	1	1		1			
11						1	1	1	1	1		1			
104						1	1	1	1	1		1			
103						1	1	1	1	1		1			
23						1	1	1	1	1	1	1			
25						1	1	1	1	1	1	1			
27						1	1	1	1	1	1	1			
29						1	1	1	1	1	1	1			
90						1	1	1	1	1	1	1			
97						1	1	1	1	1	1	1			
94		1				1	1	1	1	1	1	1			
8						1	1	1	1				1		
65				1	1	1	1	1	1	1			1		
61				1	1	1	1	1	1	1			1		
57				1	1	1	1	1	1	1			1		
84				1	1	1	1	1	1	1					
69				1	1	1	1	1	1	1					
54				1	1	1	1	1	1	1					
101				1	1	1	1	1	1	1					
32				1	1	1	1	1	1	1	1				
33				1	1	1	1	1	1	1	1				
36				1	1	1	1	1	1	1	1				
37				1	1	1	1	1	1	1	1				
40				1	1	1	1	1	1	1	1				
41				1	1	1	1	1	1	1	1				
44				1	1	1	1	1	1	1	1				
45				1	1	1	1	1	1	1	1				
00				1	1	1	1	1	1	1	1				
48		1		1	1	1	1	1	1	1	1				
50		1		1	1	1	1	1	1	1	1				
52		1		1	1	1	1	1	1	1	1				

	8	13	10	9	4	15	2	3	1	11	12	5	16	6	7
92		1		1	1	1	1	1	1	1	1				
91		1	1		1	1	1	1	1	1	1				
47		1	1		1	1	1	1	1	1	1				
46		1	1		1	1	1	1	1	1	1				
87			1		1	1	1	1	1	1	1				
43			1		1	1	1	1	1	1	1				
42			1		1	1	1	1	1	1	1				
39			1		1	1	1	1	1	1	1				
38			1		1	1	1	1	1	1	1				
35			1		1	1	1	1	1	1	1				
34			1		1	1	1	1	1	1	1				
31			1		1	1	1	1	1	1	1				
30			1		1	1	1	1	1	1	1				
100			1		1	1	1	1	1	1					
68			1		1	1	1	1	1	1					
83			1		1	1	1	1	1	1					
56			1		1	1	1	1	1	1			1		
60			1		1	1	1	1	1	1			1		
64			1		1	1	1	1	1	1			1		
9	1				1	1	1	1	1				1		
66	1				1	1	1	1	1	1			1		
62	1				1	1	1	1	1	1			1		
58	1				1	1	1	1	1	1			1		
85	1				1	1	1	1	1	1					
76	1				1	1	1	1	1	1					
70	1				1	1	1	1	1	1					
55	1				1	1	1	1	1	1					
20	1				1	1	1	1	1	1					
18	1				1	1	1	1	1	1					
102	1				1	1	1	1	1	1					
93	1	1			1	1	1	1	1	1	1				
53	1	1			1	1	1	1	1	1	1				
51	1	1			1	1	1	1	1	1	1				
49	1	1			1	1	1	1	1	1	1				
96	1				1	1	1	1	1	1	1				
89	1				1	1	1	1	1	1	1				
28	1				1	1	1	1	1	1	1				
26	1				1		1	1	1	1	1				
24					1	1	1	1	1	1	1			1	
22					1	1	1	1	1	1	1			1	
82					1	1	1	1	1	1				1	
81					1	1	1	1	1	1				1	
75					1	1	1	1	1	1				1	
74					1	1	1	1	1	1				1	
7					1	1	1	1	1	1				1	
16					1	1	1	1	1	1				1	
14					1	1	1	1	1	1				1	
12					1	1	1	1	1	1				1	
80					1	1	1	1	1					1	
5					1	1	1	1	1					1	
4					1	1	1	1	1						1
2					1	1	1								1
1					1	1	1							1	
3					1	1	1			1				1	
6							1	1							

Fig. 3-17. PR Analysis Type I for UniPrint project.

3.2.9 PR Analysis Type II

PR Analysis Type II shows the jobs that share similar processes. The jobs are listed along the bottom of a tree shown in figure 3-18. The different branches of the tree enclose jobs with similar processes. It can be seen in the figures that one branch encloses all of the jobs. Moving closer to the numbers on the tree and down the branches will lead to more specific product routings. In the UniPrint example, it can be seen that jobs 1 and

2 are underneath the same branch. Therefore, they have similar product routings and use similar machines and processes.

Using this analysis, family groups can be created. A family group is similar to a cell; all jobs in the specific family group share similar work centers and product routings. The family group analysis can help the facility make process improvements. For example, if a family group represents a high revenue and quantity in the facility, a manufacturing cell could be created for that group of jobs to reduce travel distances and quickly move jobs between processes.

In the UniPrint example, five family groups were created. The groups were divided so that each group contained two or three levels of the type II tree. Referring to the family group analyses, it can be seen that the groups are divided depending on which press was used to create the product. For example, all jobs using the 2-Color press were included in Family Group 1, and those using the 5-Color press were included in Family Group 2. The five family group examples will be described in the following section.

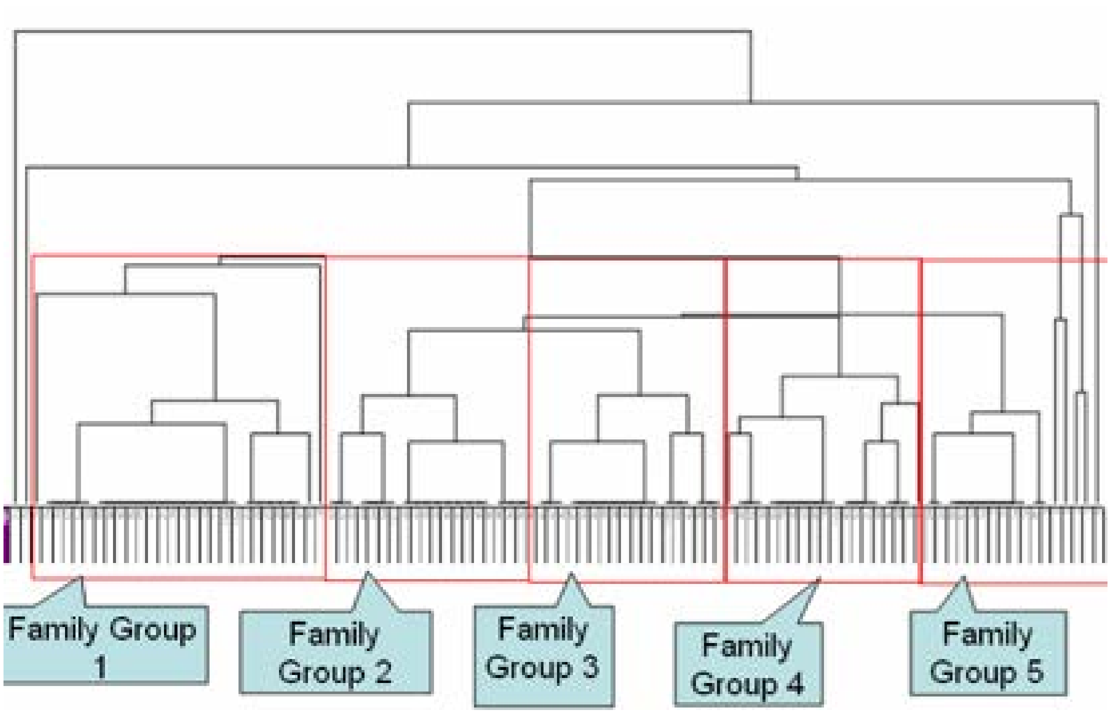


Fig. 3-18. PR Analysis Type II for UniPrint project.

3.2.10 Family Groups

Family Group 1 is comprised of products 33, 18, 20, 23, 25, and 26. This group represents $1,309,664 of revenue and a quantity of 431 of the jobs produced at UniPrint.

This group was analyzed using PFAST, $-Type From-To, P-Q-$ Analysis, and Storm. The $-Type From-To information in figures 3-12 and 3-13 shows that all of the jobs move through the Prepress processes and then to the 2-Color press. The jobs then move to the Bindery, but it can be seen from figure 3-16 that the jobs flow through the Bindery using different routings. The revenue flow was placed into the Storm program to create an optimal facility layout. The facility layout should begin with Prepress processes, followed by the 2-Color press, the Bindery, and then end with Shipping. These flows were mapped onto the actual facility layout in figure 3-14. Process improvements could involve reducing the travel distances between these processes. As discussed previously with the P-Q-$ Analysis, additional process improvements could be performed on 80 percent of the revenue and quantity for this family group. The jobs included in the 80 percent are 26, 25, and 18. This type of analysis is further demonstrated in the examples provided in appendix B.

3.2.11 PR Analysis Type III

PR Analysis Type III analyzes the product routings for the various jobs created within a company's facility. This analysis shows the revenue flow and quantity flow between each group of product routings. An example of this analysis can be seen in figure 3-19. When conducting process improvements, it is important to use the percentages to determine which product routings will greatly impact the success of such improvements. In the UniPrint example, approximately 43 percent of the total quantity of jobs moves from Cutting to Shipping. This represents approximately 18 percent of the total revenue flow. Because a substantial volume of jobs flow between these processes, reducing the travel distances between Cutting and Shipping will create a more efficient production flow.

Length	Frequency	% Qty.	% Rev.	Substring
7	6	3.97	3.92	1->2->3->5->11->12->15
6	7	4.14	4.28	1->2->3->5->11->12
2	27	25.30	14.63	5->11
3	15	20.73	7.64	5->11->15
6	14	16.35	7.24	1->2->3->5->11->15
5	26	20.92	14.23	1->2->3->5->11
7	5	0.43	2.71	1->2->3->5->11->16->15
2	38	41.98	20.03	11->15
3	29	16.55	21.04	11->12->15
2	43	27.82	57.38	11->12
4	13	11.24	36.32	11->12->13->15
9	3	3.75	11.47	1->2->3->4->10->11->12->13->15
7	12	7.49	16.16	1->2->3->4->10->11->12
8	9	3.75	4.69	1->2->3->4->10->11->12->15
7	3	0.15	0.40	1->2->3->4->10->11->15
6	18	7.96	19.13	1->2->3->4->10->11
8	3	0.32	2.57	1->2->3->4->10->11->16->15
8	3	0.30	2.57	1->2->3->4->9->11->16->15
6	20	8.50	23.50	1->2->3->4->9->11
7	4	1.01	1.32	1->2->3->4->9->11->15
8	9	4.83	8.52	1->2->3->4->9->11->12->15
7	13	7.20	19.61	1->2->3->4->9->11->12
9	4	2.37	11.09	1->2->3->4->9->11->12->13->15
9	4	2.35	11.09	1->2->3->4->8->11->12->13->15
7	8	5.33	14.18	1->2->3->4->8->11->12
8	3	2.96	3.08	1->2->3->4->8->11->12->15
7	7	5.63	4.60	1->2->3->4->8->11->15
6	18	11.26	21.35	1->2->3->4->8->11
5	19	12.30	23.77	1->2->3->4->8
4	70	56.97	80.00	1->2->3->4
8	3	0.30	2.57	1->2->3->4->8->11->16->15
2	98	78.21	94.61	2->3
3	97	77.91	94.38	1->2->3
5	12	19.20	8.95	1->2->3->4->6
6	2	5.46	2.29	1->2->3->4->6->15
7	8	12.70	5.83	1->2->3->4->6->11->15
6	10	13.74	6.66	1->2->3->4->6->11
8	2	1.04	0.83	1->2->3->4->6->11->12->15
3	2	7.92	1.51	2->4->6
2	3	13.50	2.61	2->4
3	2	14.58	5.75	4->7->15
3	3	11.61	3.56	4->6->15
2	14	27.13	10.46	4->6
3	11	15.51	6.90	4->6->11
4	9	14.47	6.07	4->6->11->15
3	14	1.34	10.41	11->16->15
2	16	2.40	12.99	16->15

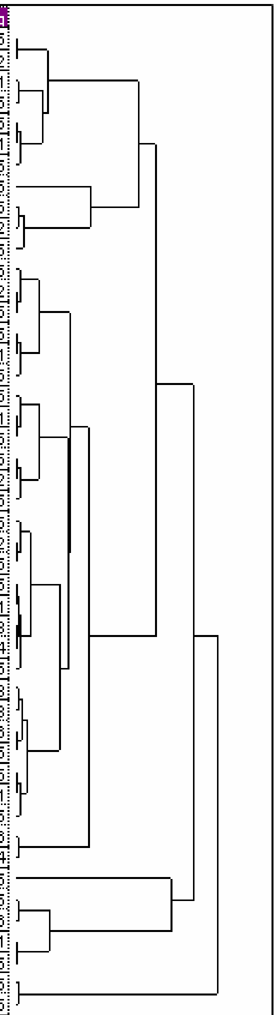


Fig. 3-19. PR Analysis Type III for UniPrint project.

3.2.12 PR Analysis Type IV

PR Analysis Type IV is used to determine an optimal facility layout. It provides another table showing the product routings for each of the jobs. The processes and work centers are listed in columns, but those that are similar are grouped under the same column. To determine a facility layout, each work center group under each column should be highlighted or circled to distinguish it from the other work centers in the same column. This should be done for each column given in the type IV output. An example of this can be seen in figure 3-20. After each group is distinguished, the user should determine the product flow from each process or work center. In the UniPrint example, Cutting precedes Folding, Shipping, and Outside Sources. This implies that the Cutter should be located near these other processes.

Part	1	2	3	4	5	6	7	8
73								
2		2		4	7			
1		2		4	6			
3		2		4	6	11		
72	1					11	12	13
103	1	2	3		5	11		
104	1	2	3		5	11		
11	1	2	3		5	11		
13	1	2	3		5	11		
15	1	2	3		5	11		
17	1	2	3		5	11		
19	1	2	3		5	11		
21	1	2	3		5	11		
23	1	2	3		5	11	12	
25	1	2	3		5	11	12	
27	1	2	3		5	11	12	
29	1	2	3		5	11	12	
90	1	2	3		5	11	12	
94	1	2	3		5	11	12	13
97	1	2	3		5	11	12	
59	1	2	3		5	11		16
63	1	2	3		5	11		16
67	1	2	3		5	11		16
78	1	2	3		5	11		16
79	1	2	3		5	11		16
71	1	2	3		5	11		
77	1	2	3		5	11		
86	1	2	3		5	11		
95	1	2	3		5	11		
98	1	2	3		5	11		
99	1	2	3		5	11		
101	1	2	3	4	9	11		
54	1	2	3	4	9	11		
57	1	2	3	4	9	11		16
61	1	2	3	4	9	11		16
65	1	2	3	4	9	11		16
69	1	2	3	4	9	11		
84	1	2	3	4	9	11		
28	1	2	3	4	8	11	12	
49	1	2	3	4	8	11	12	13
51	1	2	3	4	8	11	12	13
53	1	2	3	4	8	11	12	13
93	1	2	3	4	8	11	12	13
89	1	2	3	4	8	11	12	
96	1	2	3	4	8	11	12	
32	1	2	3	4	9	11	12	
33	1	2	3	4	9	11	12	
36	1	2	3	4	9	11	12	
37	1	2	3	4	9	11	12	

Part	1	2	3	4	5	6	7	8
40	1	2	3	4	9	11	12	
41	1	2	3	4	9	11	12	
44	1	2	3	4	9	11	12	
45	1	2	3	4	9	11	12	
48	1	2	3	4	9	11	12	13
50	1	2	3	4	9	11	12	13
52	1	2	3	4	9	11	12	13
92	1	2	3	4	9	11	12	13
88	1	2	3	4	9	11	12	
30	1	2	3	4	10	11	12	
31	1	2	3	4	10	11	12	
34	1	2	3	4	10	11	12	
35	1	2	3	4	10	11	12	
38	1	2	3	4	10	11	12	
39	1	2	3	4	10	11	12	
42	1	2	3	4	10	11	12	
43	1	2	3	4	10	11	12	
46	1	2	3	4	10	11	12	13
47	1	2	3	4	10	11	12	13
91	1	2	3	4	10	11	12	13
87	1	2	3	4	10	11	12	
100	1	2	3	4	10	11		
56	1	2	3	4	10	11		16
60	1	2	3	4	10	11		16
64	1	2	3	4	10	11		16
68	1	2	3	4	10	11		
83	1	2	3	4	10	11		
12	1	2	3	4	6	11		
14	1	2	3	4	6	11		
16	1	2	3	4	6	11		
22	1	2	3	4	6	11	12	
24	1	2	3	4	6	11	12	
7	1	2	3	4	6	11		
74	1	2	3	4	6	11		
75	1	2	3	4	6	11		
81	1	2	3	4	6	11		
82	1	2	3	4	6	11		
102	1	2	3	4	8	11		
18	1	2	3	4	8	11		
20	1	2	3	4	8	11		
55	1	2	3	4	8	11		
70	1	2	3	4	8	11		
76	1	2	3	4	8	11		
85	1	2	3	4	8	11		
58	1	2	3	4	8	11		16
62	1	2	3	4	8	11		16
66	1	2	3	4	8	11		16
9	1	2	3	4	8			16
26	1	2	3	4	8	11	12	
4	1	2	3	4	7			
5	1	2	3	4	6			
80	1	2	3	4	6			
8	1	2	3					16
10		2			5	11		
6		2	3					

Fig. 3-20. PR Analysis Type IV for UniPrint project.

4.0 Further Assessment and Data Analysis

4.1 Analysis of Current-State Process using IE Tools

In order to analyze UniPrint's facility and its manufactured products, the project team decided to follow a Saddle Stitch job throughout the production process. This decision was based on the PFAST analyses that showed Saddle Stitch jobs as contributing to the highest quantity produced and revenue generated at UniPrint. To better understand the specific components used to assemble a Saddle Stitch job, the project team created a Bill of Materials (BOM) for this job, which can be seen in appendix C figure C-1. This BOM was created from a job ticket received from UniPrint. An assembly diagram and an operation process chart were also created to provide a visual representation of the BOM. The assembly diagram and operation process chart can be found in appendix C figures C-2 and C-3, respectively. The job ticket was also used to determine each machine's cycle time (C/T) and changeover time (C/O) required to complete a Saddle Stitch job. The project team used this production information along with insights from the operators to determine First Time Through (FTT) rates. To determine the inventory levels within the facility, the project team observed the current-state operations on several visits and obtained proper documentation from the Plant Manager. The cycle and changeover times, FTT rates, and inventory levels were then used to create UniPrint's current-state Value Stream Map (VSM), which can be seen in appendix C figure C-4.

After creating the VSM, the project team constructed a flow process chart to help visualize the non-value added (NVA) processes within the current-state VSM. The flow process chart shows the transportation processes, assembly operations, and various decisions that must be made during the production of a Saddle Stitch job. The current-state flow process chart contains similar information as the VSMs but allows for a visual representation of the NVA time. Travel distances were determined by measuring the distance between work centers (WCs) and shadowing operators to record the path taken to transport materials. The distances that materials are transported are also mapped onto the flow process chart, a dimension that is not captured by the VSM. The current-state flow process chart can be found in appendix C figure C-6.

Upon completion of the current-state flow process chart, the project team created a flow diagram by mapping this process onto UniPrint's facility layout. This provides another dimension for the flow process chart, as it determines the actual floor space that is required for each operation. Assembly operations, production delays, and transportation processes are shown with the actual machines used to manufacture the products. This diagram shows the issues that can result from an inefficient facility layout, such as large travel distances and a lack of line of sight between manufacturing processes. The current-state flow diagram can be found in appendix C figure C-8.

4.2 Optimizing Space Utilization

To further assess UniPrint's current-state operations, the project team conducted a space utilization analysis. This type of analysis is used to understand the non-value adding operations occurring in the main production areas within the facility. The analysis was conducted in the Press Room, Bindery area, and the Shipping and Receiving department. The primary issues with space utilization in these areas were the amount of work in process, the wasted motion, and the lack of line of sight between workstations. These concerns and suggestions for improvement are discussed in detail in the following sub-sections.

4.2.1 Press Room

For the Press Room, the space utilization analysis focused on the location of the presses, work-in-process (WIP) inventory occupying the floor space, and product flow through the room. The Press Room is approximately 2,900 square feet in size. In order to process jobs on the presses, materials such as ink and paper are input in the machines. Once the printing process is complete, jobs are transported from the presses and stored at any available location in the room.

The primary concern with space utilization in the Press Room is the location of the presses. Figure 4-2-1 shows the current layout for the Press Room. The 6-Color Press is included in the figure and is labeled with an "A" and a "B." Currently, the paper is loaded into the machine via location A, and the finished job is removed from the press via location B. Because of this configuration, the material handling equipment must travel a distance of 250 feet from where the paper is stored in the Shipping department to where the paper is loaded on the machine. Figure 4-2-2 shows an example of an ideal layout for the Press Room, with the 6-Color Press situated in a way to reduce the travel distance for the material handling equipment. By implementing the layout shown in figure 4-2-2, the material handling equipment would reduce its travel distance by approximately forty feet per job. This relocation of the machine also improves the line of sight for the material handling equipment. Currently, the material handling equipment must maneuver around the WIP and three large machines to load the 6-Color press with paper. With the new configuration, the material handling equipment must only move around two machines and operators can easily load the presses in the aforementioned area shown in figure 4-3-3.

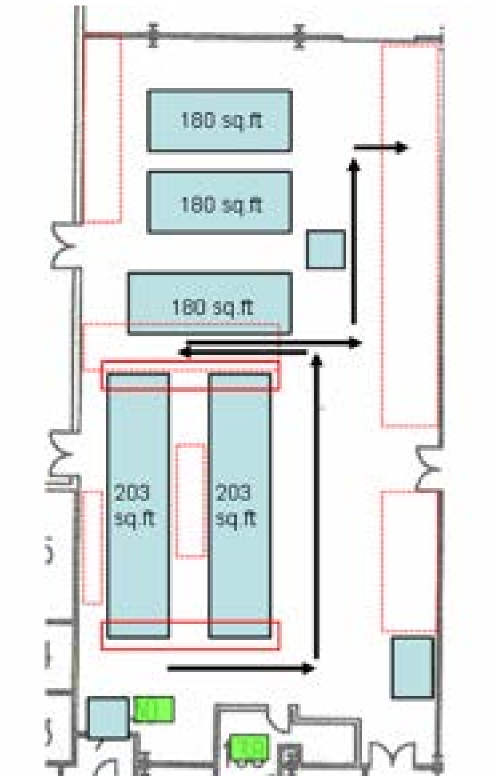


Figure 4-2-1. Current layout for Press Room at UniPrint.

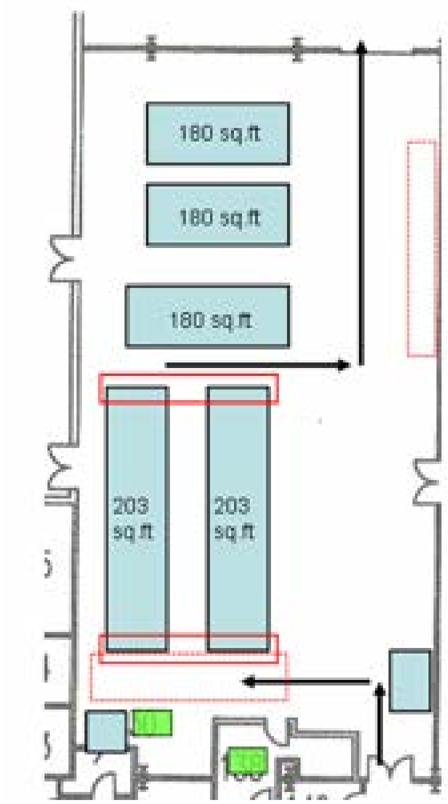


Fig. 4-2-2. Proposed layout for Press Room at UniPrint.


