AUTOMATION AND PRODUCTIVITY IMPROVEMENT AT THE AMERICAN RED CROSS

Jason Kistner
Industrial and Systems Engineering

Jim Izzano
Industrial and Systems Engineering

Mike Bolles
Mechanical Engineering

Jason Douglass
Mechanical Engineering

Tom Oldani
Mechanical Engineering

Jeff Lubkowski
Electrical Engineering

Steve Skelley
Electrical Engineering

ABSTRACT
Processing donor blood into blood products used in healthcare is a primary service performed by the American Red Cross. Efficient processing is required to maximize the utility of the blood products as well as to minimize the processing costs. This project involves the automation of two processing operations – agitating and expressing. A mechanical agitator is designed to mix multiple units of blood to replace a manual mixing process with the goal of improving productivity and reducing repetitive motions and fatigue. A clamping device is designed to automate the expressing process to replace the tedious task of observing and precisely clamping the flow of plasma as it is separated from red blood cells. Fully functional prototypes of both devices have been built, tested, and implemented with an estimated payback period of one month.

INTRODUCTION
The American Red Cross Biomedical Division is a subsidiary of the American Red Cross and is responsible for the collection, processing, and distribution of blood products throughout the country. The demand for human blood remains high and is required for such events as surgery or severe trauma. In order to meet this high demand in a manner that provides the best quality product for the patient, the American Red Cross Biomedical Division is composed of approximately 35 service regions throughout the United States. The New York-Pennsylvania service area is one of these regions and is headquartered in West Henrietta, NY. Through a network of central collection locations, this facility processes roughly 340,000 units of blood annually. This makes the NY-Penn. Region one of the largest in the American Red Cross Biomedical division, supplying blood to a network of 120 hospitals and serving a population of roughly seven million.

The Red Cross Blood Processing Center in West Henrietta is responsible for the testing and evaluation of donated blood as well as the processing of blood units. Blood is made up of three main components, plasma, red blood cells and platelets, which the Red Cross separates and distributes to hospitals and medical centers individually.

The separation of the blood components consists of a variety of processing steps. When the units arrive to the processing center, they must be agitated to ensure an even distribution of components throughout the unit before further processing. Agitation is currently done by manually shaking individual bags. The units are then readied for the main separation process. To separate the components of the blood, the units are spun in a centrifuge at high speeds. The first centrifuge spin will separate the plasma from the red blood cells as the plasma rises to the top of the bag during the spin. The units are then placed in a device that places pressure on the bag called an expressor. The pressure on the bag from the expressor forces the plasma to exit the bag through a tube at the top of the bag connected to another bag. The transfer is manually stopped by clamping the tube with a dull, scissor type object called a hemostat when the plasma is completely transferred into a new bag. Some units can have platelets harvested from them as well.
depending on the time elapsed since their donation. Platelets are obtained out of separated plasma using the same centrifuge and squeeze transfer process as plasma and red cells.

**PROBLEM STATEMENT**

The Red Cross Blood Processing Center can improve their facility in many ways but certain tasks are more important than others. Agitating units in a more efficient manner will allow the center to reduce the time between arrival of units and the time when they are placed into refrigeration, a very important metric at the Red Cross. In addition, defects that occur during the expressing process can be highly detrimental to productivity and can result in loss of product.

Thus, this project will focus on the following initiatives; 1) analyze and improve the task of manual agitation for all receivables, and 2) analyze and improve the existing expressing task. Both of these problems are to be addressed with the intention of reaching specific project goals outlined by the Red Cross. Most importantly any modifications to either task will decrease the biomechanical and mental demands placed on the employees. Paralleling this goal is the improvement of product throughput by reducing processing times.

Designs for equipment, including materials and their operation, will need to comply with specific parameters dealing with health and safety policies/regulations. Because this is a facility that processes bio-hazardous material, equipment must be designed such that it does not pose any threat to workers by compromising the integrity of the blood units or the sanitation of the facility.

All phases of the design process including the manufacturing, assembly, and implementation of any equipment needed to be completed over a 22 week timeframe. This deadline was established by the college of engineering at RIT as well as the Red Cross.

**AGITATION DEVICE**

One of the main problems with the existing agitation process is that it is very labor intensive. This causes problems such as worker fatigue and variable productivity. There are also few standards for the agitation process and those that exist are very vague and subjective.