Fig. 4-2-3. Proposed loading area for 6-Color and 5-Color presses.

The second concern with space utilization is the amount of WIP within the Press Room. Approximately 15 percent of the 2,900 square-foot room is consumed by WIP that is stored directly on the shop floor. These areas are represented in figure 4-2-1 by dotted-line boxes. The areas with the highest WIP levels are represented as "C" and "D" on this figure. Location C is where many jobs are stored before being transported into the Bindery. This area consumes approximately 200 square feet, and jobs sit in this location for approximately three to twelve hours before entering the Bindery. Figure 4-2-4 shows the WIP being stored in this location. This WIP limits the operators' line of sight into the Bindery. One simple improvement would be to move this WIP into the Bindery instead of keeping it in the Press room. This will enhance the Bindery operators' line of sight and allow them to visually see a queue of work needing processed. Location D, previously mentioned, also contains high levels of WIP. As a result of this WIP, the line of sight is reduced for the operator when using material handling equipment to transport raw materials. By rearranging the machines within the Press Room as demonstrated in figure 4-2-2, line of sight around the presses will be improved and operators will easily see when a new job is ready to be processed. Therefore, the WIP levels previously stored in Location D will be eliminated.

Fig. 4-2-4. WIP stored in location C at UniPrint.

The third issue with space utilization in the Press Room is the inefficient flow of jobs through the room. By rearranging the 6-Color Press as previously mentioned, the product flow will be improved. Furthermore, implementing the new layout will reduce travel distances for material handling equipment used to load paper on the press and for finished jobs transported to the Bindery.

4.2.2 Bindery

The Bindery Room is 2,600 square feet in size; 10 percent of this floor space is occupied by WIP inventory. This high level of WIP causes significant issues for the

Bindery's floor space utilization. As with the Press Room, the location of WIP is indicated by dotted-line boxes shown in figure 4-2-5. WIP accumulates in front of each work center in the Bindery and typically remains in each location for approximately three to twelve hours before being transported to the next work center.

The amount of WIP occupying the Bindery's floor space decreases the line of sight and increases the travel distance between work centers. Most of the WIP stored in the Bindery is approximately four to five feet high. This reduces the line of sight for the operators when maneuvering material handling equipment. One job that accounts for high levels of WIP in the Bindery is the Keep Book, shown in figure 4-2-6. The current travel distance between Cutting to Folding is twenty-two feet. The distance between Folding to Saddle Stitching is sixty-six feet. Finally, the distance between Saddle Stitching to Shipping is 169 feet. All of these distances will be dramatically reduced if the amount of WIP is reduced or eliminated in the Bindery Room.

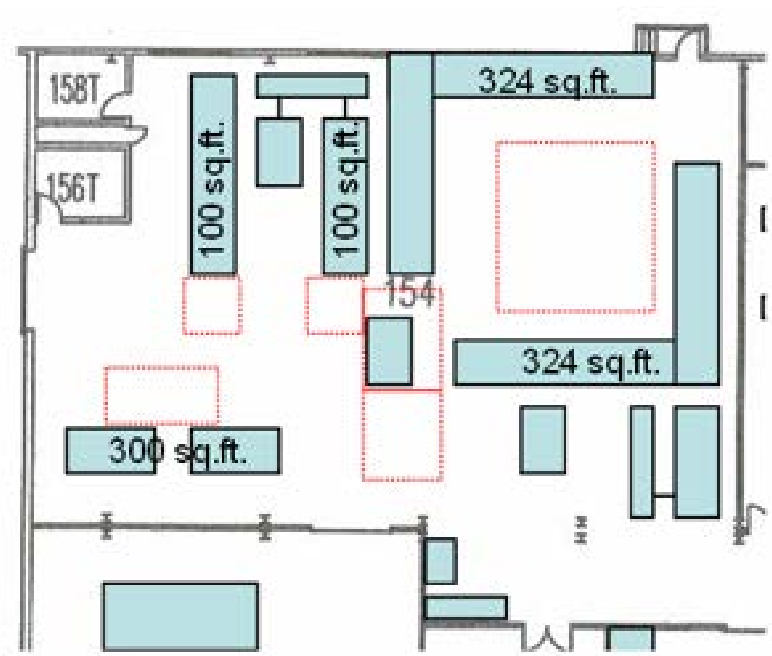


Fig. 4-2-5. Current space utilization for the Bindery Room at UniPrint.

Fig. 4-2-6. Keep Books stored in the Bindery Room at UniPrint.

4.2.3 Shipping and Receiving

The Shipping and Receiving Room at UniPrint is approximately 1,500 square feet in size. The primary issue within the Shipping and Receiving Room is the poor utilization of the vertical storage racks. These racks, shown in figure 4-2-7 along the perimeter of the room, occupy 640 square feet and are filled with outdated finished goods produced at UniPrint. The company is not permitted to dispose of these older jobs and instead stores them on the vertical racks; this prevents the current raw materials from being placed in vertical storage and organized for easy access by the facility's operators. Consequently, raw materials are stored directly on the floor, which is indicated in figure 4-2-7 by dotted-line boxes. Pallets of new paper and packaged finished goods occupy approximately 400 square feet of floor space. Because of this unorganized storage method, the Shipping supervisor spends approximately five minutes per job per day maneuvering material handling equipment to access the needed materials.

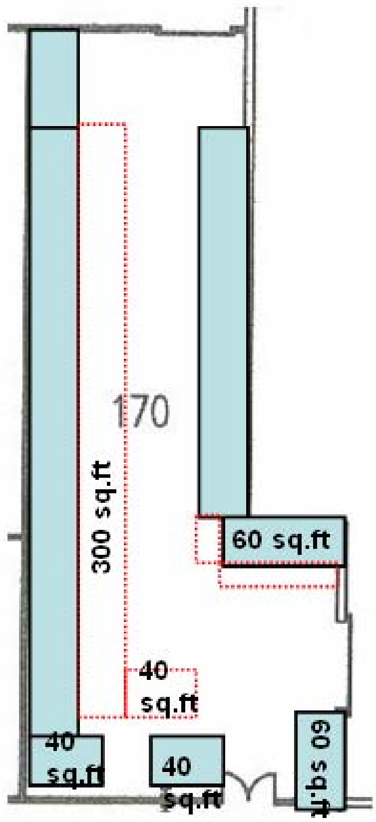


Fig. 4-2-7. Space utilization for Shipping and Receiving at UniPrint.

By efficiently utilizing vertical storage in the Shipping and Receiving Room, current raw material orders can be appropriately organized on the racks and UniPrint can lease the unused space for other storage purposes. Outdated finished goods should be removed from the vertical storage and either scrapped or sent to the customer. This will allow the current raw materials to be organized on the racks using an Earliest Due Date (EDD) priority rule. This priority rule orders the jobs by due date, and it schedules the processing of older jobs before new jobs are released into the production system. By incorporating a priority scheduling rule and designating locations for the raw materials, non-value added time associated with operator motion will be eliminated. If customers request to store their jobs in the Shipping and Receiving Room, UniPrint should require the customer to lease space on vertical storage racks. If UniPrint chooses to lease the space for forty dollars per square foot per year, the company can earn approximately $25,000 per year.

4.3 Alternative Facility Layout

In order to present UniPrint with a feasible facility design to enable just-in-time (JIT) workflow and improve Line of Sight (LOS) efficiency between workstations, the team developed alternative shop floor layouts and performed several analyses to support its final recommendations for the plant manager. As discussed in Section 4.0 and indicated on the future-state flow diagram provided in appendix C-9, the team considered re-locating the Shipping department to an available dock adjacent to the Bindery department. After conducting further assessments, the team created an alternative layout that involves the implementation of this new Shipping area while still utilizing the current Shipping department. Since UniPrint now has two Cutters and two Folders available, the team proposed placing a Cutter and Folder near the new Shipping area (only the Cutter would need to be moved) and the other Cutter and Folder near the current Shipping department. Smaller job orders and those orders that are finished after the Folding process can be shipped from the new dock, whereas larger job orders and those orders that require the Saddle Stitch operation can be routed through the currently designated Shipping department. Jeff Dible, plant manager, explained that the facility is considering hiring a part-time assistant for the Shipping processes. Therefore, this assistant could be placed in charge of one of the Shipping areas and allow UniPrint to effectively operate two separate Shipping docks. This facility layout, shown in figure 4-3-1 below, will allow jobs flowing from the Press Room to be sent to the proper Cutter depending on the size and type of job. It will also allow those smaller orders and those orders with Folding as the last process to be quickly processed and sent to the customer through the new Shipping dock, rather than transporting these jobs over a large distance. While these smaller jobs are processed on those machines closest to the new Shipping area, larger jobs and those jobs processed on the Saddle Stitch machine can be routed directly to Cutter #1 (refer to figure 4-3-1) and then sent through the current Shipping department. By implementing a second Shipping dock, UniPrint will be able to send orders to its customers more quickly and allow operators to better distribute the workload within the Bindery department.

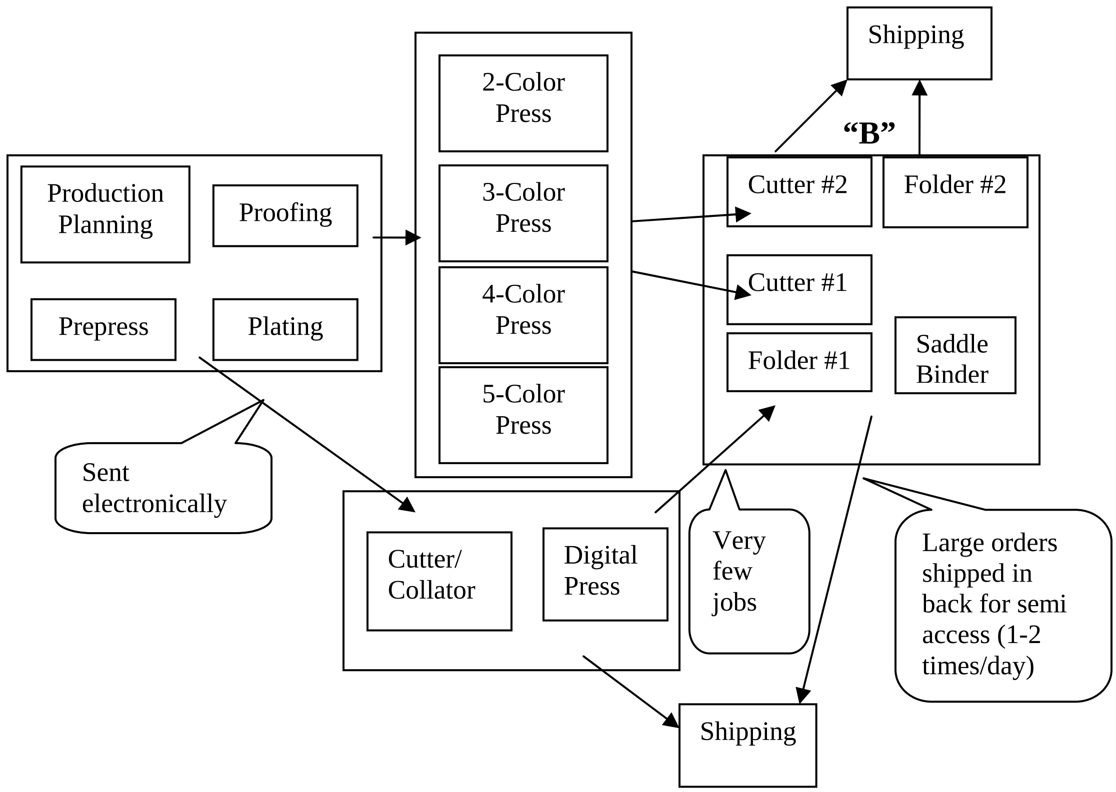


Fig. 4-3-1: Alternative facility layout involving additional shipping dock.

A second alternative facility layout was created by the team in the event that a second Shipping department cannot be implemented at UniPrint. This layout, shown in figure 4-3-2 below, involves locating one of each Cutter and Folder machine near the current Shipping department and locating the other two adjacent to the Saddle Binder machine (which was classified earlier as a monument and cannot be moved). With this layout, jobs that are completed after the Folding processes can be sent to Cutter #2 and Folder #2 and then to the Shipping department. Jobs that require Saddle Binding operations can be sent to Cutter #1 and Folder #1 and then completed on the Saddle Binder. This will allow jobs to be distributed to the Cutters based on their product routings and for operators to balance the workload between the machines. Rather than having all jobs completed in the Press Room placed into one overall queue in front of the Cutters, the jobs can be routed directly to the appropriate Cutter and Folder pair.

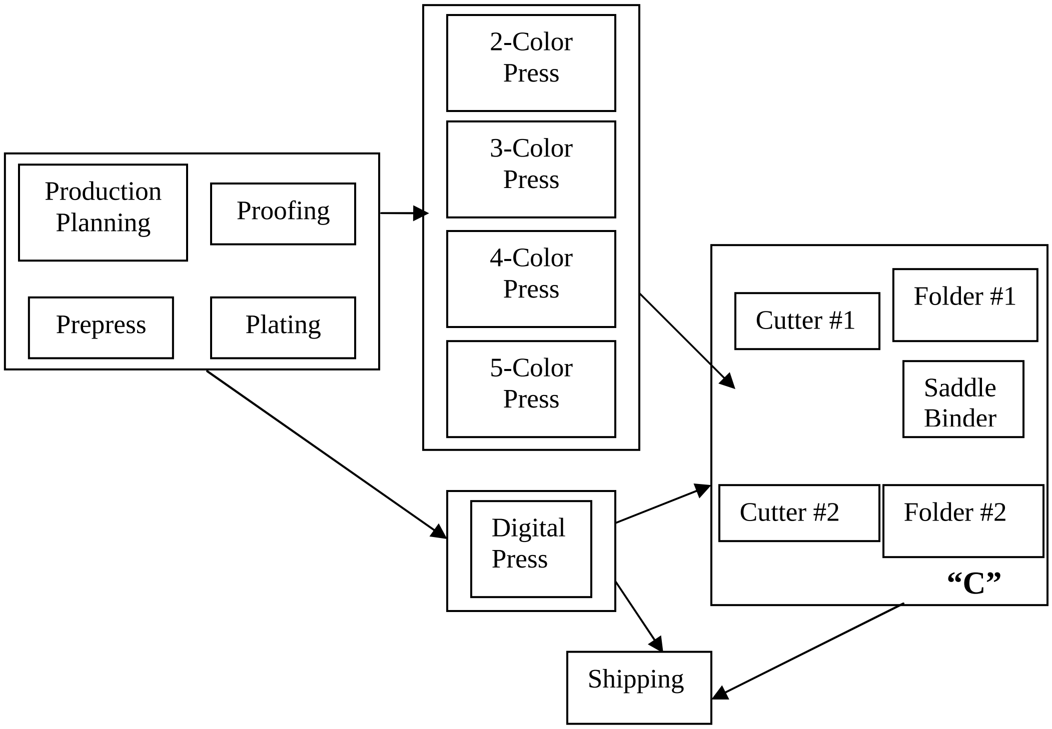


Fig. 4-3-2: Alternative facility layout with Cutter and Folder #2 placed near current Shipping.

PFAST analyses here as well as saved distances/$ for all jobs

For both of these layout alternatives, UniPrint would incur costs for re-locating the Cutters and Folders. The team met with the machine maintenance supervisor and discussed the costs associated with re-locating these machines to achieve the proposed layouts. It costs UniPrint approximately $5,000 to hire contractors to bring in riggers to physically move a machine to another area on the shop floor. Additionally, it costs between $2,000 and $3,000 to set up new conduits and air supplies at the machine's new location. Therefore, the team performed analyses to determine the cost savings that can be achieved by implementing a new facility layout as well as a possible secondary shipping location. The first analysis performed by the team was the generation of the Q and $ Type From-To Charts and Flow Diagrams to indicate the revenue and volume of jobs that flow for the Cutting-Shipping and Cutting-Folding-Shipping routes. In order to create these From-To Charts and Flow Diagrams, the team altered UniPrint's product routings by separating those jobs with the routings Cutter -Shipping and Cutter- Folder-Shipping from the jobs that route through the Saddle Binder. The team also renamed the

Cutter and Folder machines in the input data to Cutter1 and Folder1 and added the machines Cutter2 and Folder2. This allowed the team to analyze the level of volume and revenue that will flow through these separate pairs of machines in the proposed facility layout. These charts and diagrams are provided in appendix B. Referring to appendix B-12, the $ Type From-To Chart and Flow Diagram were generated for jobs with the product routing Cutter2-Folder2-Shipping. These analyses indicated that 60% of UniPrint's revenue will flow through this "virtual cell" producing jobs that are completed after the Folding process and then shipped. Jobs that require the Saddle Stitch processes consist of 40% of UniPrint's revenue and will flow to the second "virtual cell" with the other Cutter and Folder pair. Referring to appendix B-13, the Q Type From-To Chart and Flow Diagram were generated for jobs with the product routing Cutter2-Folder2-Shipping. These analyses indicated that 76% of UniPrint's revenue will flow through this "virtual cell" producing jobs that are completed after the Folding process and then shipped. Jobs that require the Saddle Stitch processes consist of 24% of UniPrint's revenue and will flow to the second "virtual cell" with the other Cutter and Folder pair. The Q and $ Type From-To Charts and Flow Diagrams were also generated for those jobs with the product routing Cutter2-Shipping, which are provided in appendices B-14 and B-15, respectively. These analyses indicated that 23% of UniPrint's revenue and 59% of its volume will flow through the "virtual cell" producing jobs that are completed after the Cutting process and then shipped.

Based on the PFAST analyses described above, the project team determined the total reduction in travel distance along with the associated revenue flow for each alternative facility layout. In order to perform these calculations, the team first measured the travel distances between processes in order to determine which of the proposed layouts would result in the largest reduction in travel distances for products flowing through the Cutter and Folder. These distances were measured for three scenarios: (a) the current location for the Cutters and Folders (b) the layout involving implementing a second Shipping location used for jobs with the product routing Cutter2-Folder2-Shipping (shown in figure 4-3-1) and (c) re-locating one Cutter and Folder cell next to the current Shipping location (shown in figure 4-3-2). Referring to the calculations below in table 4-1, it can be seen that both scenarios B and C reduce the travel distances for the jobs. Scenario B, which corresponds to the layout shown in figure 4-3-1, results in an annual reduction of 301,552 feet traveled by sending jobs with the routing Cutter2-Folder2-Shipping through the cell located adjacent to the second Shipping area. This scenario provides the largest overall reduction in travel distance for UniPrint's jobs. The remaining jobs that require Saddle Stitch processes will be routed to the second Cutter-Folder cell. However, operators will still have the option of re-routing products to the opposite cell in order to balance the workload within the Bindery in the event that the designated Cutter is behind schedule and contains a queue of jobs in front of it. Operators will be able to easily visualize any queuing before the Bindery machines with the implementation of a kanban system, which is explained in further detail in Section 5.2.6 of this document. If a secondary shipping location cannot be implemented, the team will recommend that UniPrint follow the re-layout process involving Scenario C. This alternative layout, shown in figure 4-3-2, results in an annual reduction of 169,454 feet traveled by sending jobs with the routing Cutter2-Folder2-Shipping through the cell located near the current Shipping department. While this layout does not provide as much of a reduction in travel distance, it does allow the Cutters and Folders to be grouped into two separate cells and for one of these cells to be designated to jobs requiring Saddle Stitch processes.

TABLE 4-1

CALCULATIONS OF REDUCED TRAVEL DISTANCES AND ASSOCIATED REVENUE FLOW FOR ALTERNATIVE LAYOUTS

	TO						
FROM	Cutter	Folder	CutterB	FolderC	CutterC	Shipping	Shipping2
5-Color	115		136		139		
6-Color	104		125		127		
2-Color	52		73		77		
Duplicator	37		58		63		
Dig Press	142		164		191		
Cutter		22		100		149	49
Folder						181	27
CutterB		22		122		170	28
CutterC				5		84	
FolderC						84	

CutterB: 2nd cutter closest to new shipping
CutterC: move 2nd cutter near current shipping
FolderC: move 2nd folder next to CutterC

	Distance/Job	**Total # Jobs**	**Total $**	**Total Dist./Yr.**
5-Color-Cutter-Shipping:	264	84	223962	22176
6-Color-Cutter-Shipping:	253	319	442237	80707
2-Color-Cutter-Shipping:	201	24	179390	4824
Dup-Cutter-Shipping:	186	681	329006	126666
DigPress-Cutter-Shipping:	291	1135	637227	330285
	Total	**2,243**	**$1,811,822**	**564,658**
5-Color-Cutter2-Shipping2:	164	84	223962	13776
6-Color-Cutter2-Shipping2:	153	319	442237	48807
2-Color-Cutter2-Shipping2:	101	24	179390	2424
Dup-Cutter2-Shipping2:	86	681	329006	58566
DigPress-Cutter2-Shipping2:	192	1135	637227	217920
	Total	**2,243**	**1,811,822**	**341,493**
5-Color-CutterC-Shipping:	223	54	$81,486	12042
6-Color-CutterC-Shipping:	211	300	$281,226	63300
2-Color-CutterC-Shipping:	161	8	$24,915	1288
Dup-CutterC-Shipping:	147	776	$373,773	114072
DigPress-CutterC-Shipping:	275	877	$445,816	241175
	Total	**2,015**	**$1,207,216**	**431,877**

	Distance/Job	Total # Jobs	Total $	Total Dist./Yr.
5-Color-Cutter-Fold-Shipping:	286	259	524597	74074
6-Color-Cutter-Fold-Shipping:	275	159	189711	43725
2-Color-Cutter-fold-Shipping:	223	99	289157	22077
Dup-Cutter-Fold-Shipping:	208	56	51189	11648
DigPress-Cutter-Fold-Shipping:	313	213	240900	66669
	Total	**786**	**$1,295,554**	**218,193**
5-Color-Cutter2-Fold-Shipping2:	186	259	524597	48174
6-Color-Cutter2-Fold-Shipping2:	175	159	189711	27825
2-Color-Cutter2-Fold-Shipping2:	123	99	289157	12177
Dup-Cutter2-Fold-Shipping2:	108	56	51189	6048
DigPress-Cutter2-Fold-Shipping2:	214	213	240900	45582
	Total	**786**	**$1,295,554**	**139,806**
5-Color-CutterC-FoldC-Shipping:	228	271	$659,286	61788
6-Color-CutterC-FoldC-Shipping:	216	57	$227,304	12312
2-Color-CutterC-FoldC-Shipping:	166	218	$447,363	36188
Dup-CutterC-FoldC-Shipping:	152	56	$51,189	8512
DigPress-CutterC-FoldC-Shipping:	280	224	$288,934	62720
	Total	**826**	**$1,674,076**	**181,520**
Moving Cutter & Folder Near Current Shipping:		**2,841**	**$2,881,292**	**613,397**
Having Secondary Shipping Location:		**3,029**	**$3,107,376**	**481,299**
Current-State:		**3,029**	**$3,107,376**	**782,851**
Reduced Distance for Moving Cutter & Folder:				**169,454**
Reduced Distance for Having Secondary Shipping:				**301,552**

This separation of product routings, along with the incorporation of the kanban system described in Section 5.2.6, will allow for more efficient Line of Sight and a balanced workload in the Bindery department. The implementation of either of these proposed layouts along with the kanban system will allow UniPrint to achieve a more consistent product flow throughout the facility and ultimately realize benefits such as reduced WIP levels, increased throughput, and reduced lead times for its customers.

5.0 Solutions

5.1 5S

5S is a widely-used process in Lean manufacturing to improve workplace efficiency, organization, housekeeping, and product quality. This philosophy is based on Japanese words beginning with the letter “S” (Seiri, Seiton, Seiso, Seiketsu, and Shitsuke). 5S simplifies the workplace by reducing waste and non-value added (NVA) time as well as improving safety and quality. The following sub-sections provide brief descriptions of each of the 5S’s and discuss the recommendations that the project team presented to UniPrint’s plant manager.

5.1.1Sort (Seiri)

Sort is the first step in eliminating unnecessary items from the workplace. As seen frequently in manufacturing settings, items are stored on the shop floor that have not been used in the past six to twelve months. One way to determine which items to keep on the floor and which to either discard or relocate is to allow operators to tag items in their area. Red tags are placed on items critical to the worker’s ability to complete his or her job; yellow tags should be placed on items that are used within several workstations; and green tags should be placed on items that are not used at the workstation and can be removed. Other color schemes are used, sometimes reversing the green to the critical items; regardless of color assignments, the ultimate goal is to remove unnecessary items from the shop floor. Once all the items have been tagged, managers and production supervisors should schedule a meeting with the employees to determine which tools need to be shared among workstations and which items can be discarded. At UniPrint, the Sort step should be completed for each workstation by labeling items such as forklifts, raw materials, trash, outdated technical drawings and product inventories, and any other unnecessary materials.

5.1.2 Straighten (Seiton)

Straighten evaluates how items are stored throughout the facility. The first question to consider is “What items are needed to complete my job?” Having each worker answer this question will determine where raw materials and tools need to be located. The second question is “Where should this item be located?” If only one worker needs the item, then the product should obviously be located at his/her workstation. If the item is shared among multiple locations, the following two options should be evaluated: (1) if usage is low among workers, then sharing one tool with a centralized location might be feasible, and (2) if each worker uses the item frequently, then management should determine if the benefits of purchasing another item outweigh its cost.

Some of the strategies to organize items on the shop floor are: paint outlines on the floor to designate proper storage locations for items and production equipment, outline areas allotted for workstations, provide shadow boards for tools and supplies, organize shelving for materials, and install storage cabinets. These strategies can help eliminate wasted movement caused by workers searching for items such as assembly tools or forklifts. For example, outlining a centralized storage location for forklifts allows employees to visually recognize the location of the forklift rather than spending non-value added time searching around the facility. All items essential to the manufacturing process should have a designated area in the facility so that each worker can easily locate the materials necessary to complete his/her job.

By completing the Sort step within UniPrint's facility, the project team identified which tools need to be shared among workstations. These tools should be placed in a centralized location to accommodate the operators in these areas. One possible method for executing this plan is to encourage employee involvement, as the operators are extremely familiar with the requirements of the workstation processes are use the associated tools on a daily basis. Below are the suggestions presented by the project team for each area within UniPrint's facility:

- **Press room:** The cleaning materials are used by operators to maintain the machines between jobs. UniPrint should determine a location that is central to the presses, possibly near the 5-Color Press, to store the cleaning cart. This would allow easy access from the 6-Color Press and Duplicator. Forklifts are shared among operators to move paper from Shipping to the Press Room and to place paper on the presses. Currently, these forklifts are left where the operator last used them. Having a standardized location for the forklifts would reduce operator motion and create a safer work environment. Placing a square on the floor would indicate proper forklift location; if this square is empty, this means that the forklift is currently in use.

- **Bindery:** Similar to the Press Room, forklifts do not have a standardized location. Wooden three-sided carts are used to move materials from Bindery to Shipping. These carts are stored on the production floor and do not have a specified storage location. Creating a specified location for these materials on the shop floor would further eliminate NVA operator motion.
- **Shipping:** Currently, forklifts designated for the Shipping department are often borrowed by the Press Room operators and are not returned, leaving the Shipping supervisor without necessary material handling equipment and delaying the Shipping/Receiving processes. Outlining a centralized storage location in the Shipping area and labeling the area's forklift with the words "Shipping Dept." would ensure that workers return it to the room, thus eliminating delays caused by NVA operator motion.

5.1.3 Shine (Seiso)

The Shine step requires that each workstation be thoroughly cleaned. Daily housekeeping should then be conducted to keep the workstation clean. When the area is clean, it is easier to visually recognize equipment leakages and spills. This will reduce the time required to repair machines so that issues can be addressed before the equipment completely fails.

Currently, UniPrint does not have a preventive maintenance program in place for its machinery. Implementing such a program would ensure that weekly inspections are performed on each machine to remove dirt and foreign materials, add necessary fluids, and repair any damages that have occurred during the week. A clipboard containing a weekly checklist should be placed near each machine; operators and floor supervisors must write their initials next to each maintenance task upon completion. To ensure that all workstations are clean and safe for the next shift, a daily housekeeping walk-through should be performed by all operators at the end of their shift. Operators should remove all scrap and trash from the shop floor and any materials on or near machinery to ensure the shop floor's cleanliness and safety.

5.1.4 Standardize (Seiketsu)

Standardizing best practices in each area allows workers to have a Standard Operating Procedure (SOP) for the workstation's machines and processes. For example, consider how hamburgers are made at McDonalds. Each time a new worker makes a hamburger, it is created the same way and the raw materials are always located in the same position. Having a standard workstation layout and outlined procedures allows employees to operate more efficiently and also alerts them when raw materials are low.

If multiple workers on different shifts perform the same operation, it is important that each worker uses the same procedures to complete the work. This will minimize errors between workers and improve the learning curve for new employees. Some companies use cards with SOP instructions and visual aids to explain the different procedures. For example, McDonalds provides visuals with a bun, ketchup, mustard, pickles, onions, and hamburger patty to show employees the steps required to make a hamburger. Depending on the environment, SOPs may require thorough instructions and elaborate visual aids.

At UniPrint, the project team recommended the creation of detailed SOPs with corresponding photos for each process in the production system. A detailed SOP should be created for each workstation's machines to instruct the operator how to use each machine required to process jobs**.** SOPs should contain clear and concise instructions for setting up machines, loading raw materials, operating machines, unloading finished jobs, and performing any necessary maintenance**.** Instructions must be complemented by digital images of these processes being performed; this will allow operators who are unfamiliar with the processes to easily learn how to use machinery**.** Using SOPs will also reduce variation in set-up and processing procedures between operators.

5.1.5 Sustain (Shitsuke)

Sustain requires maintaining the new procedures implemented in the first four steps. This requires resisting human nature to reject these new concepts and return to practicing former work methods. Encouraging management to stress the importance of keeping workstations clean and following procedures is one method for sustaining the changes that have been implemented. Without successfully executing the Sustain step, the changes made will not have a lasting impact on the workplace. Follow-up 5S events could be organized on a yearly basis to re-evaluate the workplace and reinforce the importance of maintaining these improved processes. Once completed, 5S can increase the company's bottom line by reducing waste, manufacturing higher quality products, and reducing product lead times. Improved employee morale can also increase the efficiency and organization of the workplace.

For UniPrint, the project team recommends hosting a Safety/Continuous Improvement Day each month. On the last Friday of every month, the plant manager and supervisor can schedule a Safety Day to ensure continuous practice and improvement of the 5S program. Each event will have a specific theme (e.g., HazMat Day); operators will spend the afternoon performing a walk-through and recording each instance where a violation of the event's safety rules occurs (e.g., operators find leaky ink container, etc.). The operator that identifies the most violations can be awarded a gift certificate, vacation day, etc. At the end of the safety event, management can host a barbeque or luncheon for operators. Hosting these types of events allows management to ensure that operators are working to continuously improve the 5S program. This will result in increased worker satisfaction and a healthier work environment.

5.2 Theory of Constraints: Drum-Buffer-Rope

Theory of Constraints is contributed to the work of Eli Goldratt, who introduced the principle that the productivity or revenue generation is always limited by at least one constraining factor, the bottleneck. Increasing productivity or throughput at the bottleneck in turn increases the throughput of the entire system.

5.2.1 Identifying the Bottleneck

The first step in increasing capacity is identifying the bottleneck that is constraining the production rate of the system. This can be done by determining the cycle time for each process and machine in the system. The cycle time is the time it takes the machine to complete one item. The machine that performs the slowest in a system is considered to be the bottleneck. For example, a fast food restaurant may have ten cooks working in the grill area; however, if only one employee is taking the orders then customers can only move through the system as quickly as the orders can be taken. For any given facility, a Value Stream Map (VSM) should be available containing the relevant cycle times and changeover times. This is a good starting point for determining the bottleneck of the production system.

At UniPrint, the project team determined that the 5-Color Press was the bottleneck in the process of completing a Saddle Stitch job (refer to figure 5-2-1). This is the process with the longest cycle time on the VSM. For the Saddle Stitch job, the press required 19.27 hours to complete the job with a changeover time (C/O) and cycle time (C/T) of 135 minutes and 3 seconds per page, respectively. The initial analysis showed that capacity is being lost on the press due to the high cycle time of 135 minutes. Table 5-2-1 shows the comparison of C/T and C/O between work centers. It indicates that, in-between jobs, the press remains idle for over two hours while it is cleaned and prepared for the next job. One factor to consider regarding the 5-Color Press is that paper must be maneuvered on pallet jacks since it is too heavy to be loaded manually onto the press. Furthermore, UniPrint does not have a designated material handler at the facility. Therefore, the press operator must retrieve the raw materials (ink, paper, etc.) from the Shipping area. This requires the operator to leave the workstation idle while retrieving the necessary supplies.

TABLE 5-2-1

IDENTIFYING THE BOTTLENECK WORK CENTER

Work Center	**Press**	**Cutter**	**Folder**
C/T (seconds)	3	0.19	0.7
C/O (minutes)	135	5	150
Total time for 23,000 items (hours)	19.27	1.25	7

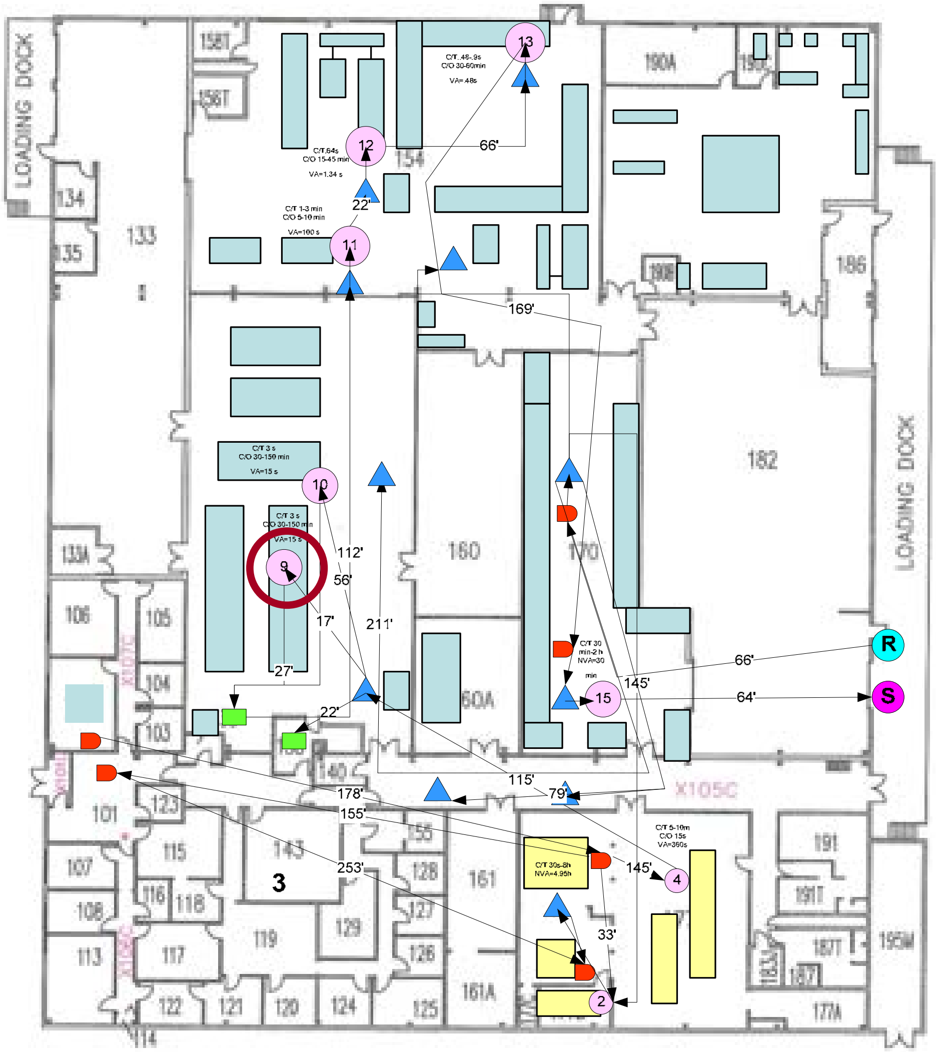


Fig. 5-2-1. Facility layout with the location of the bottleneck workstation circled in red.

5.2.2 Exploiting the Bottleneck

Exploiting the bottleneck refers to identifying opportunities to increase the capacity at the bottleneck. Evaluating the processes that occur in the system before the bottleneck may reveal opportunities to decrease set-up times at the bottleneck. By improving changeover processes and assigning more operators to the workstation, capacity at the bottleneck can potentially be gained back. When documenting the capacity that can be re-gained, only the time associated with performing a value-added (VA) activity should be considered.

At UniPrint, several opportunity areas were identified that can increase the 5-Color Press' capacity. To prepare the press for printing, the plates must be installed on the machine. Currently, one operator and one assistant hang the plates, regardless of the job size. Assigning three additional assistants to this activity would allow all four plates to be hung at once, thus saving four minutes of capacity (one minute per plate). After large jobs have been processes, one operator and one assistant are assigned to clean the press. Increasing the number of assistants to four would increase the press' capacity by 108 minutes, as the machine's changeover time would be decreased. Instead of requiring operators to retrieve the raw materials and leave the press idle, an assistant should obtain the raw materials while the press is processing the next job. This would gain 10 minutes of capacity. Assigning assistants to load the paper onto the press would also gain 10 minutes of capacity, since the operator could use this time to check proofs against the press' print results for quality inspection. Implementing all of these suggestions would gain a total of 132 minutes of capacity. With this re-gained capacity of 132 minutes, the following activities could be performed: print an additional 2,600 sheets of paper, eliminate the production system's downtime caused by the changeover of the 5-Color Press, or save $44 labor/day*(250 days/year) = $11,000/year if increasing production capacity is not the optimal choice.

5.2.3 Serving the Bottleneck: Drum-Buffer-Rope

Increasing the capacity at the bottleneck will result in an increase in throughput at that workstation. The ultimate goal is to then increase the capacity of the entire manufacturing system. As previously discussed, the system can only complete a product as quickly as the bottleneck can complete its process. The bottleneck is therefore referred to as a drum, because it determines the rate or beat at which the system can perform. Drum-Buffer-Rope is a method that ensures that raw materials are at the bottleneck at the moment they are needed. The drum is the bottleneck stamping out the beat, the rope is the signal sent to retrieve raw materials for the drum, and the buffer is the lot of raw materials ready and waiting to be used by the drum. This method allows the buffer to be replenished before the drum is left without any material to process.

To identify the buffer, one must determine which process needs to be completed immediately before the drum on the production line in order for the drum to have a sufficient amount of material to process. The rope would be the method used to signal to that preceding workstation that the drum is ready to accept new jobs.

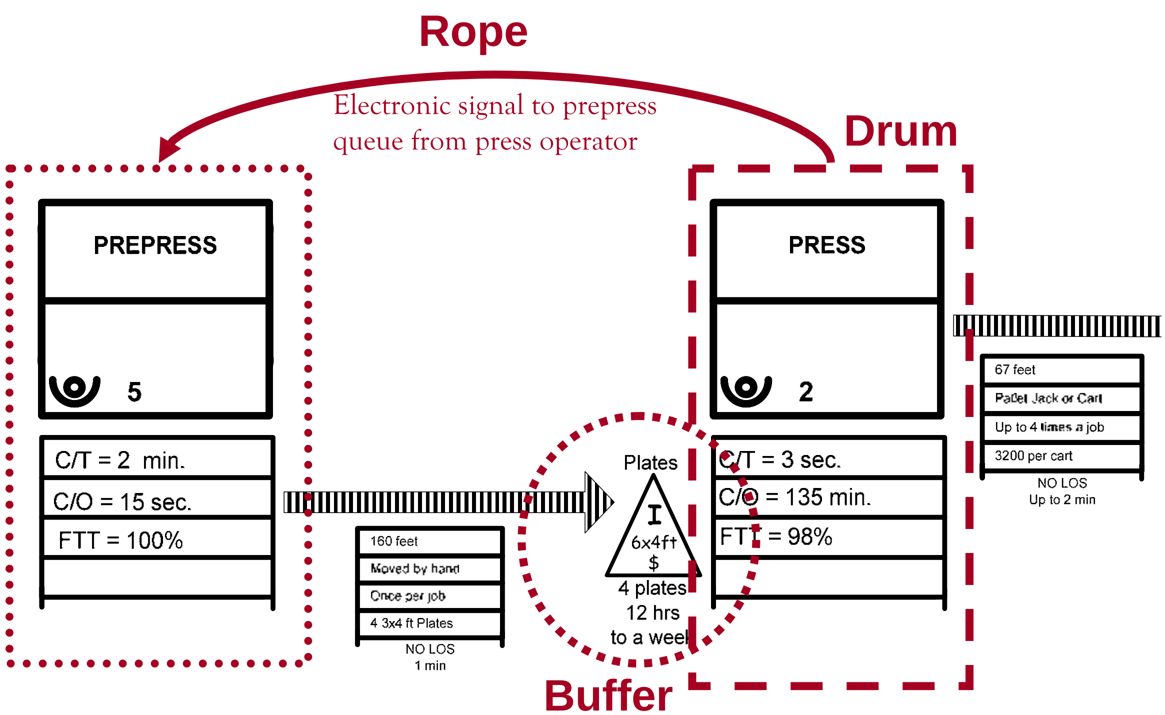


Fig. 5-2-3. The press was identified as the drum, a signal to print the plates as the rope, and the plates as the buffer for the drum.

Buffer: To decrease the waste between the prepress and the press areas it is suggested that a drum-buffer-rope be put into place to monitor the creation of plates for the presses. In the current process the prepress operators are in charge of creating the design for the plates and printing the plates. The printing of the plates requires that the job be digitally sent to the plating machine. The prepress operator then picks up the plates and carries them to the press room. The press room operator then uses the plates to print the job on the press. The current problem is that there is no communication between the press room and prepress area. The order that the prepress operators complete jobs is currently set by the press room supervisor in the morning. He manually puts the jobs in order that he thinks will be best and then the operators work through the orders, creating plates as soon as they complete the design. This current process results in plates being created several hours to several days before the press can run the job. The plates then hang on a rack as waste until they can be used. The goal of the DBR would be to signal the creation of plates so they will be available for the press JIT. Figure 5-2-3 is a diagram showing the drum, the press, the rope, the signal to create the plates, and the buffer, the actual printed plates.

The press room operator is acutely aware of when a plate is needed to run a job. His job is to follow the schedule of jobs. He knows when there is a back up or break down on a machine. Rather than having the prepress operator print the plates who does not know how the press is operating because he/she is in a separate room, the press assistant who works under the press operator should be in charge of printing the plates. A kanban storage bin will be used to signal the need for plates to be printed to the press room assistant.

In the press room there is a rack that the plates hang on. This rack can be turned into a kanban storage unit by a few simple modifications. The rack will be marked with two sections, Ready for Press and Waiting for Press. There should always be a group of plates in each area (group implies the set of 2-6 plates needed to run the job on the press). This means that there is a buffer of one in the storage rack. After the plates in the Ready for Press section are removed, the plates in the Waiting for Press section will be moved to the Ready for Press section by the assistant. Since the Waiting for Press Area will be empty the assistant knows that he/she needs to print the next needed set of plates. See figure below for example of Kanban racking.

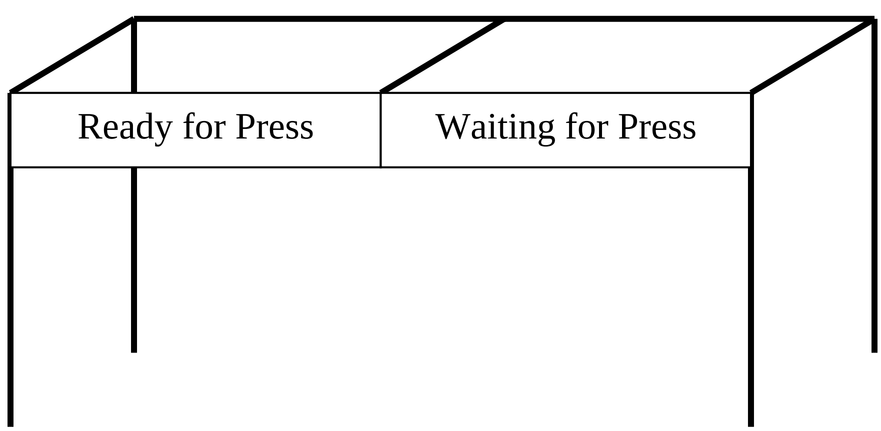


Fig. 5-2-4. Prototype of the buffer plating rack.

Rope: The next piece of the DBR system is the rope. The assistant sees from the kanban storage bin that plates need to be created and now he needs to print the plates. UniPrint is using Avanti to schedule its production. There are two computer terminals in the press room where the assistant can access the production schedule. The assistant can access the schedule and see which job is schedule to run next and print the corresponding plates.

To print the plates the assistant can access the queue for the plating machine. After the prepress operators have made all adjustments to the design, they will send them to the queue to be printed on the plating machine, shown below in figure 5-2-5. This is the process that is currently done. The only difference is that the prepress operators would actually send the job to the plating machine queue and signal the ob to print. Now the prepress operator will only submit the job to the queue and the press room assistant will determine when to print the job.

The press room assistant selects the plates to be printed from the queue, selects print and picks up the plates from the plating room approximately five minutes later. This allows the prepress operator to work more efficiently without having to worry about creating the plates and taking them to the press room. The press room assistant will be in charge of keeping the DBR moving smoothly.

The added dimension to the DBR is that the workers in the Press and Prepress area are all union workers. Luckily, they are members of the same union so there will not be a division of labor issue by having the press assistant rather than the prepress operator making the plates.

Fig. 5-2-5. Plating machine, with digital queue to store orders, waiting for the rope to signal production of plates.

5.2.4 Permanently increasing production capacity

If additional capacity needs to be achieved after the bottleneck has been exploited, then it may need to be permanently increased. This could require additional Full-time (FT) workers, new machinery, facility expansion, etc.