To improve the process of agitation, the team decided to create a design and prototype for an automatic agitation device that would help address the issues with the existing agitation process. Using an automated device, the Red Cross will be able to offload work from the operator to the device, reducing fatigue and improving productivity as well as bring more standardization to the agitation process. To develop the device, brainstorming sessions for concept development, feasibility studies and analysis, component design, final design and integration, prototyping, and testing activities all took place.

**Design Specifications**

To determine the specifications of the device, several tools were used including objective trees and Quality Function Deployment (QFD). Objective trees were used to identify very specific objectives of the device rather than general. QFD was used to translate very qualitative customer requirements into quantitative specifications that could be designed against. The QFD identified several engineering metrics such as speed of motion, minimum length of agitation time, and weight capacity. From these tools, design specifications were identified.

Agitation Device Design Specifications:

1. The device shall thoroughly mix a full rack (12 units) of blood to the current visual inspection within 4 minutes.
2. The device shall be able to sustain the weight of a full rack (12 units) of blood (~35 lbs) for the entire mixing cycle without shifting around on the floor.
3. The device shall hold a full rack (12 units) of blood or a full tote for the specified angle of 45 degrees without any blood product or the container falling off of the device.
4. All circuitry shall be enclosed and away from operator contact.
5. The materials used to construct the device shall meet current Red Cross porosity standards.
6. The device shall not use more than 15 amps of continuous current to prevent excessive current draw.
7. The device shall withstand water and potentially blood spills without losing functionality.

**Concept Development and Feasibility Assessment**

The first task in the design process was to develop some ideas for potential design components. Brainstorming sessions were conducted to determine concepts for different functions of each device such as agitation motion. Using the ideas for each function that resulted from the brainstorming session, several concepts were generated using morphological analysis. These concepts were then evaluated against one another in a feasibility assessment study. The four concepts chosen for evaluation differed in many ways with some more complex than others. Rocking motions and rotational motions were examined with a variety of load holding mechanisms and structures.

To determine the feasibility of the different concepts, several tools were used including Failure Modes and Effects Analysis (FMEA) [1], cost estimates, engineering metric comparisons, and input from a focus group of employees at the Red Cross. A functional FMEA was conducted for the automatic agitation device and the potential concepts evaluated against the potential failures identified. To estimate total cost, the initial material cost, the labor cost to build the devices, the cost for service parts and the labor cost to service the device were evaluated. Engineering metrics from the QFD having relative importance greater than 0.5 were used to evaluate the concepts as well. Finally, an employee focus group at the Red Cross evaluated the concepts and additional input from the employees was obtained.
Once each individual analysis was completed, the results from each analysis were used to evaluate the concepts in a weighted attribute analysis. The analysis methods were weighted based on the team’s perception of their importance. This method allowed the team to obtain a comprehensive feasibility assessment of the concepts across multiple analysis criteria. The results for the agitation device are shown in Figure 1.

### Figure 1 - Agitation Device Feasibility Assessment Results

The concept with the best score in the feasibility assessment was chosen to move into component design. A sketch of the final concept for the agitation device is shown in Figure 2.

### Analysis and Component Design

With final concept chosen, analysis and component design work could begin. To determine specifications of fabricated and purchased components, some analysis needed to be done.

A designed experiment was used to determine the optimal specifications of the rocking motion used in the chosen concept for the agitation device. Three factors were analyzed: orientation, rocking speed, and rocking angle. The experiment showed that a slower speed of 30 oscillations/min, is optimal with a large rocking angle of approximately 45 degrees. In addition, the orientation of the bag was significant with the orientation described in Figure 3 returning the fastest mixing cycle.

The information from the designed experiment was used to create a flywheel and linkage component that would create the rocking motion. The information was also used to determine the orientation of the load while the device rocked.

The height of the agitation device was determined based on anthropometric optimality and conformance to NIOSH lifting guidelines [2]. With this information, the frame and structure could be designed. Finally, the specifications of the motor that would provide the motion on the agitation device were determined using the free body diagrams shown in Figure 4. The resulting torque requirement was 126 in*lbs and a motor was chosen with three times the required torque.