5.2.5 Re-evaluating the System

By increasing throughput at the former bottleneck in the system, a different machine or process may now be causing a new bottleneck to prevent efficient throughput on the line. If additional throughput is desired from the system, then the same Drum-Buffer-Rope (DBR) process should be completed to locate the new bottleneck and exploit it. Therefore, the Theory of Constraints and DBR concept are not meant to be one-time fixes for a production system. In order to achieve a Lean manufacturing process, companies must engage in continuous improvement through the application of these concepts and other useful Industrial Engineering tools.

5.2.6 Kanban System for Bindery

The cellular layout within the bindery room created a kanban system. This is shown on the value stream map in figure 5-2-6. The bindery room has two virtual cells. The first virtual cell, cell 1, consists of a cutter, folding machine, and a saddle stitcher. Any job not needing processing on the saddle stitcher will move through the second cell. The second cell, cell 2, consists of a cutter and a folding machine. Whether these machines are moved to a new location or an additional shipping location is used, this kanban system is valid.

The value stream map shows a kanban in front of each machine. One set of plates serve as a kanban for the presses. This is simply a buffer because the changeover time for the presses exceeds the cycle time to create the plates. This was described in the drum-buffer-rope section, 5-2. The jobs will then move to the bindery using an earliest due date priority scheduling. The job will be placed in front of either of the cutters depending on the job's sequence. After this process, the jobs will be pulled through the job sequence in the bindery room as "one job flow." Two jobs will sit in the kanban before the folding machines. This will ensure that the bottleneck of the bindery room, the saddle stitcher, is always being utilized to its capacity. To maximize the utilization of the saddle stitcher, a buffer of one job will serve as the kanban.

The bindery room can be analyzed using the Theory of Constraints. The operation of with the longest cycle time is the saddle stitcher. The saddle stitcher can be considered to be the bottleneck of the operation, and its drum beat will drive the other operations in the bindery room. The bottleneck will have ropes to both the folder and the cutters. To optimize the utilization, the saddle stitcher must constantly be processing. Whenever the buffer for the saddle stitcher is empty, it serves as a cue to process a job on the folder and possibly the cutter as well. Maximizing the utilization of the saddle stitcher will give visual cues to the operators in the bindery. For example, when the saddle stitch machine is being used and a job is waiting in the kanban queue, the operator should discontinue work on the folder in cell 1 and focus on jobs in cell 2.

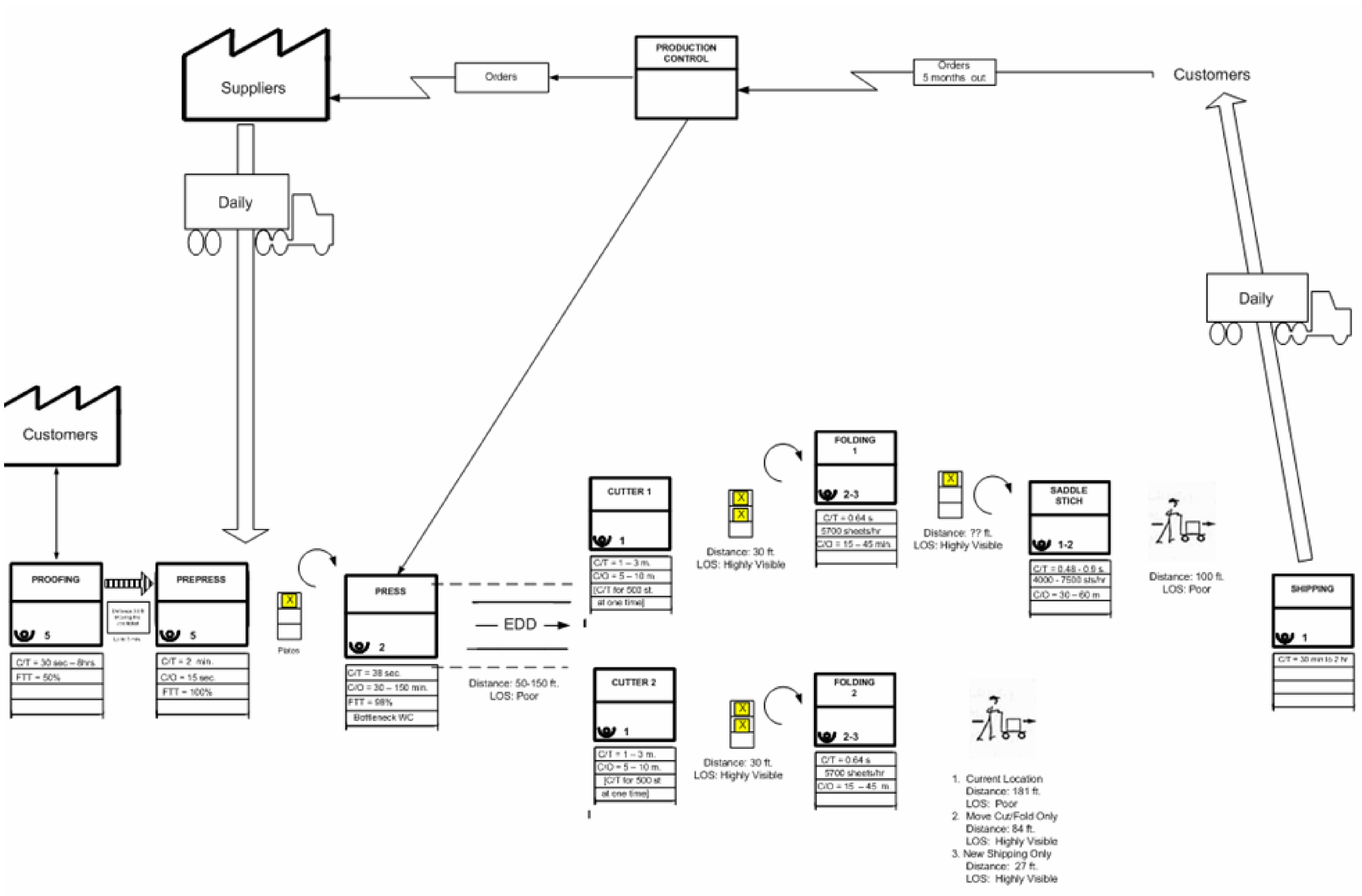


Fig. 5-2-6. Value Stream Map with virtual cells.

5.3 Finite Capacity Scheduling

Finite Capacity Scheduling (FCS) is the scheduling of resources and jobs such that precedence constraints and resource capacities are not violated. In other words, FCS involves determining the appropriate order to process jobs on each machine. The goal of FCS is to complete all orders on time using the available resources. If Job I needs to be processed through steps ABC and job II needs to be processed through steps ACD, which job should be scheduled first on Machine A? This problem is difficult to solve because no universal answer exists. Depending on the size of the facility and number of orders to be scheduled, this scheduling issue can be resolved by manually creating a Master Production Schedule (MPS) or implementing appropriate production scheduling software.

5.3.1 Ordering Sequences

The ordering of jobs that need to be completed can impact the rate at which an order is completed and determine whether it will be delivered to the customer on time. The following scheduling priority rules are commonly used in industry. After briefly describing the sequences, comments will be made as to which scheduling sequence should be implemented at UniPrint.

- **First Come First Serve (FCFS):** Jobs are processed in the order that they arrive at the station. This is similar to waiting in line at the grocery store; the customer that is first in line receives service first from the cashier. UniPrint could utilize this method if there was an overall production schedule for the facility. Ideally, the schedule of the Press should determine the schedule for the downstream processes. This means that the order in which items are printed should also be the order in which they are processed by the Cutter, Folder, Binder, etc.
- **Earliest Due Date (EDD):** EDD involves sequencing the jobs such that those orders that are due immediately should be processed before jobs that are due much later. This method is rather intuitive, as the jobs that need to be completed the soonest should be processed first. UniPrint currently attempts to schedule jobs using this method. However, issues arise because no overall production schedule

exists within the facility. This also causes issues with the raw material ordering process. Because no overall schedule or standardized priority scheduling rule exist, raw materials are ordered months in advance as soon as orders are entered into the system.

- **Slack Time Remaining (STR):** STR involves sequencing jobs by the length of time remaining until the due date subtracted by the processing time remaining. This sequence ensures that orders are completed before the due date by considering the available slack time that each job has. Currently, UniPrint does not utilize this scheduling concept. STR would provide UniPrint with a useful measure to evaluate whether it is beneficial to begin jobs with longer processing times and in turn delay the start of smaller jobs that have sufficient slack time remaining before due date.

Many other ordering sequences are practiced in industry. By selecting the most feasible scheduling priority rule and successfully implementing it in the production system, manufacturing companies can maximize their key measures of performance.

5.3.2 Measures of Performance

This sub-section discusses possible measures a company can use to evaluate the efficiency of its scheduling methods and overall production system. Some of the criteria that are commonly used as measures of performance (MOP) include the following:

- Percentage of late jobs
- Average tardiness of the product arriving to the customer
- Machine utilization
- Dollars of work-in-process in the system
- Average queue length at any machine
- Average flow time through the system

Determining the appropriate criteria to measure will allow a company to evaluate its current scheduling system and identify alternative systems that can improve the efficiency of its operations.

Depending on the complexity of the work environment, a facility can simply use a manual scheduling method or instead implement a dynamic scheduling software package.

The following three figures provide examples of how to manually schedule a job sequence. Figure 5-3-1 shows the routings for three separate jobs as well as the corresponding machine processing times. Figure 5-3-2 displays a Gantt chart that illustrates the current production schedule for three jobs. Referring to this chart, it can be seen that scheduling improvements can be made to reduce the idle time for each machine in the system. Figure 5-3-3 shows the overall processing times for the three jobs.

	Processing Times			Routes		
Job	OP 1	OP 2	OP 3	OP 1	OP 2	OP 3
1	3	6	7	A	B	C
2	4	2	5	A	C	B
3	8	1	3	C	A	B

Fig. 5-3-1. Schedule processing times and routes through three machines for three jobs.

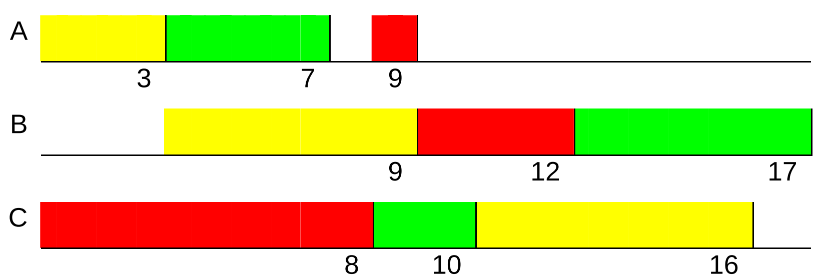


Fig. 5-3-2. Gantt chart for schedule to help minimize flow time.

Completion Times	
Job1	16 hours
Job2	17 hours
Job3	12 hours

Fig. 5-3-3. Summary of completion times for three jobs.

When a job takes longer on a machine than planned or if a machine gets behind schedule this will significantly impact the schedule. For the same processing times as shown in

Figure 5-3-1, let us look at the example that Job1 takes 5 hours rather than the scheduled 3 hours on OP1. The new gantt chart is shown below in Figure 5-3-4 with the summary completion times in Figure 5-3-5. Looking at the summary completion times shows that having a delay on one job on one machine can impact the entire schedule and the completion time of the jobs.

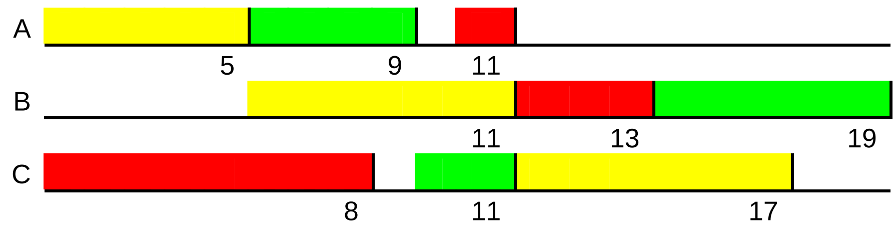


Figure 5-3-4. Gantt chart for delayed schedule.

Completion Times		
	Original	Delayed
Job1	16 hours	17 hours
Job2	17 hours	19 hours
Job3	12 hours	13 hours

Figure 5-3-5. Summary of completion times for three jobs with delay.

5.3.3 Scheduling Software

For complex schedules, it is beneficial to install scheduling software that allows for dynamic changes. One software package that is popular for both small and large companies is Preactor. A brief description of this software is provided in this sub-section.

Preactor is a software package that allows companies of various sizes to apply a Finite Capacity Scheduling method through the use of an interactive decision-support tool. The goal of Preactor is to follow the Lean approach by balancing customer demand with available capacity. The benefits of this software package include: customizability, flexibility and ease of integration, efficiency of handling complex scheduling situations, and ability of users to easily adjust the schedule and access support. Preactor is used in various industries such as manufacturing sites, airports, transportation systems, and logistics operations. Packages are offered in a wide range of prices, from $500 to $85,000. Preactor is used in more than 1,600 companies worldwide. To obtain additional information on Preactor and to view case studies, please visit http://www.preactor.com.

Procter & Gamble is the world’s largest consumer packaged goods company. P&G produces nearly 300 product brands. In 2000, Preactor was implemented at P&G’s Louveira, Brazil production site in the Fem Care plant. The Louveira plant was experiencing significant changeover times due to product and packaging variations. They were using a spreadsheet to schedule jobs, making it nearly impossible to test different scheduling scenarios. Preactor allows schedulers to create “what-if” scenarios for new product and marketing campaigns. The Louveira plant needed to sequence orders to minimize changeover times, improve resource utilization, balance inventory levels, and forecast demand. To meet scheduling objectives, a version of Preactor APS was implemented to minimize changeover times while balancing product inventories. The project team contacted Michel Nachbar, P&G’s Louveira plant manager who implemented Preactor at the facility; he commented that Preactor allowed the facility to become more flexible in its scheduling and to quickly adapt to changes in production requirements. Figures 5-3-4 and 5-3-5 are taken from the Preactor website <http://www.preactor.com/casestudies.asp?case=PG>. These tables document the P&G’s conversion process from using a spreadsheet scheduling method to using Preactor APS.

Before Preactor	After Preactor
Market Planners sends demand via Excel once per week	Market Planner sends demand via SAP once per week
Scheduler reviews the demand variation and adjusts the plan	Scheduler runs DRP & MPS in SAP and generates the production orders automatically
Scheduler generates the plan in Excel, trying to minimize setups and inventory	Scheduler downloads SAP data to Preactor APS and runs scheduling scenarios
Scheduler runs MRP in SAP and it generates the material purchase orders	Scheduler uploads Preactor data to SAP
Scheduler runs a macro in Excel to generate production orders and then upload to SAP.	Scheduler runs MRP in SAP and generates the material purchase orders

Fig. 5-3-4. “Before and After” Preactor implementation activities at the P&G Louveira plant.

Spreadsheet Solution	APS Solution
Supported by Excel only	Supported by Preactor APS and SAP
Sequence quality depends on scheduler expertise only	Sequences are generated using simple parameters previously defined by experts
SAP not fully used	SAP fully utilized
Took 2-3 days to review and agree the plan	5 minutes to review the plan and 30 minutes to generate a new optimized plan
Time Fence of 90 days used to work with MRP (purchase of material) in SAP	Time Fence of only 7 days with full integration with SAP

Fig. 5-3-5. Comparison between spreadsheet scheduling solution and Preactor APS solution.

For UniPrint, FCS could eliminate the facility's overproduction issues. Since the company operates as a job shop, it is important for UniPrint to have a flexible planning tool to schedule the orders since daily production schedules vary. Raw material is currently ordered as soon as the job order is input into the system (up to five months in advance). JIT ordering of raw material should be implemented to prevent material from accruing as inventory. Analyses will be conducted to estimate the average time to receive raw material after placing orders; this time will be used to decide when raw material should be ordered (with a temporary buffer of 1 day incorporated before the ordering process is finalized). Therefore, raw material inventory will be significantly reduced or even eliminated from the system. Since each workstation has its own production schedule, no synchronization is in place between processes. Up to 25 jobs are idle on the shop floor at once; this is because operators may start a job on their machine to keep busy even though the job does not yet need to be processed. This leads to the build-up of excessive WIP on the shop floor. Furthermore, the lack of one overall prioritized work plan causes low-priority jobs to occupy a work center when a job with an earlier due date should have been scheduled first.

5.4 Transfer Batches

Reducing the batch size that is transferred between work centers can reduce the amount of WIP in the production system. Currently, UniPrint only transfers work to the next process once the entire job has completed the preceding process. If twenty hours is required to print a job, then the piece of paper that was printed at time zero waits twenty hours to move the Cutting station. Part of this waiting period is used to allow the ink time to dry before moving to the next operation. For larger jobs, the project team recommends that items be transferred in smaller batches to the next workstation after there has been a sufficient drying period. This will allow UniPrint to reduce the amount of WIP before each work center and to increase throughput in the system.

5.5 Communication

5.5.1 Visual Management

Visual management tools within a facility display the jobs that are currently being processed as well as the location of each job within the production system. This provides a visual representation of the current production schedule for the operators and supervisors as well as the queue of WIP that is in the system. One visual management tool is a magnetic whiteboard that can display each department (please refer to figure 5-5-1 for the numbering scheme to be used in labeling the departments); all jobs on the schedule are symbolized with magnets and are placed underneath the department in which they are currently being processed or are being stored as WIP. The whiteboard should be placed in a centralized location so that it is easily visible to schedulers, floor supervisors, and operators. For UniPrint, a central location would be in the Press Room because the press is the "drum" of the system and therefore determines the schedule for all subsequent operations. On the board, a magnet should be placed under the work center at which the job currently resides, with the current operation being performed written on the magnet. Figure 5-5-2 shows an example of a magnet that could be used on the whiteboard. The Master Scheduler will be responsible for placing new job order Gantt charts on the whiteboard in the correct order sequence (EDD, FCFS, etc.). Floor supervisors will then update the whiteboard as jobs flow through the shop. An advantage to placing all jobs in order at each work center using the EDD priority rule is that operators can follow a prioritized schedule for processing jobs on the respective machines.

Measures of Performance (MOPs) can also be displayed on the whiteboard to show employees the production system's current operating efficiency. Key MOPs such as flow time, maximum tardiness, average work-in-process inventory, and profit levels can be displayed using charts that can be posted on whiteboards. Figure 5-5-3 shows an example of an MOP whiteboard; the board can be located in the employee work room to display the current performance levels, to communicate quality issues, and to encourage employee involvement

Process #	Process Name
1	Production Planning
2	Prepress
3	Proofing Approval Process
4	Plating
5	Digital Press
6	Duplicating
7	Envelope Press
8	6 Color Press
9	5 Color Press
10	2 Color Press
11	Cutting
12	Folding
13	Saddle Binding
14	Addressing
15	Shipping
16	Outside Sources

Fig. 5-5-1. The numbering scheme to be used to identify operations for the visual management board.

Job	Prepress	Press	Cutting	Folding	Binding	Shipping	Other
1234						1,2,3,5,15	
2356				1,2,3,4,8,11,15			
4578				1,2,3,4,10,12,13,15			
4457			1,2,3,4,9,11,12,15				
3456		1,2,3,4,7,15					
9788		1,2,3,4,8,9,11,15					
2334	1,2,3,5,15						

Fig. 5-5-2. Sample drawing of magnets to be used on the whiteboard to promote visual management throughout the facility.

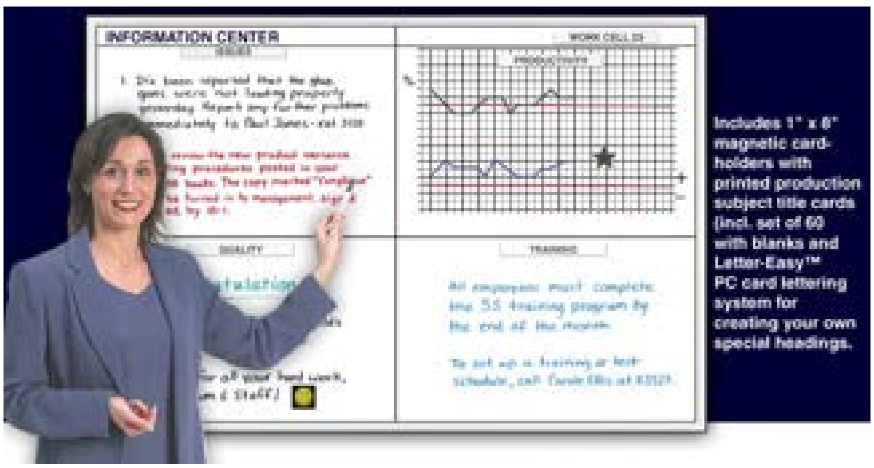


Fig. 5-5-3. Sample image of MOP whiteboard for a facility.

5.5.2 Avanti Print Management Software

Avanti is a scheduling software used by large and small printing facilities. The program was created to help facilities manage scheduling, costing, inventory, job fulfillment, and purchasing. This software interfaces with PCs and can be personalized to fulfill the needs of the print shop. Avanti software features will be discussed in this subsection. This subsection will also describe how UniPrint has adopted the program along with recommendations from the project team to enhance the program.

Avanti is meant to be used in all processes within the printing facility. In the Order Entry Module, computer generated job jackets are created. This job jacket will follow the job from start to finish, and it ensures that all necessary information is always attached to the particular job. If problems should arise, messages can be attached to the specific job jacket, so all necessary parties are aware of the situation. Shop floor messaging is also a method used in Avanti for communication between departments. Messages can be sent to different jobs, departments, or employees. These messages are sent in real time, and the interface is similar to an Outlook program. Avanti is also capable of gathering specific information about the performance of departments, machines, and employees. This information can be used to see when machines or employees are not performing to the expected standards.

UniPrint currently does not utilize the full messaging capacities provided by Avanti. Every employee at UniPrint has the capabilities of using the program in their respective department. Each department is equipped with two to three PCs used to track the progress of jobs. This is where employees see messages attached to jobs or sent to a specific department or employee. However, the user must log on to the program with every status check. This causes messages to sit and wait until a status check is made. In the following section, 5.5.3, the project team will discuss the recommendation for using cordless phones with Avanti's messaging system.

5.5.3 Cordless Phones

Currently, each supervisor carries a cordless phone used for communicating with each other. These phones, however, are not used to their full potential. Supervisors still "run all over the facility" to communicate problems and concerns with one another. The challenge will be to get the supervisors to use the phones to communicate. A candidate solution would be to create a "quick-call" guide for the operators and provide brief training. The call guide would have the various extensions listed for each area and the reasons for calling, and this would be placed near the charging station for each phone. For example, if an operator just completed an order in the press room that was waiting to move to the bindery, the press room operator could call the bindery supervisor and let him know the status on the order. The same idea applies if the press schedule changed and the bindery needed to change the equipment set-up. The cordless phones could also be used alongside Avanti's messaging system. For example, if the press room operator needed to send a message to the bindery, he could send the message using Avanit and then send page to the bindery indicating to check for new messages. This will reduce the chance that messages go unnoticed and action is immediately taken.