### Final Design

The frame of the automatic agitation device was designed first so that the size of interior parts could be determined. After the frame, the support for the motion was designed. A large plate was designed to support the load with removable pegs to hold the load on the plate. Pillow block bearings were designed to attach to the plate and pass through a pivot bar attached to the frame. A second plate was designed to attach to the frame for the motor to rest on and provide additional support to the frame. Sheet metal shielding was designed to enclose the mechanical and electrical components.

To create the motion, a flywheel was designed to attach to the motor and rotate with the motor shaft. Finally, a link bar was designed to attach to the flywheel and the plate holding the load. Thus, when the motor turned, the link bar would move up and down with the rotation, pushing the top plate up and down against the pivot bar and creating the rocking motion. The final design of the agitation device can be seen in Figure 5.
In addition, a method for stopping the device in the level position was created. A limit switch was mounted to the inside of the frame and a peg was mounted to one of the pillow block bearings. The system was designed so that the peg attached to the pillow block bearing would depress the limit switch when the pillow block bearing was in the level position. When the operator turns off the power, the system is designed to transfer power control of the system to the limit switch. When the limit switch is depressed by the peg in the pillow block bearing, the power will shut off and the plate would stop in the level position. Figure 6 shows the setup for the system to stop the device in the level position and Figure 7 shows the circuit diagram for this device.

Prototype and Test

The team developed a prototype of the agitation device during the second half of the project. The finished prototype is shown in Figure 8.

To ensure that the agitation device performed to the desired specifications, tests were conducted. The agitation device’s performance as blood was agitated was evaluated to determine the quality of the agitation. Specifically, bubbles caused by over-agitation, movement against the holding pegs, and the ability to mix were all evaluated by experience Red Cross personnel. In addition, the team tested the agitation device to ensure that the device could stop within 10 degrees of the level position, the device would not move around on the floor while turned on, and the device would not compromise operator safety through lifting violations or pinch points.

Results

The resulting effects of the agitation device were measured with the completed prototype. Tests showed that the device was able to conform to all design specifications. The device was able to fully mix a full rack of units in 30-40 seconds, far
under the design specification of 4 minutes. The load was held firmly in place throughout the cycle and the weight of the load was sustained through the mixing cycle without structural shifting relative to the floor. The electrical and mechanical parts of the device were covered to prevent water damage to components and eliminate the safety concerns from exposed wires and moving parts.

In addition to meeting the specifications of the design, the following performance metrics were measured for the automated agitation device:

- Load/Unload Time = 10 sec.
- Setup Time for Different Load Size = 4 min.
- Teardown for Service Time = 2.5 min.
- Throughput for Agitation Cell = ~3 min/batch.

**EXPRESSING DEVICE**

The expressing process is another process at the Red Cross Blood Processing Center that can be improved greatly. The main problem with the expressing process is the large amount of wasted time that an operator spends during this task because the operator must remain at the expressor while the expressor is running. The operator must watch for a color change between plasma (yellow color) and red cells (red color) which occurs very quickly and clamp off the transfer tube to separate the product, which can be a tedious task. Clamping too late will result in very costly rework, greatly reducing productivity. To make matters worse, those operators whose time is wasted are usually more experienced because of the difficulty of the task. These experienced operators could be better utilized by performing other tasks.

To solve some of the problems with the expressing process, the team decided to design an automatic expressing device that would detect the color change and perform the clamp for the operator. The operator would load and unload the product in the automatic expressor, but while running, the operator could be utilized to perform other tasks. This would eliminate the tedious nature and wasted time of the task and also reduce the need for experienced operators in this process. In addition, the amount of rework required can be reduced by improving the accuracy of the clamping process through automation. To develop these designs, brainstorming sessions for concept development, feasibility studies and analysis, component design, final design and integration, prototyping, and testing activities all took place.

**Design Specifications**

Objective trees and QFD were used to evaluate the automatic expressing device as well. These tools allowed the team to develop some design specifications which could be designed to.