5.6 New Layout

The root causes from the cause and effect diagrams along with PFAST analysis support the project team's recommendation to relocate the Shipping department and separate it from the Receiving operations. Figure 5-6-1 shows the proposed location of the Shipping dock. Receiving would remain in its current location. Raw materials would be stored on the vertical racks already available for storage. The new Shipping location will be an existing loading dock next to the Cutting workstation. Currently, the room next to the loading dock is used for storing outdated finished goods. The project team's PFAST analyses showed that $950,962 of revenue moves from Cutting directly to Shipping. With the new layout, the distance between Cutting and Shipping would be reduced to 55 feet. Additionally, $626,150 of the total revenue needs requires processes performed by outside sources. These jobs would be able to move directly from the Press Room to the new Shipping dock, a distance of 60 feet. Moving the Shipping dock also reduces the travel distances for all jobs by 50 percent. Currently, the total distance moved between the Envelope Press, Duplicator, Cutter, Folder, and Saddle Binder and then to Shipping is 1,176,344 feet. The relocation of the Shipping dock reduces this total travel distance to 525,895 feet, a reduction of 44.7%. This travel distance reduction for employees transporting jobs through the facility would save $1,326 in labor per year. However, one issue that may affect this implementation is that the customer parking lot is directly adjacent to this Shipping dock. The lot would need to be moved closer to the facility's entrance to provide ample room for trucks to access the Shipping dock. This process would need to be approved by the University before moving forward. Figure 5-6-1 shows the flows of products to the new Shipping dock (circled in red), with thicker arrows representing higher volume flows.

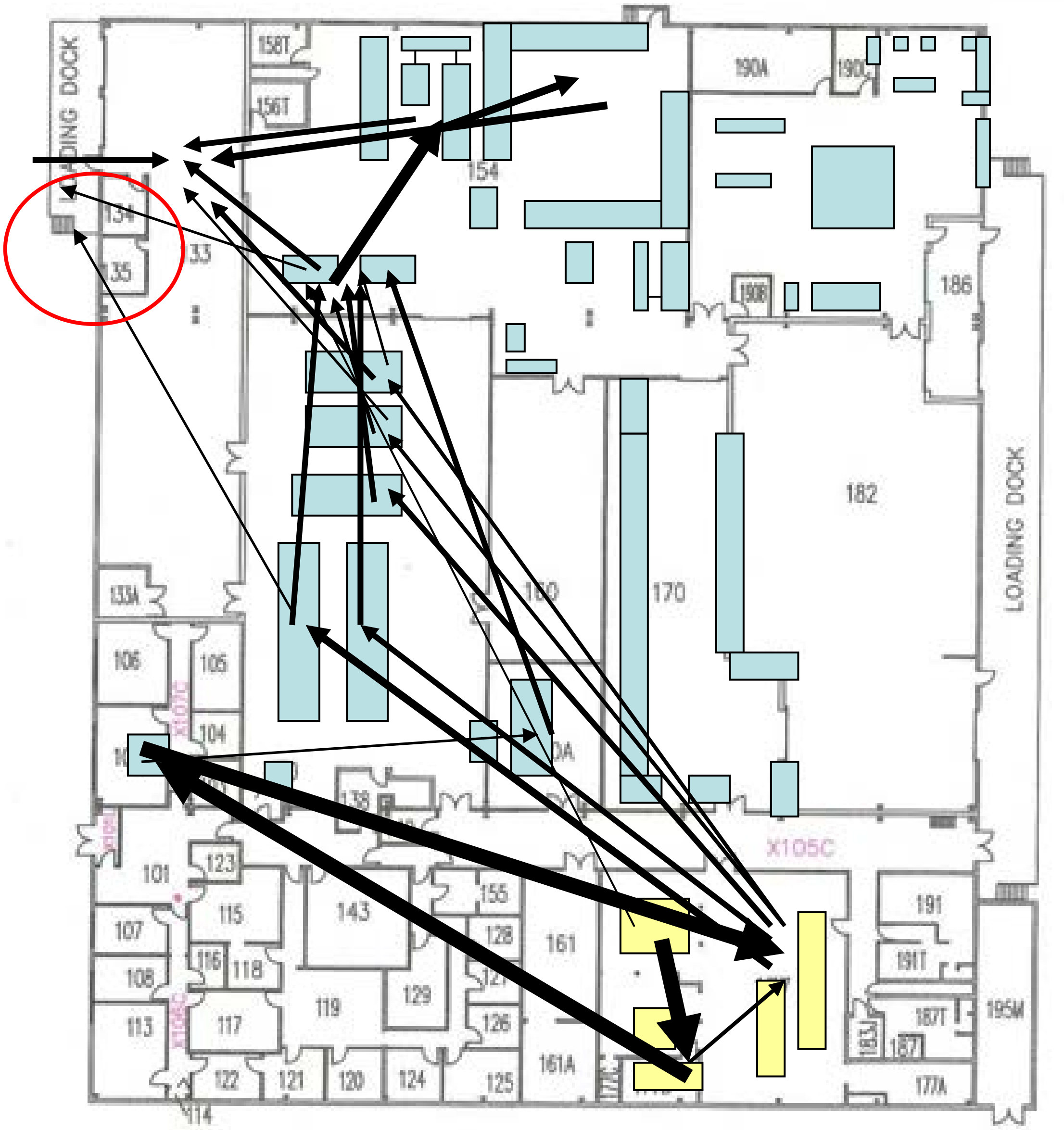


Figure 5-6-1. New layout displaying the proposed relocation of the Shipping dock to the area circled in red.

5.7 Cost Avoidance for Operator Motion

In the Shipping and Receiving area, vertical storage racks are occupied by scrap and outdated finished goods; additionally, raw material clutters the warehouse floor and causes non-value added operator motion of maneuvering material handling equipment to access pallets of paper. The calculations shown below quantify the monetary value of this non-value added activity:

- (5 min/job)*(1 hr/60 min)*(avg. 5 jobs/day)*(250 days/yr) = 104.17 hrs/yr

- Operator hourly rate = $20/hr

- Money spent on wasted operator motion = ($20/hr)*(104.17 hrs/yr) = **$2,083.33/yr**

Because excessive WIP occupies the shop floor around the Bindery machines, the operator must take a longer route when transporting jobs from the Folder to the Saddle Stitch machine. Currently, the travel distance is 66 feet; removing WIP from the shop floor would allow the operator to transport the jobs in a linear flow, thus reducing the travel distance by 40 feet. The calculations for the costs associated with this activity are provided below:

- Walking speed = 3 mph = 264 ft/min

- Time spent on wasted operator motion = (40 feet/job)*(1 min/264 ft) = 0.15 min/job

- Operator hourly rate = $20/hr

- Money spent on wasted operator motion = ($20/hr)*(0.15 min/job)*(1 hr/60min)*(avg. 8 jobs/day)*(250 days/yr) = **$100/yr*(3 operators) = $300/yr**

6.0 Evaluation of Solutions and Recommendations

6.1 Summary of Candidate Solutions

To summarize the candidate solutions for improving the UniPrint operations the project team suggests:

Short Term Recommendations

- Implementing 5S to standardize the facility
- TOC to pull orders through the facility
- Kanban pull system in the Bindery to organize work flow
- Avanti Messaging System utilizing Cordless Phones to promote communication between work centers

Long Term Recommendations

- Re-layout of bindery to improve travel distances, Line of Sight, and product flow.
    - Two Cutter-Folder cells with one located near the new Shipping dock
    - Locate one Cutter-Folder cell near Shipping, and keep the other Cutter-Folder cell in its current location to be designated for jobs requiring Saddle Stitch processes

A summary of the potential savings that can be realized from implementing the team's candidate solutions is provided in appendix C figure C-10.

6.2 Next Steps

Due to time constraints, the team will not be able to implement the recommendations within UniPrint's facility. After meeting with Plant Manager, Jeff Dible, the team is confident that UniPrint understands the opportunities to improve its current facility layout and production processes and is now knowledgeable of the Lean concepts and communication methods that it must implement in order to achieve efficient future-state operations.

7.0 Acknowledgements

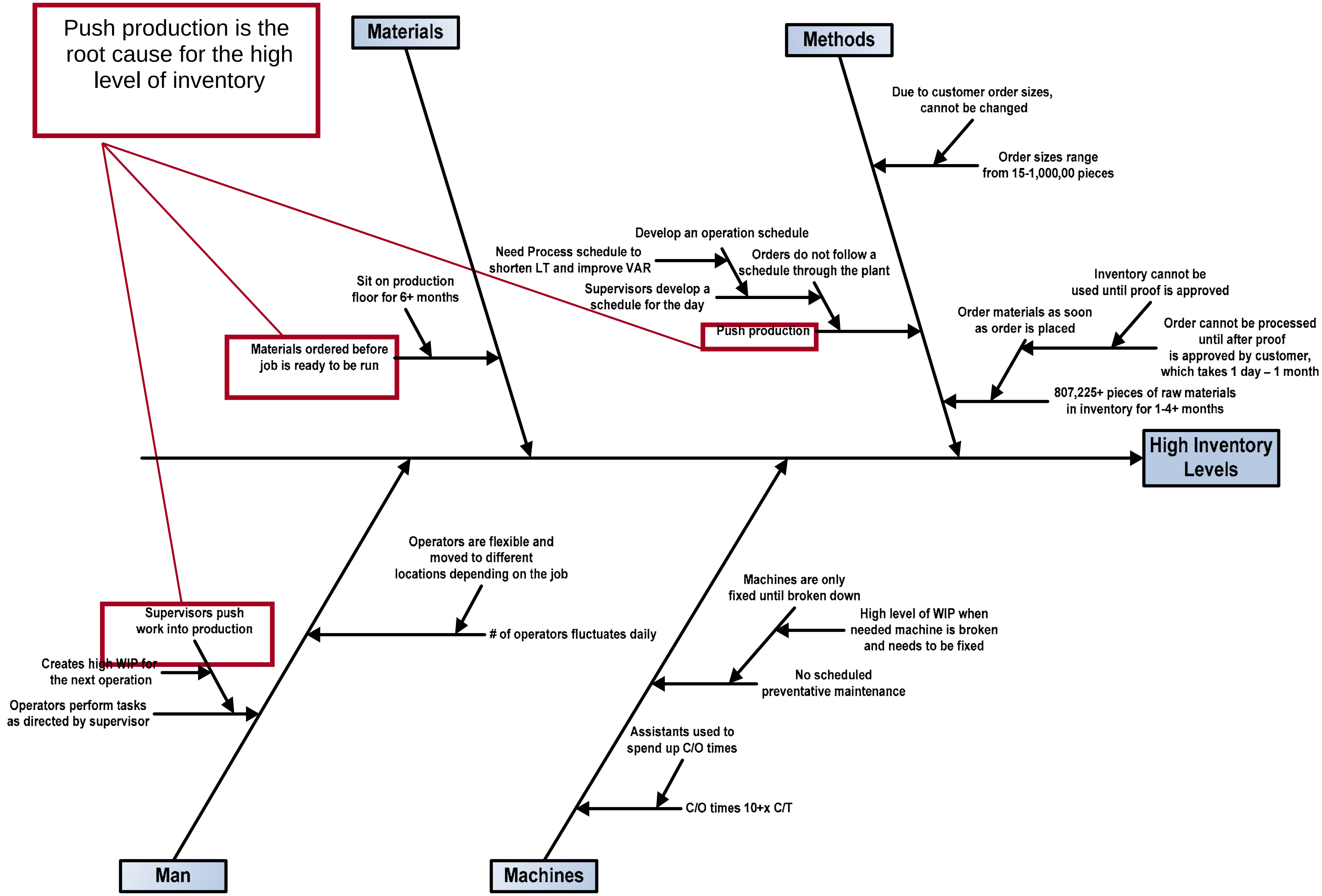
The project team would like to extend its gratitude to those individuals that have greatly contributed to the success of this project. The team would first like to acknowledge UniPrint for its cooperation and continued support throughout the duration of this project. The facility's management and staff were extremely informative during the team's data collection process and were flexible during operating hours. The team would like to especially thank Jeff Dible, UniPrint's plant manager for his outstanding participating as a project sponsor and his willingness to locate essential documents that were invaluable to the team's success. The team would also like to recognize Dr. Clark Mount-Campbell for allowing the continued study of Lean manufacturing concepts with UniPrint. Finally, the team would like to thank Dr. Shahrukh Irani for providing knowledge about the numerous concepts involving Lean manufacturing and for his guidance throughout the course of this project.

APPENDIX

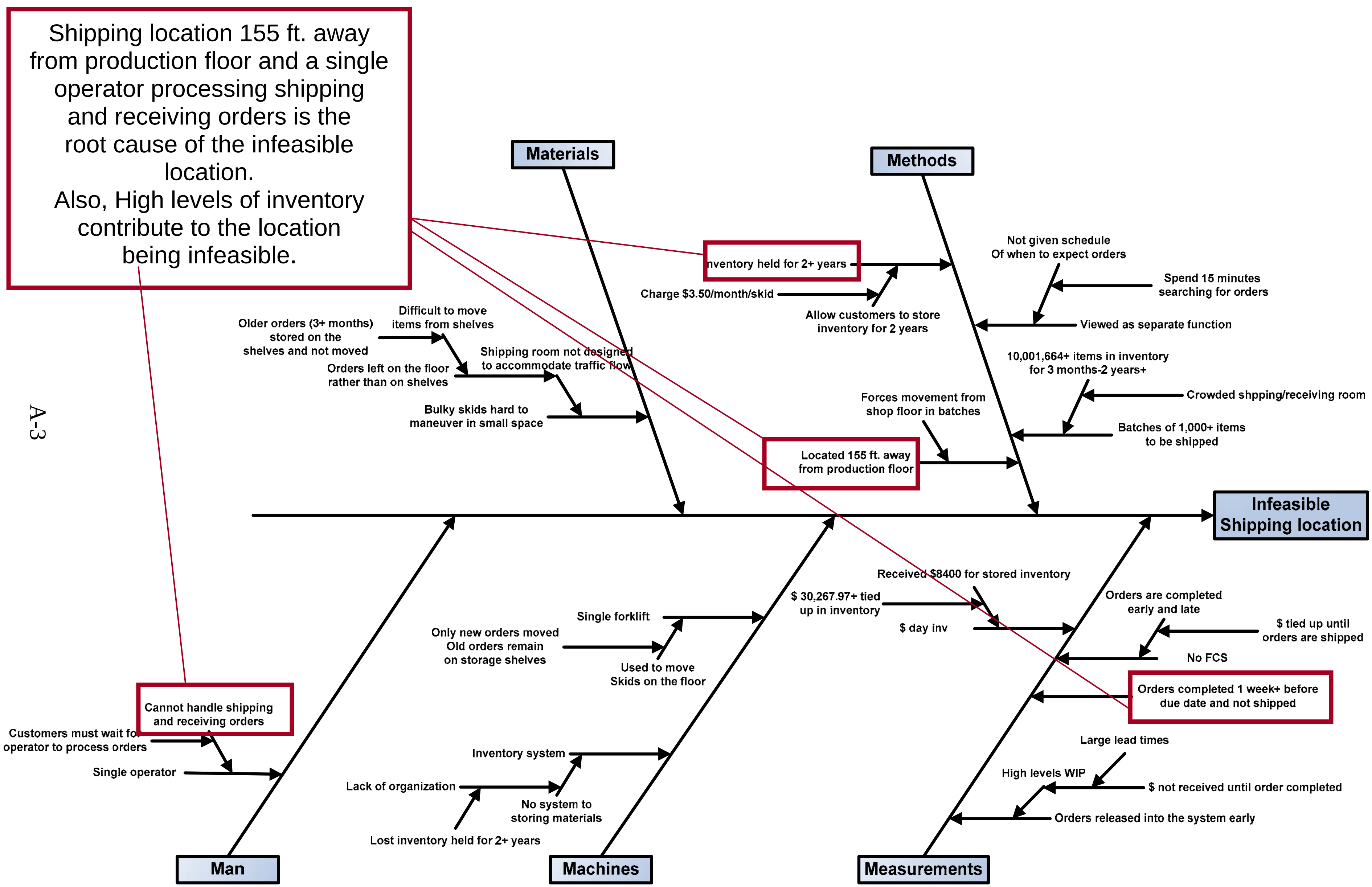
APPENDIX A: PRELIMINARY ASSESSMENT: PROBLEM IDENTIFICATION

A-1: CAUSE AND EFFECT (FISHBONE) DIAGRAMS I AND II

This section includes the Fishbone Diagrams created by the project team to determine the root causes of excessive inventory levels and overall issues with the facility's operations. To begin constructing the fishbone diagram, the project team listed the problem to be studied in the "head" of the fish. After deciding on the problem to study, the team then used an idea-generating technique (e.g., brainstorming) to identify the factors that may be causing the high inventory levels. This is done by adding branches or "bones" to the fish. Each bone is labeled with one of the five "M" categories: Materials, Machines, Man, Methods, and Measurements. The team then began asking questions such as "What machine issues are affecting/causing..." under each category to identify sub-factors that contribute to high inventory levels. The next steps were to continue asking, "Why is this happening?" and put additional segments under each factor and subsequently under each sub-factor until the team no longer generated new ideas. The team members then analyzed the results of the fishbone after an adequate amount of detail had been provided. This is done by looking for those items that appear in more than one category. These become the "most likely causes" of the overall issue, which was high inventory levels for this particular diagram. The two primary issues were found to be "High Inventory Levels" and "Infeasible Shipping Location," each of which are displayed as the "head" of the two diagrams. The "most likely causes" are outlined in red.



Cause and Effect Diagram I



Cause and Effect Diagram II

A-2: LAYOUT-RELATED PROBLEMS: CHECKLIST FOR ASSESSMENT OF A FACILITY LAYOUT

This Checklist for Assessment was created by the project team to evaluate several possible causes of an inefficient facility layout. It was used as a supplement to the Fishbone Diagrams in the identification of the primary issues with UniPrint's facility operations. Each cause is listed under the Description column and is assigned a level of concern ranging from Minor to Major. The team has included its comments for each possible cause in the checklist below:

Description	**Level of Concern**	**Comments**
Difficulty in relocating equipment and re-design the facility layout	Minor-Major	Machines can not be moved; some jobs require 40+ hours of machine usage; some machines require up to 4 operators; machines cause waste due to 6+ feet separation between printing presses; no line of sight between consecutive operations.
Expansion and Reconfigurability of Existing Facility	Minor	Machines located out of line of sight and hard to move; humidity a factor in certain locations; no land/space located around building for expansion
Measures of Flexibility for Existing Facility	Minor	The facility is only 45,000 sq ft, has only 40 employees, difficulty in moving machinery, and excess inventory does not allow for flexibility in the facility.
Levels of RM, WIP and Fin. Goods Inventory	Major	Push system causes 2-25 orders of WIP to sit before an operation and finished goods to sit around for up to 3 days; inventory has about 5% of the facility to fit in, which is not nearly enough.
Utilization of Shop floor and (Vertical) Storage Space	Major	WIP and inactive materials are randomly placed throughout facility with only two rows of vertical storage located primarily in shipping and receiving.
Current Equipment and Facility Layouts	Minor-Major	Machines are sometimes located in the wrong direction or in tight areas throughout facility that disrupt routing and require excessive travel distances of 6-50 ft and times of 30 secs to 5 mins.
Flow of Materials, Equipment, Personnel, etc.	Minor-Major	Inventory takes up 25% of floor space and is located in various areas of the facility. Forklifts do not have any store location, so the operators leave it where ever there is space on the floor.

Travel Distances between Machines and Support Areas	Major	There is a high utilization of forklifts to transport finished and in process products. Employees are required to move inventory using carts 6-50 ft.
Design of Material Handling Aisles	Major	Aisles do not exist due to excessive inventory and lack of organization of the inventory.
Flow of Information from Prod. Control & Scheduling	Major	Push production and lack of communication causes poor production control and excess inventory that is not moved for 3 to 12 hours on the floor and up to a year in inventory.
Miscellaneous Criteria for Assessment	Minor	A computer program is used for the plants job scheduling. This program is only used by printers and is very out-of-date. They are looking into getting a new program to use.

A-3: MATERIAL HANDLING PLANNING CHART

The Material Handling Planning Chart for a Saddle Stitch job was created by the project team to summarize the processes required to transport the job between workstations and includes the following details: material handling time, number of containers required, sizes of containers, quantity of material in each container, material handling frequency, distances traveled between locations, and material handling method.

Company OSU Printing Services
Product 4-Color Saddle Stich - Qty = 23000

Prepared by OSU Document Team
Date 5/15/2006

Step No.	O	T	S	I	Description	Dept	Time	No. Cont.	Size	Wt	Qty per Cont	Freq	Dist	Method of Handling
1			X		Paper stock in Storage Room	Storeroom	2 days		300 ft^2					
2	X				Prepress	Prepress	C/T = 2 min C/O = 15 sec		4 3x4 ft Plates					
3		X			Transport paper from Storage Room to Pressroom		1 min	1	27" x 48" per Cont.		10K to 50K	1 to 3 times daily	213 ft	Pallet Jack
4		X			Transport plates from Prepress to Pressroom		10 min		4 3x4 ft Plates			3 to 5 times daily	160 ft	By hand
5			X		WIP of Paper	Pressroom	Up to a day	4	48" x 36" x 42"/Cont.		18000			
6			X		WIP of Plates	Pressroom	12 hrs to a week	1	72" x 48" x 36"		4 Plates per Job			
7	X				Print Job on 4-Color Printer	Pressroom	C/T = 2 min C/O = 15 sec							
8				X	Inspect Printed Jobs	Pressroom	C/T = 1 min							
9		X			Transport Job to Cutting		Up to 2 min	3	27" x 48" or 30" x 48"		3200	Up to 4 x a Job	67 ft	Pallet Jack or Cart
10			X		WIP Cutting	Press	2 hrs	3	30" x 48" x 36"/Cont.		3200			
11	X				Cutting Process	Bindery	C/T = 2 min C/O = 15 sec							
12				X	Measure Cut Jobs		C/T = 1min							
13		X			Transport Job to Folder		30 sec	2 to 3	27" x 48" or 30" x 48"		4500	Once per Job	28 ft	Pallet Jack or Cart
14			X		WIP Folding	Bindery	1.15 hrs	3	30" x 48" x 36"/Cont.		7000			
15	X				Folding Process	Bindery	C/T = 2 min C/O = 15 sec							
16		X			Transport Job to Saddle Stitch		1 min	3	30" x 48"		5000	Once per Job	66 ft	Cart
17			X		WIP Saddle Stitch	Bindery	0.5 to 2 hrs	6	30" x 48" x 36"/Cont.		5000			
18	X				Saddle Stitch Process	Bindery	C/T = 2 min C/O = 15 sec							
19			X		Inventory of finished goods	Bindery	Until the job is finished	Up to 8	30" x 48" x 36"/Cont.		6000			
20		X			Transport finished goods to Storage Room		5 min	8	45" x 133"		6000	8 times per Job	169 ft	Fork Lift
21			X		Store finished goods in the Storage Room	Storeroom	17 hrs		600 ft^2		23000			
22		X			Ship final product to Customer		C/T = 30 min to 2 hrs							

Material Handling Planning Chart

APPENDIX B: PFAST

The five family groups were analyzed using both Storm and PFAST. The groups were determined by using PR Analysis Type II. These family groups were divided into groups of jobs that are processed by the same Press. Appendix B-1 shows all of the jobs using the 2-Color Press; appendix B-3 shows all jobs using the 5-Color Press; appendix B-5 shows all jobs using the 6-Color Press; appendix B-7 shows all jobs using the Duplicator; and appendix B-9 shows all jobs using the Digital Press. These jobs displayed in these analyses represent forty-seven of the 104 total jobs produced at UniPrint.