Automatic Expressor Design Specifications:
1. The device shall sense the color difference between plasma and red cells with at least 99% certainty.
2. The time elapsed between the color change sense and the finished clamping process shall not exceed the time that the fluid takes to flow between the sensing device and the clamping device (approx 1.5 sec).
3. The device shall fully clamp the tube with no leakage between separated sections of the tube.
4. The device shall secure the tube at the point of sensing and at the point of clamping from which the tube can not fall out on its own.
5. The electrical circuitry shall be enclosed by shielding to prevent users from touching the circuit for safety.
6. The solenoid trigger for the clamping mechanism shall be able to reset after being activated.
7. The current of the circuit shall be no more than 3 amps so that excessive power consumption is limited.
8. The device shall be able to be used in a manual mode without requiring any additional setup or teardown.
9. The device materials shall be able to be cleaned and the electrical components shielded from any potential liquid spills.

**Concept Development and Feasibility Assessment**

Brainstorming sessions were used to develop component concepts for the expressing device as well. Such component concepts for the expressing device were sensing device and clamping mechanism. Concepts were generated using morphological analysis and three concepts were chosen to go through a feasibility assessment. The three concepts each had different sensing and clamping mechanisms and the location of these mechanisms relative to the expressor varied as well.

A functional FMEA was developed for the expressing device and the same feasibility metrics were used for the feasibility assessment. The results from the expressing device feasibility assessment are shown in Figure 9.

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**Figure 9 - Expressing Device Feasibility Assessment**

The best concept from the feasibility assessment was concept one. This concept had an optical sensor and a magnetic solenoid to perform the clamp with both mechanisms mounted to the back of the expressor. However, before moving into analysis and component design, the team first conducted an analysis of concept synthesis. Concept synthesis allowed the team to identify the beneficial qualities of the other concepts and apply these qualities to the chosen concept. For example, it was determined that a spring loaded clamp would be most unlikely to fail while a magnetic solenoid would be easy to implement with sensor electronics. Thus, the final concept was
redesign to have a spring loaded clamp that would be triggered by a magnetic solenoid. The final concept chosen can be seen in Figure 10.

![Figure 10 - Expressing Device Concept Chosen](image)

**Analysis and Component Design**

To design the automatic expressor, the force required to clamp a tube needed to be determined. A clamping force experiment was conducted using pressure and force meters and the force required was determined to be 5.31N with 95% certainty. The required force was used to choose a spring that would provide the clamping force.

In choosing an optical sensor to use, the team wanted a device that would provide the necessary detection but could be easily implemented. The Fairchild Slotted Optical Switch sensor was chosen because it provided the necessary detection reliability and the sensor was already in a housing which a tube could fit in. This eliminated the need to fabricate a housing. A study was also conducted to determine the Slotted Optical Switch’s capability to detect the specific color change from plasma to red blood cells. The data from this experiment is shown below in Figure 11. From this data, it was determined that the sensor could tell the difference between red cells and plasma.

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<td>Sample 6</td>
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**Final Design**

The automatic expressor needed to have sensing circuitry and clamping mechanics designed. Designing the sensing circuitry involved using the output voltage of the sensor and transistor gates to either charge a capacitor or discharge a capacitor, proving the necessary triggering power for a clamp. The circuit diagram for the automatic expressor is shown in Figure 12.

![Figure 12 - Expressing Device Circuit Diagram](image)

The clamping mechanics involved a triggering mechanism and a mechanism to perform the clamp. A solenoid was used as the triggering mechanism. A spring loaded clamp was designed to provide the clamping force. The solenoid pin would enter a hole on the clamp. When the solenoid received the triggering power from the sensing circuitry, the solenoid pin would retract into the solenoid chamber, the spring holding the clamp would retract and the clamp would pull a tube against the wall of the expressor, performing the clamp. A resetting mechanism was designed so that when the operator pressed down the handle and locked the handle in place on the expressor, the clamp would open. The clamping mechanics for the automatic expressor are shown in Figures 13, 14, and 15.

![Figure 13 - Expressing Device Front View](image)

![Figure 14 - Expressing Device Bottom View](image)
The team developed a prototype of the automatic expressing device during the second half of the project. The expressing device prototype can be seen in Figure 16.

To ensure that the automatic expressing device prototype was performing to design specifications, several tests were conducted. The team evaluated the clamps ability to respond to the sense of color change before the color change reached the clamp. The clamp’s ability to hold 1.3 psi of tube pressure and provide greater than 6N of force was also evaluated. In addition, the device was tested to see if the tube would fall out of the sensor or clamp while expressing.