The individual jobs were analyzed with PFAST and then Storm. The $-Type From-To information was used to determine the flow pattern of each family group. This flow was then mapped onto the current facility layout. The dollar flow through the facility can be seen in appendices B-2, B-4, B-6, B-8, and B-10. This information was then analyzed using Storm to determine the optimal flow. The ideal facility layouts for each of the family groups are similar, but created separately to include the specific Press used to process each family.

B-1: HOW TO USE PFAST

PFAST is a program that interfaces with Microsoft Excel. The user simply inputs data into an Excel workbook using specific formats. To begin using PFAST, the user must collect information about all of the jobs or products created by the specified company. This information includes the quantity of jobs that are produced during the year, the amount of revenue earned by each job during the year, and the steps or processes required to produce the finished job. Most companies will have this information readily available.

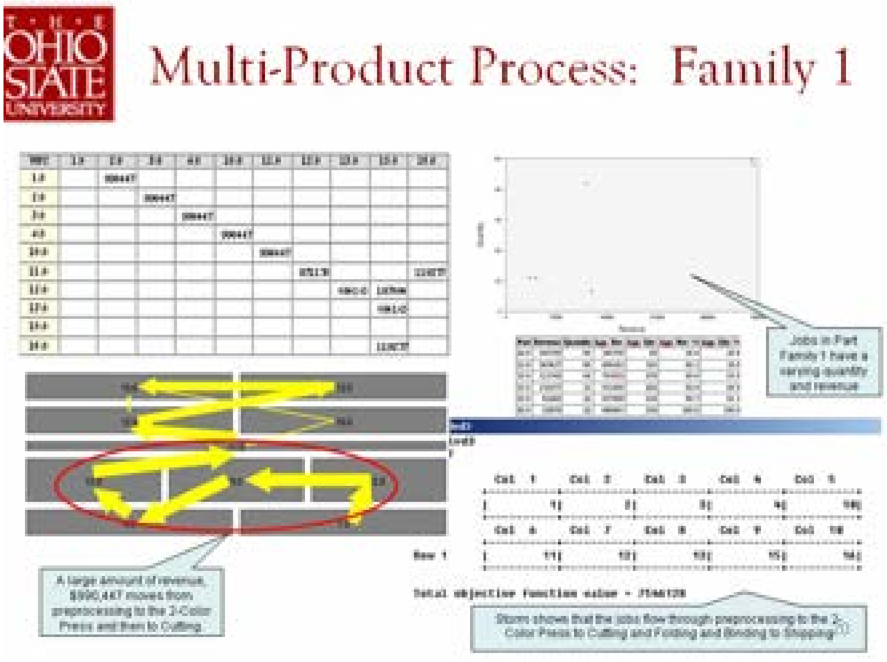
The first sheet of the Excel workbook must be named "Routing." This sheet will show the procedures and steps needed to finish a job. The sheet will contain three headers: "Part No," "Work Center No," and "Sequence No." The Part No column entries must be formatted to Text while the Work Center and Sequence No column entries must be formatted to Number.

The second sheet of the Excel workbook must be named "Part." This sheet provides the quantities and revenues of each of the products created in the facility. This sheet must contain four headers: “Part No,” “Description,” “Annual Quantity,” and “Revenue.” The “Part No,” “Annual Quantity,” and “Revenue” columns must be formatted to Number, and the “Description” must be formatted to Text.

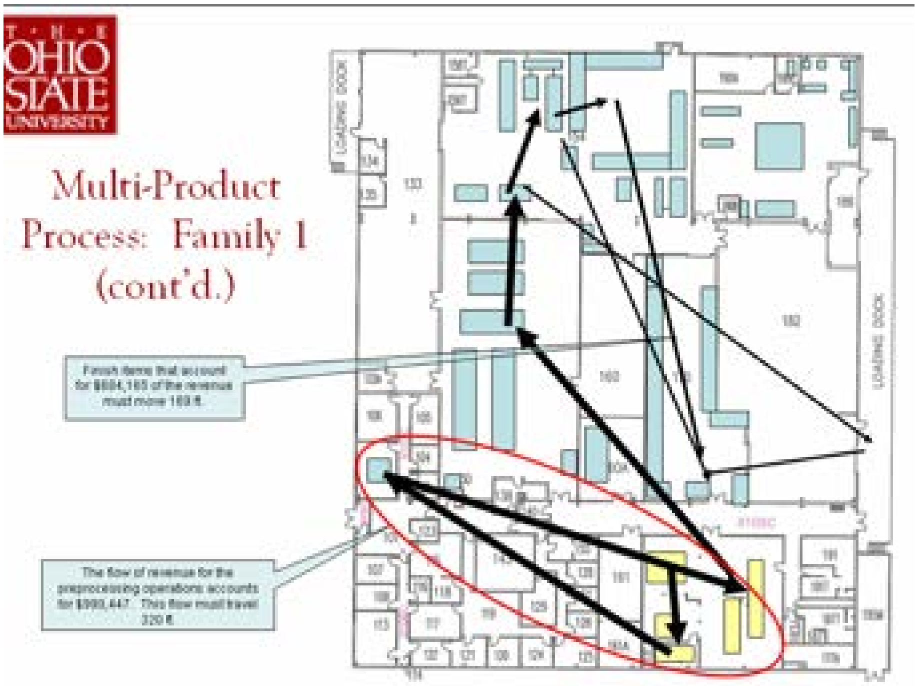
The third sheet of the Excel workbook must be named “Work center.” The “Work center” page has three columns. The columns include “Work center No,” “Description,” and “Area.” The “Work center No” and the “Area” columns must be formatted to Number, and the “Description” column must be formatted to Text. This sheet will show all of the possible work centers in the facility and also give a short description of each work center. Using numbers as the work center names and corresponding descriptions is an easy way to input the individual work centers. The names of the work centers can be changed or described in detail later in the facility design project presentation. The final part of the “Work center” sheet is the area of each of the processes. To begin the project, it is easier to leave the Area column entries as “1.” Once the user is more familiar with PFAST, the size can be adjusted to the actual area of the machine or process.

After all of the information is added and saved in the Excel file, the information can be input into PFAST. The user will simply open the PFAST program and select “Input,” which is located under the “File” option on the toolbar. The document will be read by the program, and the user will be prompted to run the data and save the given files. The files obtained by PFAST can be saved and viewed without opening the PFAST program again. The next sections will explain how to interpret and use the results obtained by PFAST.

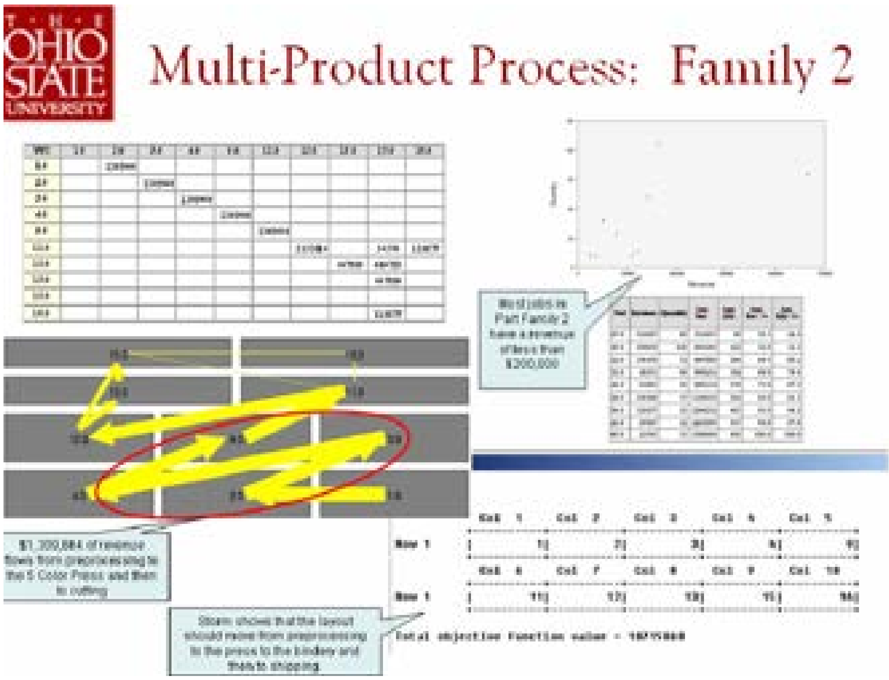
B-2: MULTI-PRODUCT PROCESS ANALYSIS FOR FAMILY 1



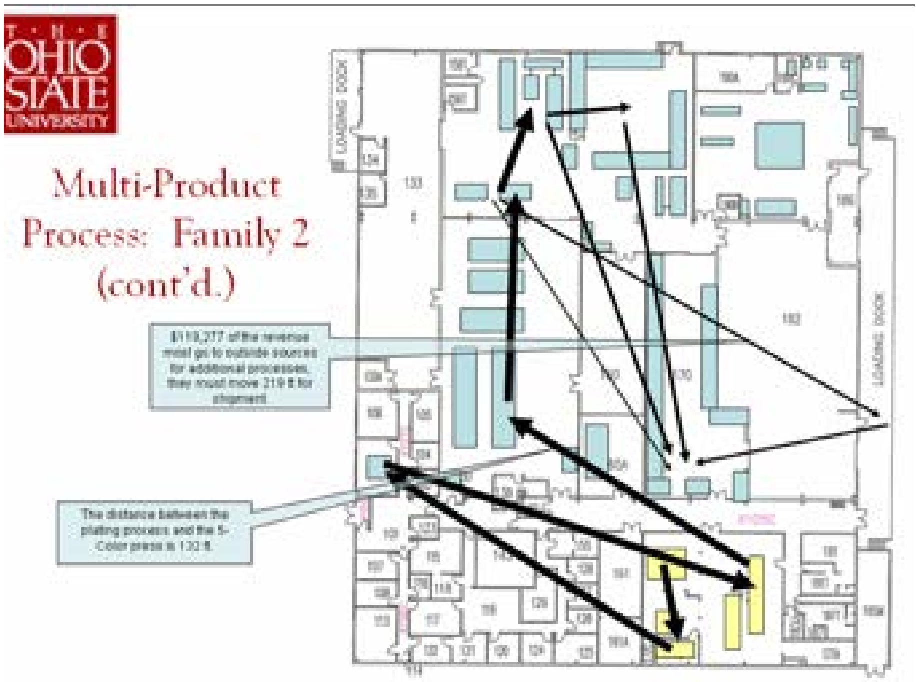
B-3: DOLLAR-TYPE FLOW FOR FAMILY 1



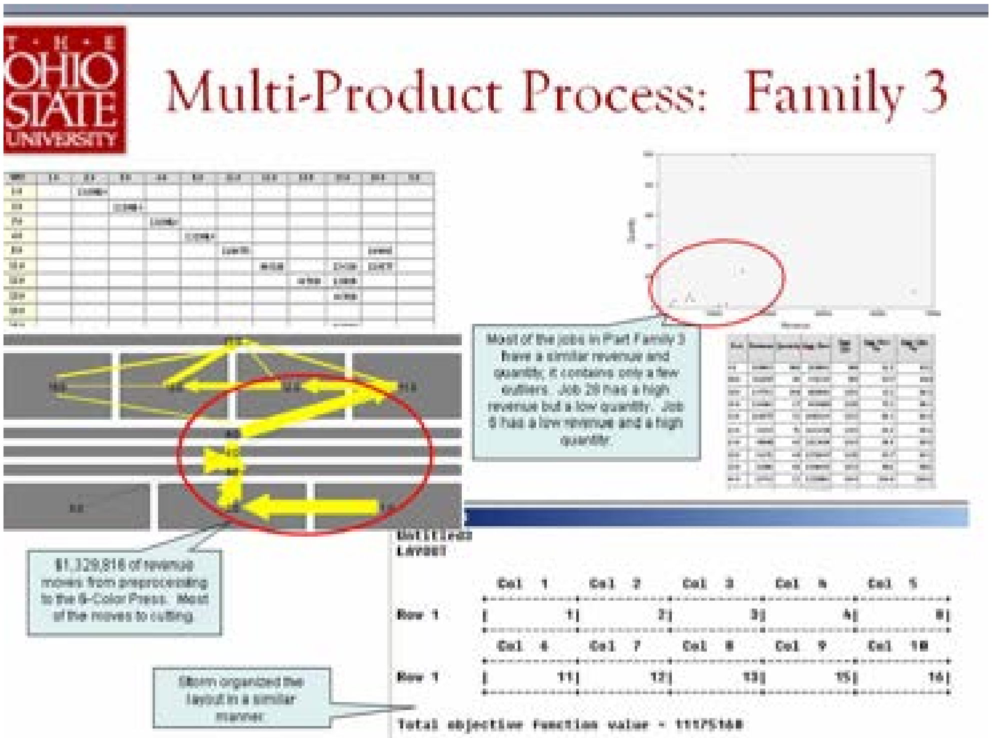
B-4: MULTI-PRODUCT PROCESS ANALYSIS FOR FAMILY 2



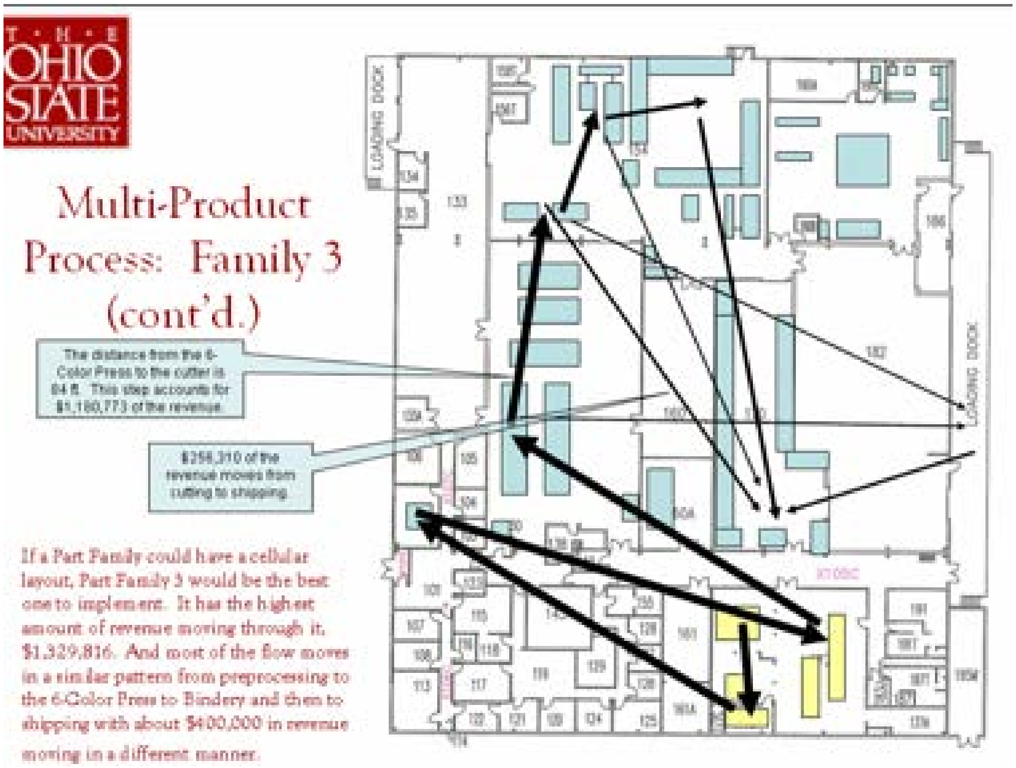
B-5: DOLLAR-TYPE FLOW FOR FAMILY 2



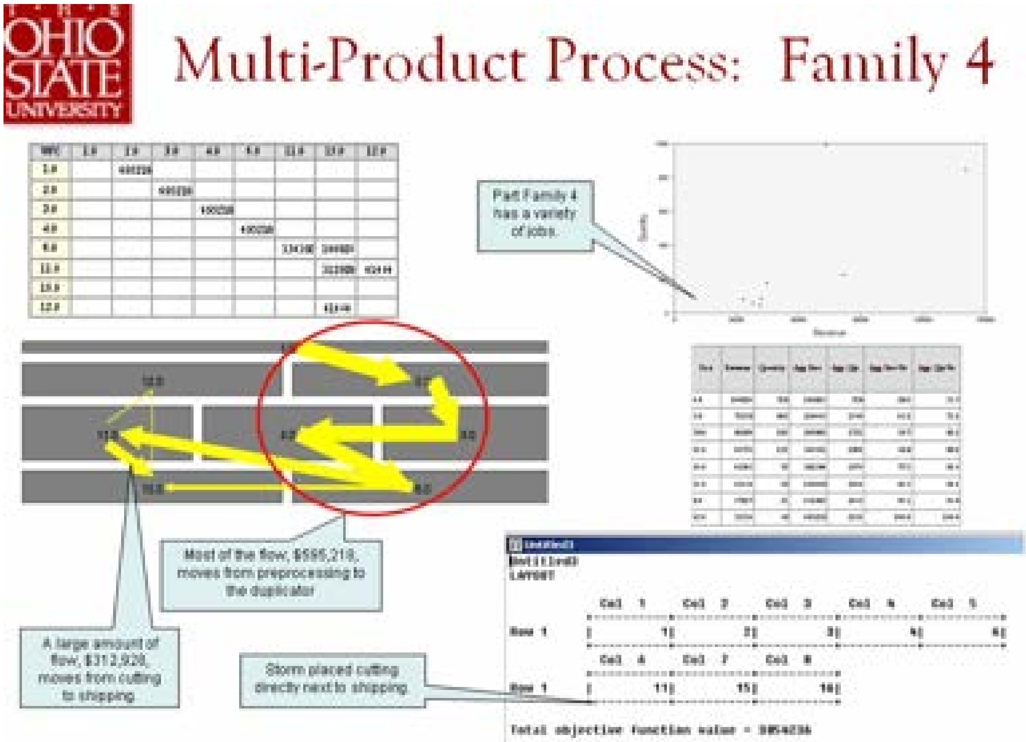
B-6: MULTI-PRODUCT PROCESS ANALYSIS FOR FAMILY 3



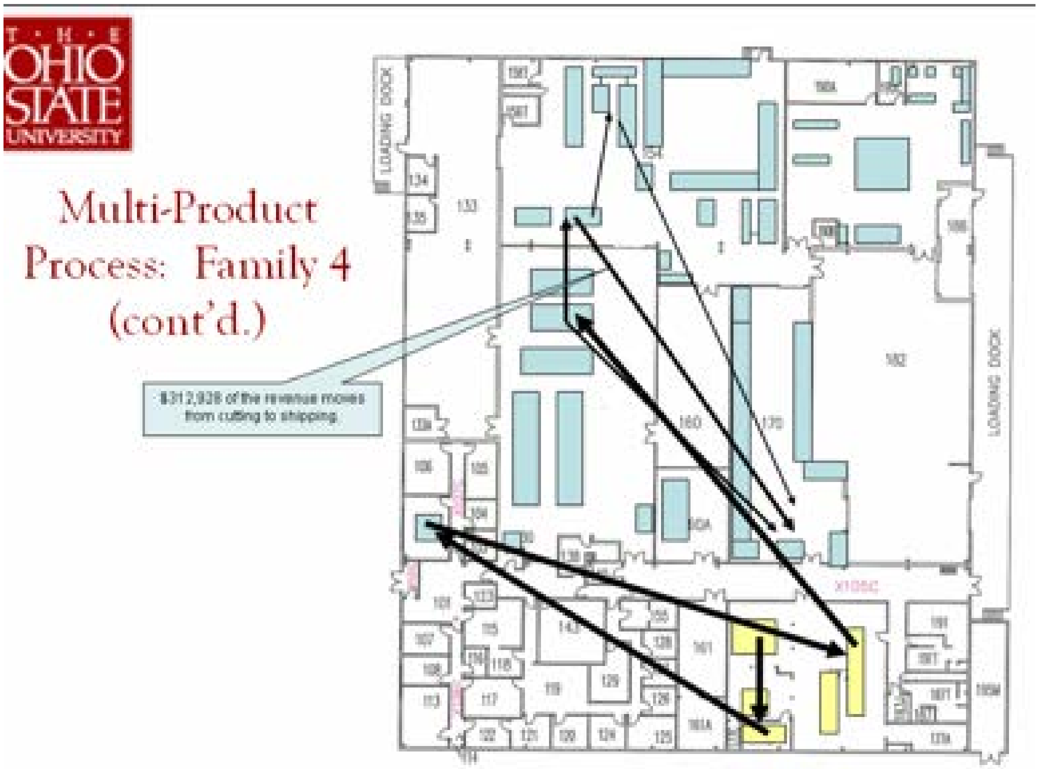
B-7: DOLLAR-TYPE FLOW FOR FAMILY 3



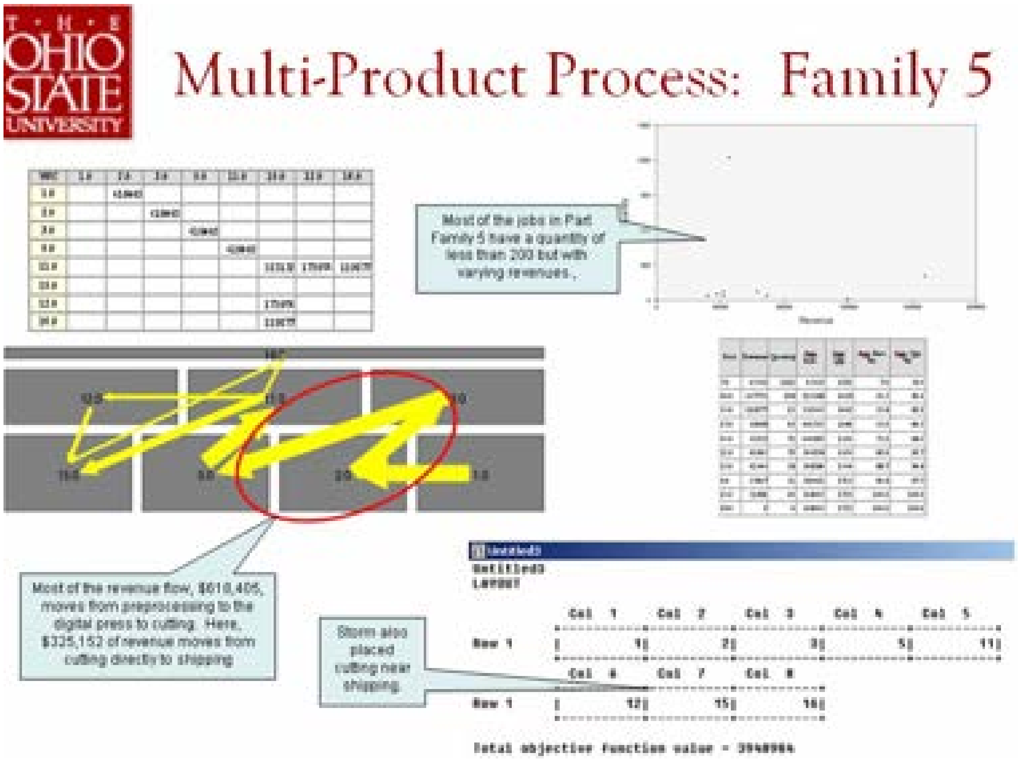
B-8: MULTI-PRODUCT PROCESS ANALYSIS FOR FAMILY 4



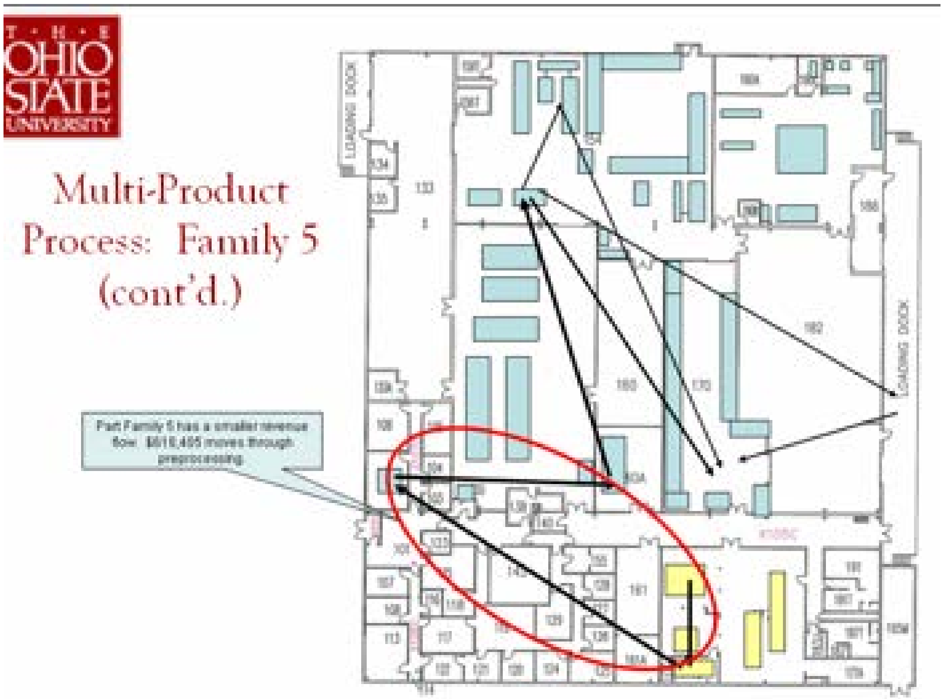
B-9: DOLLAR-TYPE FLOW FOR FAMILY 4



B-10: MULTI-PRODUCT PROCESS ANALYSIS FOR FAMILY 5



B-11: DOLLAR-TYPE FLOW FOR FAMILY 5

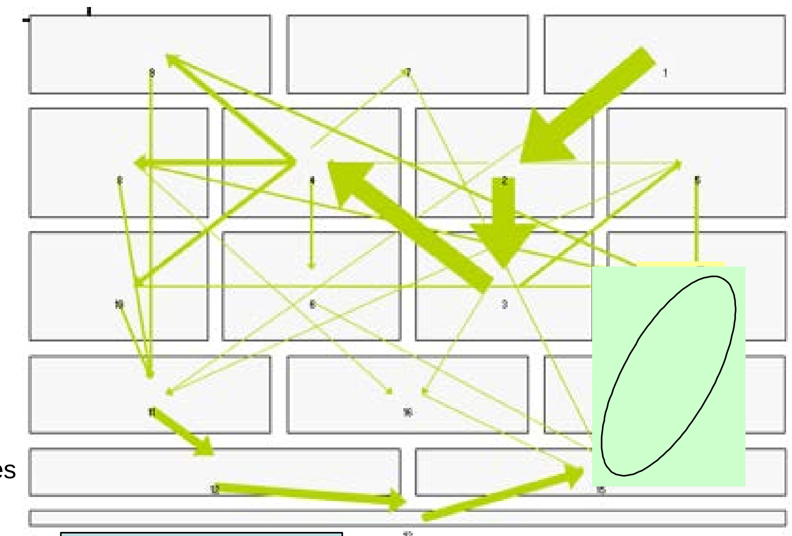


B-12: $-TYPE FROM-TO CHART AND FLOW DIAGRAM FOR CUTTER2 AND FOLDER2

Totals:

- •$3,171,615 (60%)Moves from the presses to Cutting2 (17)
- •$1,937,483 (46%)Moves from Cutting2(17) to Folding2(18)
- •$1,234,123(38% of products going to cutter2) Moves from Cutting2(17) to Shipping
- •$1,937,483 (61% of products going to cutter2) Moves from Folding2(18) To Shipping

- •$2,095,667(40%) Moves from presses to Cutting1(11)
- •$2,238,358 (54%)Moves from Cutting1(11) to Folding1(12)
  - •These indicate $ flows for jobs routed to second cell, which produces jobs requiring Saddle Stitch processes



Total $ Flow = $5,800,000

	1	2	3	4	8	9	5	17				12	11	10	6	7	16
1		5814147											142691				
2			5828352	160859			24732										
3				4927984			876316										9847
4					1464142	1447440								1178733	644342	354186	
8													683772				149043
9													683151				
5													22289				
17																	
18																	
15																	
13										2237737							
12											2237737						
11												2238358					
10													706455				
6										219380							
7										354186							
16										158890							

6-Color Press

5-Color Press

Digital Press

2-Color Press

Duplicator

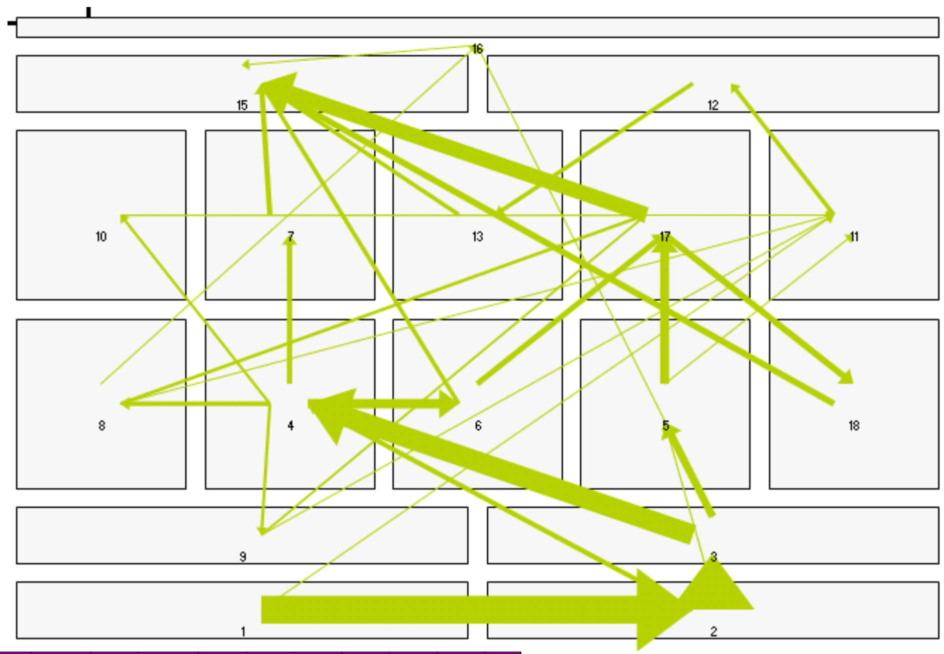
Notice that half of the 5 and 6 Color press items will go through the cutters now.

Notice that all of the Duplicator items go through cutter2 now.

B-13: Q TYPE FROM-TO CHART AND FLOW DIAGRAM FOR CUTTER2 AND FOLDER2

Totals:

- 3,212 (76%)Jobs move from presses to Cutter2
- 960 (29% of jobs going to cutter2)Jobs move from Cutter2 to Folder2
- 2,252 (71% of jobs going to cutter2)(53% of total jobs) Jobs move from Cutter2 to Shipping



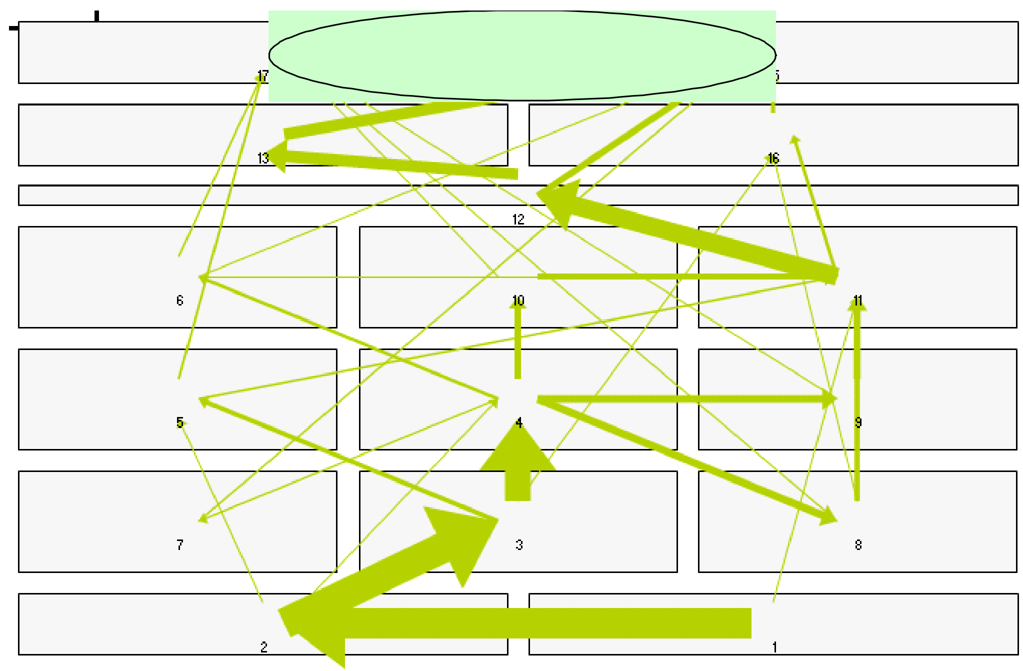
	1	2	3	4	6	7	15	17	18	5	8	9	10	11	12	13	16
1		4179												140			
2			4195	724						235							
3				3056						1122							1
4					1455	782					660	456	427				
6							623										
7							782										
15																	
17																	
18																	
5														9			
8														127			56
9														127			
10														201			
11															604		
12																603	
13							603										
16							57										

B-14: $ TYPE FROM-TO CHART AND FLOW DIAGRAM FOR CUTTER2

Totals:

- •$1,234,132 (23%) Moves from presses to Cutter2(17)
- •$1,234,132 Moves from Cutter2(17) to Shipping

- •$4,033,150 (77%)Moves from presses to Cutter1(11)
  - •This indicates $ flows for jobs routed to second cell, which produces jobs requiring Saddle Stitch processes



	1	2	3	4	8	9	5	17	6	10	11	12	13	15	16	7
1		5814147									142691					
2			5828352	160859[illegible]			24732									
3				492798[illegible]			876316								9847	
4					1464142	1447440			644342	1178733						354186
8											1031689				149043	
9											1365954					
5											430500					
17																
6											51189			219380		
10											1153818					
11												3534533			641308	
12													2237737	1296175		
13														2237737		
15																
16														800198		
7														354186		

6-Color Press

5-Color Press

Digital Press

Duplicator

2-Color Press

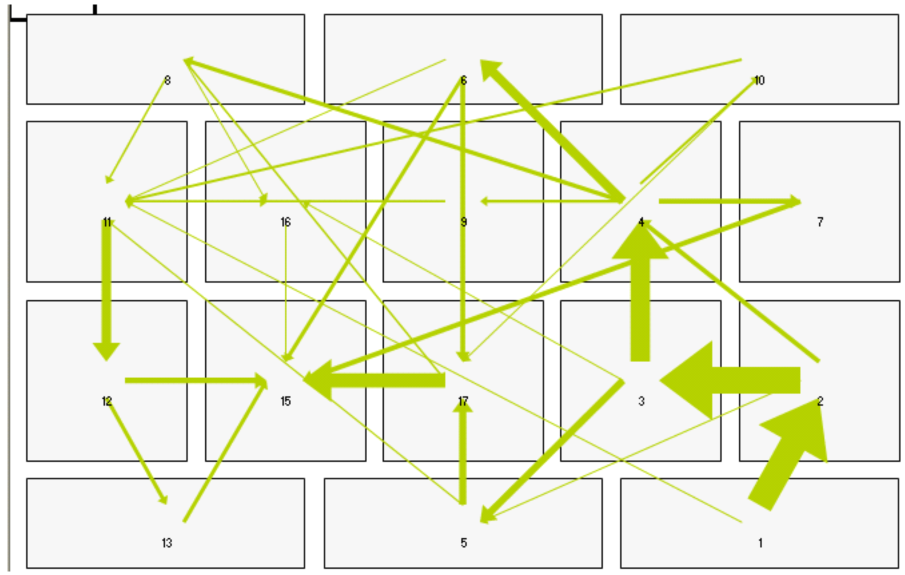
B-15: Q TYPE FROM-TO CHART AND FLOW DIAGRAM FOR CUTTER2

Totals:

•2,252 (59%)Jobs move from presses to Cutter2
•2,252 Jobs move from Cutter2 to Shipping

•1,564 (41%)Jobs move from presses to Cutter1

•NOTE: If we knew the distances to the proposed machines, then we can calculate the travel distance saved…



	1	2	3	4	6	7	15	17	5	8	10	11	12	13	9	16
1		4179										140				
2			4195	724					235							
3				3056					1122							1
4					1455	782				660	427				456	
6							623					56				
7							782									
15																
17																
5												245				
8												302				56
10												419				
11													1492			72
12							888							603		
13							603									
9												402				
16							129									

APPENDIX C: FURTHER ASSESSMENT AND DATA ANALYSIS

C-1: BILL OF MATERIALS FOR SADDLE STITCH JOB

TABLE C-1
Bill of Materials for Saddle Stitch Job

Bill of Materials					
Level	Part Name	Quantity	Units	Cost per unit	Make or Buy
1	WOSU Station Job no. 214743	20000	Books		
2	Cardboard Packing Boxes				Buy
2	Plastic Wrap				Buy
3	Saddle Stitching				Buy
4	Paper 26x40	2000	sheets	$6.79	Buy
4	Paper 26x36	23000	sheets	$0.000043	Buy
4	PMS Ink	44	pounds	$4.56	Buy
4	Black Ink	3	pounds	$2.40	Buy
5	40" Plates	10	plates	$17.21	Buy
6	Prepress	12	pages	$3.00	Buy

C-2: ASSEMBLY DIAGRAM

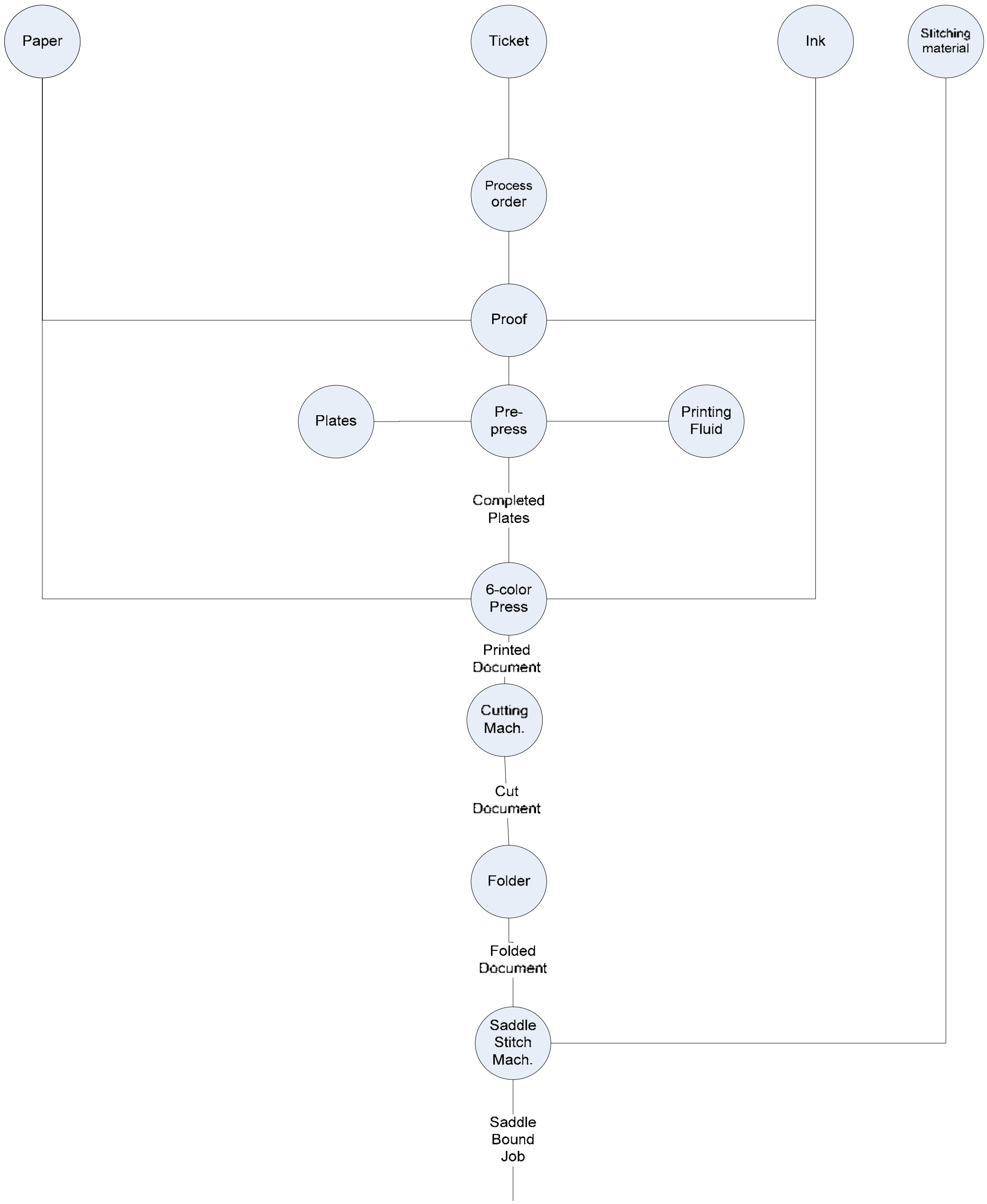


Fig. C-2. Assembly diagram for a saddle stitch job at UniPrint.

C-3: OPERATION PROCESS CHART

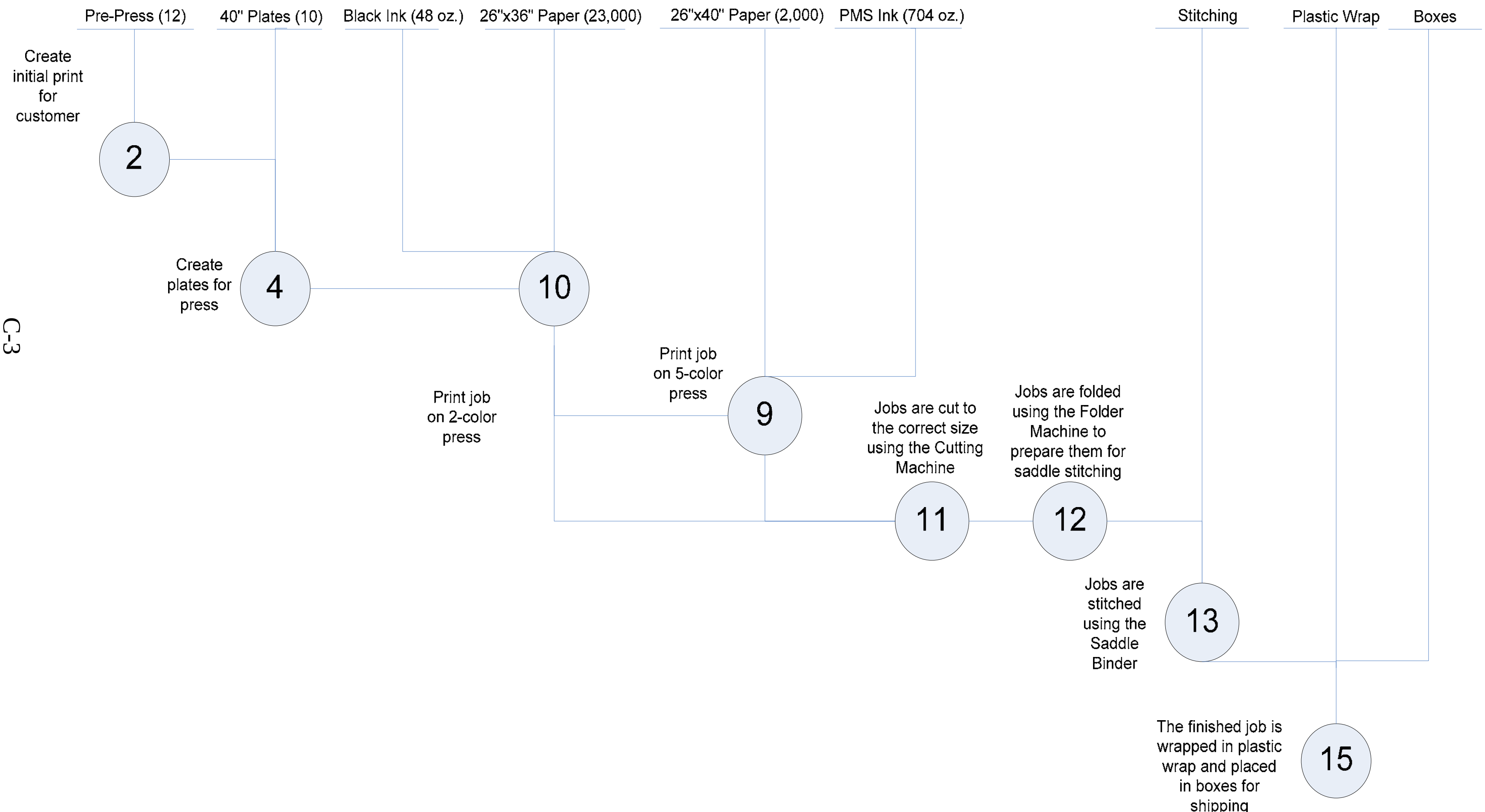


Fig. C-3. Operation process chart for a saddle stitch job at UniPrint.