The results from testing showed that the device could perform to the design specifications set by the team. The device was able to clamp the tube before the red cells could flow past the clamp and the clamp was able to sustain the pressure of the tube with no leakages. The device was able to repeat this performance over a number of trial runs. The tube was held firm in the sensor and the clamp before the color change during the process and after clamping. Also, the clamping device was able to reset with the same motion that operators use to reset the expressor.

The resulting effects of the device on process performance metrics were evaluated as well. The following results were observed for the automatic expressing device:
- Load/Unload Time = 25sec/15 sec.
- Operator Time Savings per Batch = ~ 2 min.
- Cell Throughput = 3 min/express batch.

The inclusion of automated devices into the work cells at the Red Cross Blood Processing Center can reduce the amount of straining activities that operators experience and improve productivity within cells at the same time. However, some long term effects of the automation devices that could not be physically tested needed to be investigated.

A simulation model was developed for the blood processing system to estimate the long term effects and savings of device implementation. Two models were created, one for the existing process and one with the introduction of the devices. The process times for the devices were generated from data from their respective tests. The models were validated using a combination of real data comparison and expert opinion.

The simulation model results showed that the throughput time of the agitation cell could decrease by 60%, effectively doubling the throughput of this cell by introducing the automatic agitation device. However, the overall system throughput time was not affected by the introduction of the agitation device. This is because the next process cell after agitation, called cut down and segment, absorbed the increased throughput of the agitation cell and became a bottleneck. This was indicated by a doubling in wait time for the cut down and segment cell after introduction of the automatic agitation device.

The throughput time of the centrifuge and expressing cell was not increased but this is not all together unexpected. The cycle times were not improved in any way and the product takes a similar amount of time to process. However, the amount of time that product waits for a centrifuge and later, for an expressor, was reduced by over 70%. In addition, the utilization of the centrifuge and express operators was reduced by over 50%. This indicates that operators have much more time to perform other tasks in their cell but there are not enough tasks within their cell to perform. Thus, changing the cell processing logic to take advantage of this extra capacity could increase the throughput of the cell.

**CONCLUSIONS**

**Automation Benefits**

By implementing the automatic agitation device, the Red Cross can see improvements to the individual process times of units as well as overall cell throughput. With a 60% increase in cell
throughput, the worker productivity has been improved. This results in a cost savings of $15,200/year. In addition, the strenuous task of manual agitation has been eliminated. This could result in fewer work related injuries, potentially decreasing the cost of worker compensation or loss of skilled employees.

Implementation of the automatic expressing device will allow operators to perform other tasks while the product is expressing. A decrease of 50% in operator utilizations results in a cost savings of $30,400/year with an operator wage rate of $15/hour. In addition, the training required of operators to perform the task has been drastically reduced. Also, the amount of rework will be reduced due to reliable and consistent means of performing the expressing process. With 340,000 products processed per year, reducing the amount of rework by 50% will save the Red Cross $4,500/year in labor costs to process rework and $85,000 in reduction of lost product.

With the implementation of both devices, the Red Cross can recognize a potential cost savings of $50,100/year through productivity improvements, $15,200/year from the automatic agitation device and $34,900/year from the automatic expressing device. The total cost of the automatic agitation device is approximately $1,200 and the total cost of implementing the automatic expressing device (total of 24 devices) is approximately $2,880. The resulting payback periods for the automatic agitation device and the automatic expressing device individually are less than 30 days. Implementing both devices will result in a net payback period of one month.

**Final Conclusions and Recommendations**

The team recommends implantation of both automated devices. Implementing the automatic agitation device will improve the throughput of the cell. This will allow the Red Cross to transfer the whole blood from the coolers into the refrigeration unit much faster, reducing ruined product and improving product quality. This improvement will also allow the Red Cross to handle fluctuations in demand much easier. Implementing both devices will cost $4,080 with a payback period of one month.

However, the cut down and segment cell will become a bottleneck with the increased throughput from the agitation cell. Thus, the team recommends improving this cell in order to improve overall system performance in the future. The time saved by the automatic expressing device for expressing operators could be used as additional capacity for performing cut down and segment until the operation is improved.

**ACKNOWLEDGMENTS**

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**REFERENCES**