C-4: CURRENT-STATE VALUE STREAM MAP

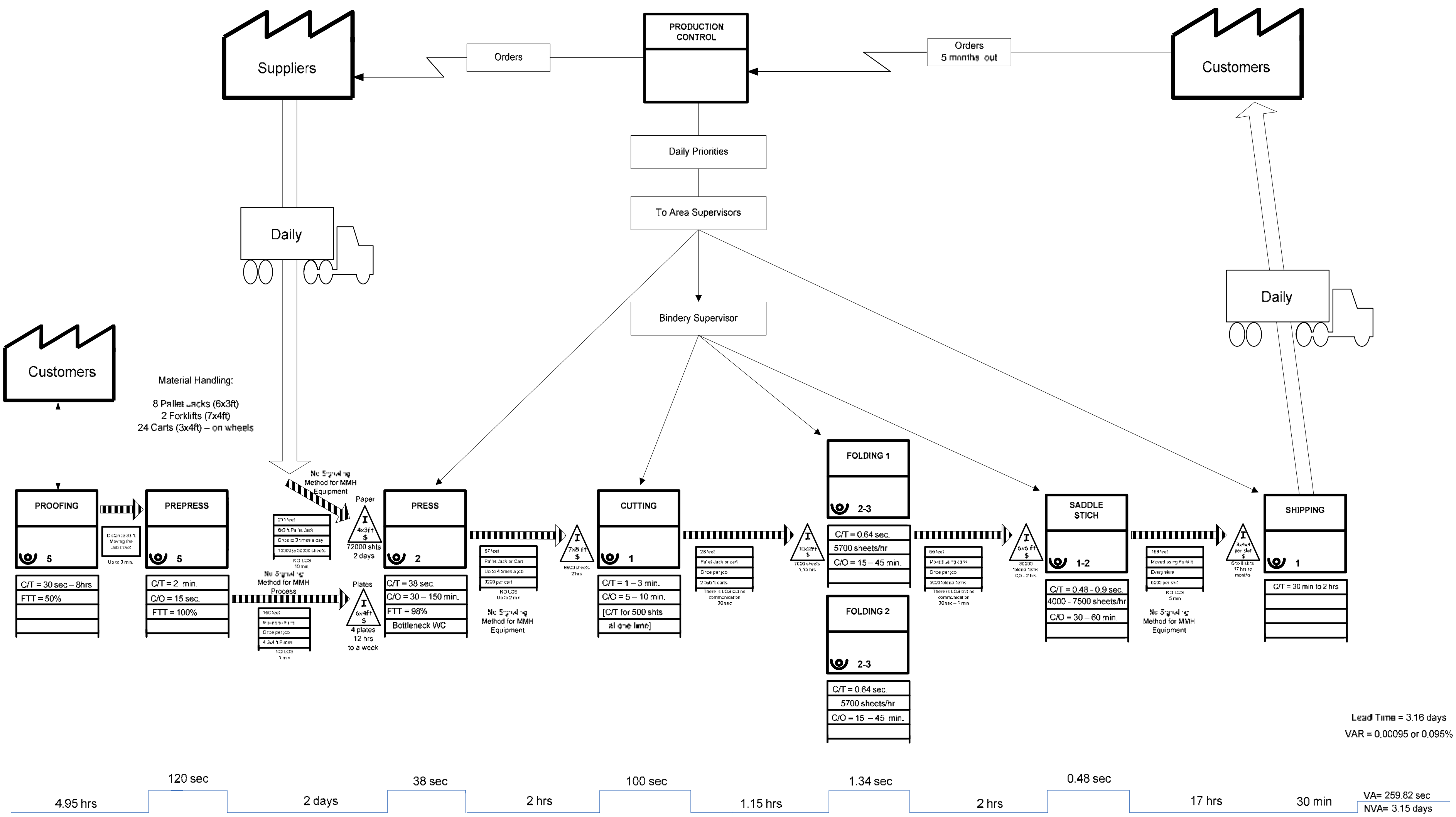


Fig. C-4. Current-state VSM for a saddle stitch job at UniPrint.

C-5: FUTURE-STATE VALUE STREAM MAP

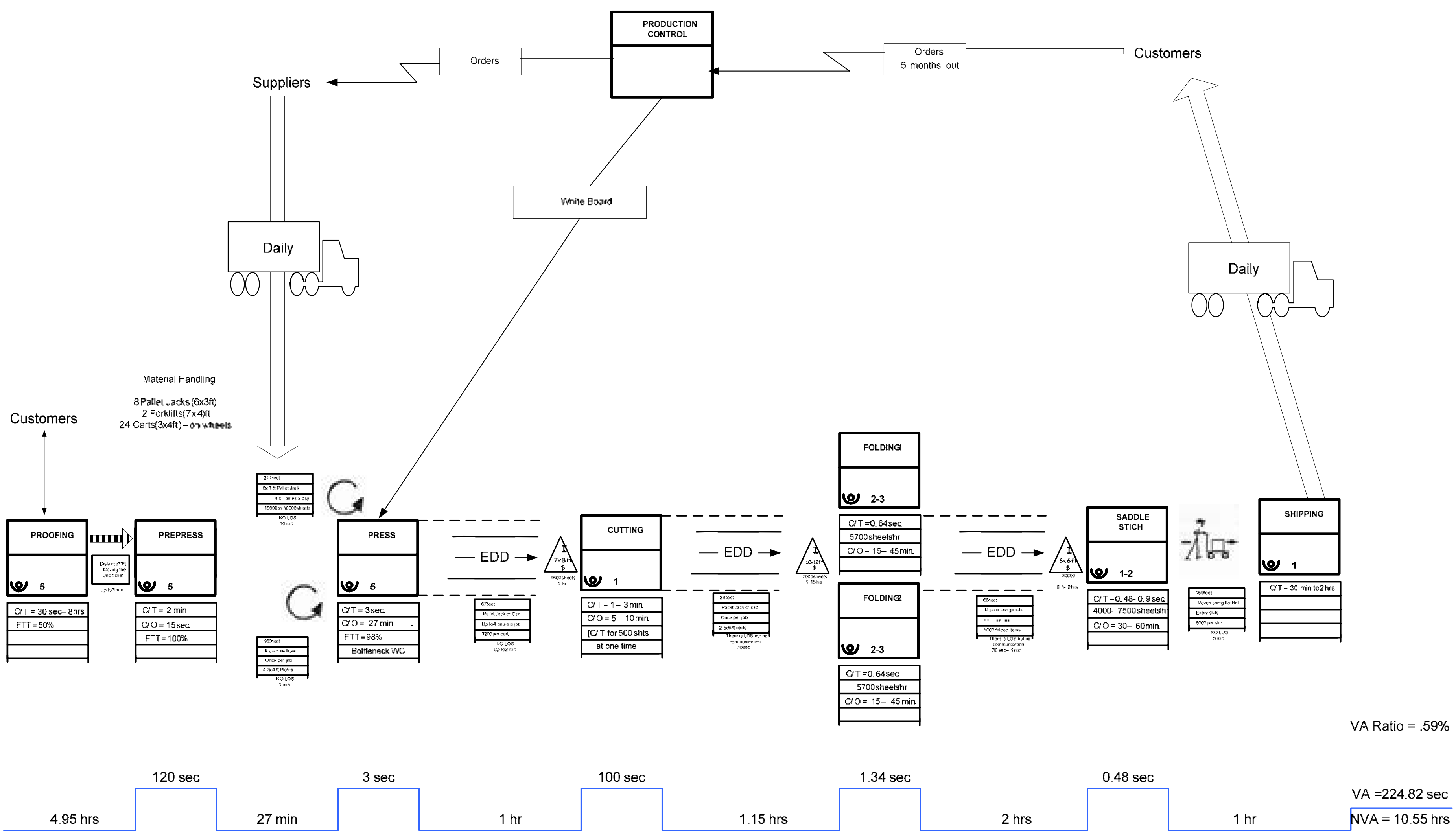


Fig. C-5. Future-state VSM for a saddle stitch job at UniPrint.

C-6: CURRENT-STATE FLOW PROCESS CHART

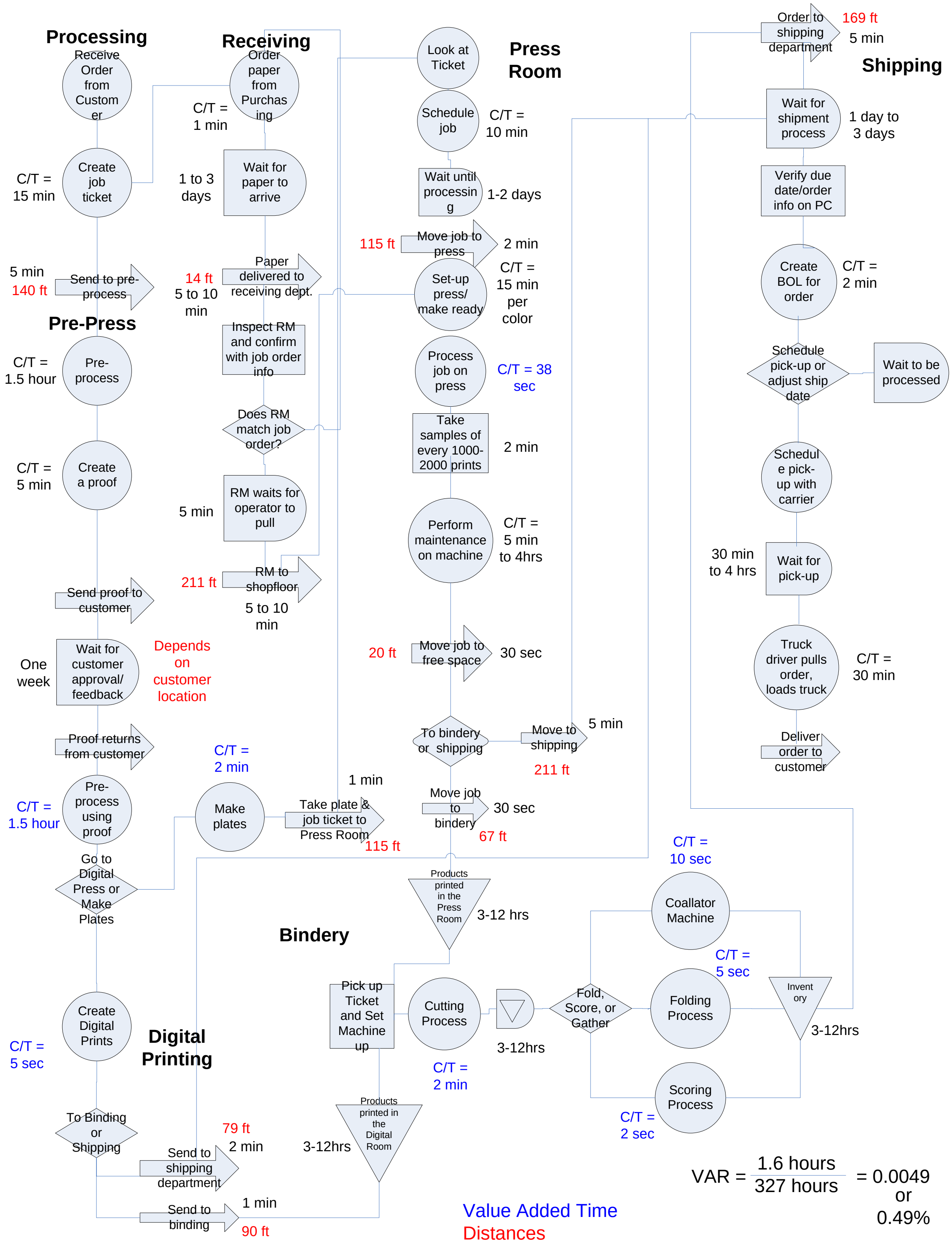


Fig. C-6. Current flow process chart for a saddle stitch job at UniPrint.

C-7: FUTURE-STATE FLOW PROCESS CHART

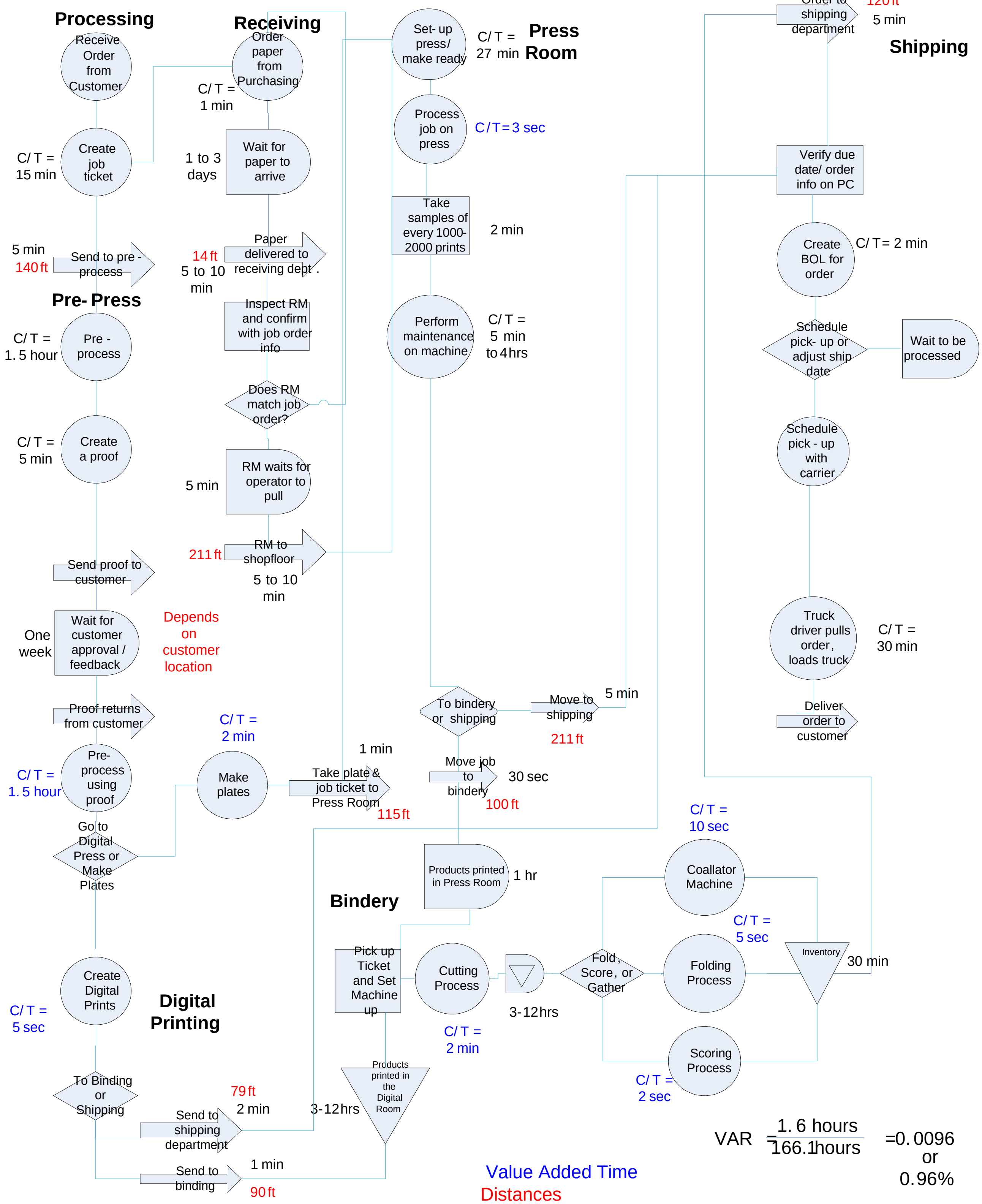


Fig. C-7. Future-state flow process chart for a saddle stitch job at UniPrint.

C-8: CURRENT-STATE FLOW DIAGRAM

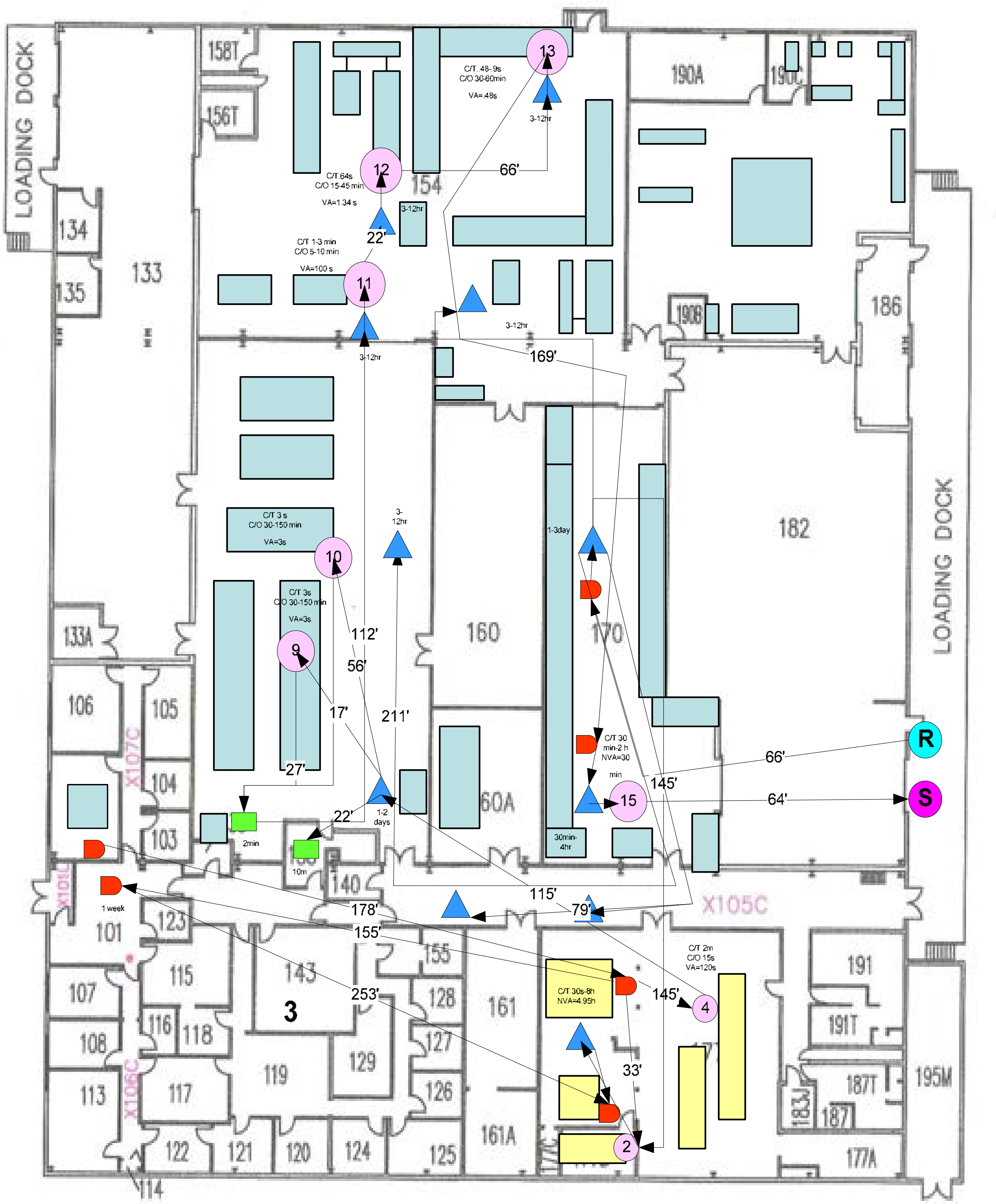


Fig. C-8. Current-state flow diagram for a saddle stitch job at UniPrint.

C-9: FUTURE-STATE FLOW DIAGRAM

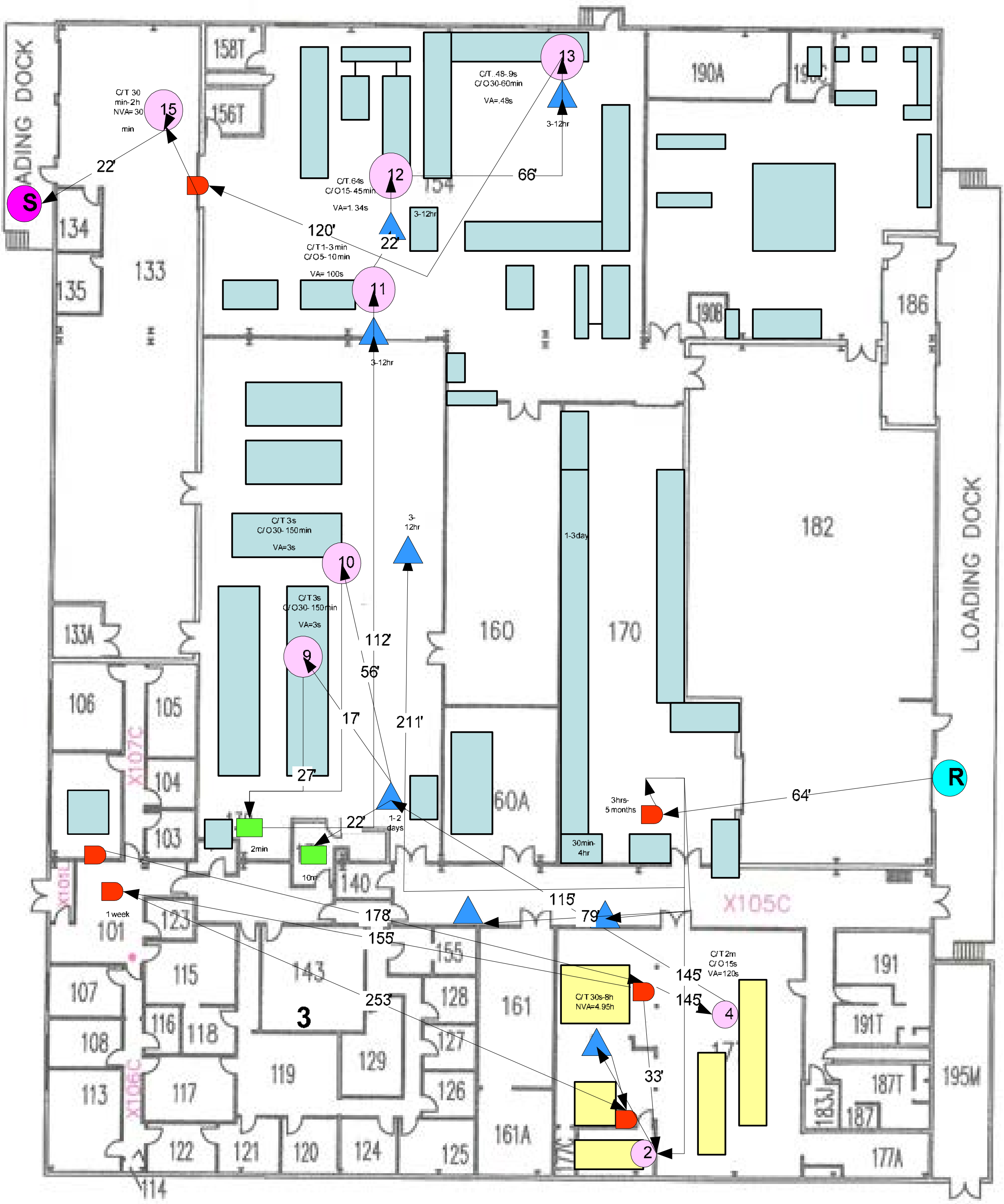


Fig. C-9. Future-state flow diagram for a saddle stitch job at UniPrint.

C-10: SUMMARY OF POTENTIAL BENEFITS FROM CANDIDATE SOLUTIONS

Solution	Soft Benefit	Quantitative Benefit	Cost
5S	Standardized organization of facilty	n/a	minimal, <$100
	Remove warehouse inventory	$90,268	labor, scrap, TBD
	Eliminate operator motion	$23,710	n/a
TOC Press Room	Reduced WIP between plating and press	$95,200	minimal, <$100
	Gain capacity/labor savings at press	$11,000	n/a
TOC Bindery	Reduced WIP between bindery processes		minimal, <$100
Avanti Messaging System with Cordless Phones	Improved communication between departments	n/a	$0
Cutter folder cell with new shipping location	Improved LOS, reduced travel distances, improved product flow	$379	$0
	Part Time shipping operator	n/a	$20,000
	Value of WIP removed from bindery shop floor	$840,000	n/a
Cutter folder cell with old shipping location	Improved LOS, reduced travel distances, improved product flow	$215	$20,000
	Value of WIP removed from bindery shop floor	$1,260,000	n/a