Packaging Line Efficiency Improvements with the Implementation of a Centralized Packaging Line Control System

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Abstract *— Efficiency is a process measurement of the ability of generating a required output with the minimum amount of resources. A high efficiency is crucial for a packaging line as it is an important aspect of cost control that results in an improved production and utilization of available resources. Poor design and operation of packaging lines result in low efficiency and therefore great cost and loss of profitability. Packaging Line 7 is used to label, stack, bundle, case, and palletize filled cans. The line provides packaging of 5oz. and 7oz. sizes in "Bundled" formats which make out 5 different production scenarios. Packaging Line 7 has been affected by low efficiencies, which were measured at an average of 56% for the 5 Production Scenarios. This project has been developed under the Lean Six Sigma principles and using DMAIC five-step approach, in order to identify opportunities to improve the efficiency of Packaging Line 7.*

Key Terms *— DMAIC, Efficiency, Lean Six Sigma, Packaging Line 7.*

INTRODUCTION

This project has been outlined with the purpose of analyzing and evaluating the performance of Packaging Line 7 in order to improve its efficiency. The project use the DMAIC methodology to achieve its goals.

An onsite audit was performed to Packaging Line 7 to identify the factors limiting its performance. The assessment was performed based in the following criteria:

- Line Design
- Line Efficiency
- Manufacturing Support

Research Description

After completing the onsite audit, the information collected was analyzed to be able to grade and categorize the factors limiting the line efficiency. In order to complete the analysis, the "4M's Process Improvement Methodology" was used to analyze the issues limiting the line as well as the V-Model Concept to analyze the speed, accumulation and recovery characteristics of the line.

From the above and based on all information gathered, we were able to determine that 82% of the limiting factors on the efficiency are Machine related and are primarily concentrated in the High impact category. At the same time, Method detractors represent the rest of the 18% of the events gathered, as illustrated in Figure 1.

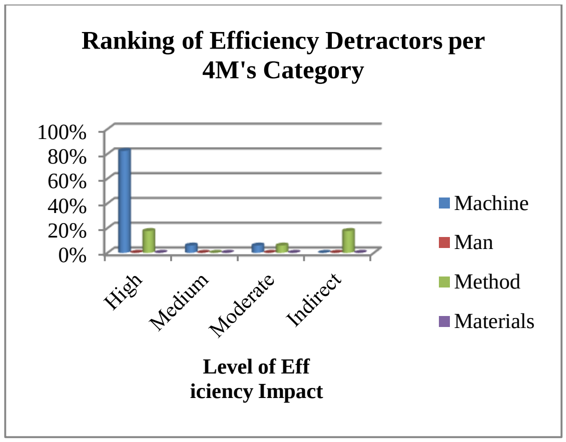

Figure 1
Ranking of Efficiency Detractors

Analysis was concentrated on the High and Machine related detractors. Special attention was placed on problems caused by the line control system since this was found to be the main efficiency detractor of this category.

A similar analysis was done to the High and Method related detractors, and the main efficiency detractor for this category was found to be inconsistent machine operating procedures, in particular at the Can dumping areas.

Research Objectives

The objectives for this project are:

- Increase in efficiency.
- Reduction in waste of product and packaging materials.
- Improvement of the utilization of available resources.

Research Contributions

With the project implementation the site was able to achieve cost savings and gains in efficiencies that result in reductions of waste and better utilization of its resources. The project also identified areas of opportunities and recommended improvements that can further increase the throughput and efficiency of the packaging line. The assessment made and subsequent implementation may extend to other packaging lines of the site, the company, as well as other companies within the manufacturing industry.

THEORY

This section provides a general understanding of the concepts behind the process to be improved and the alternatives to be implemented.

Theoretical Concepts of Process to be Improved

Packaging Line 7: Packaging Line 7 is divided in three (3) main production areas; Dumping, Labeling and End of Line areas, which are described as follows:

- **Dumping Area:** Packaging Line 7 is equipped with three (3) Dumping areas to supply unlabeled filled cans that are conveyed for labeling, stacking, tray packing, and palletizing. The three dumping areas are: Round Dumping (RD), Square Dumping (SD), and New Square Dumping (NSD). At the same time, the existing line design allows multiple dumping area configurations to be operational in order to provide flexibility and maximize the unloading and supply of filled unlabeled cans to the labelers. The existing line design allows five (5) different dumping scenarios based on the shape of the cages were the cans are transported and dumping areas. The scenarios are the following; Scenario A: RD, Scenario B: SD, Scenario C: NSD, Scenario D: RD + NSD, and Scenario E: SD + NSD
- **Labeling Area:** The line design includes two (2) X-rays and two (2) Labeling machines capable of running each at nominal speed of 850cans/min (maximum speed of each is rated at 1,100cans/min). The way these machines are operated, is dependent on the different Production Scenarios.
- **End of Line (EOL):** The line design includes two (2) cans Stackers as well as the conveyor configuration to allow running “bundles” in trays. This bundle/tray product is processed in an automatic palletizing and stretch wrapping system.
- **Process Flow:** The above three main production areas, dumping, labeling and end of line, combined produces the overall process flow diagram as illustrated in Figure No. 2
- **Line Control System:** The existing Packaging Line 7 automation architecture includes independent control systems for almost all machine centers with limited connectivity and communication as a complete system. Each piece of packaging equipment operates separately from each other. Equipment and conveyor control is limited to basic equipment interface requirements at the Critical Machine (Labelers) in the form of run permissive, start/stop conditions and speed requirements. Dumping and EOL equipment control is “on-demand” provided by sensors mounted at the infeed and discharge of the equipment. The line has a mass conveyance system that provides dynamic accumulation between machine centers. However, the existing controls for these conveyor sections are limited to fixed

speed and start/stop conditions limiting the effective flow of product throughout the line. From the above, each machine center is currently optimized for individual efficiency only, but the packaging line provides limited means for total line efficiency.

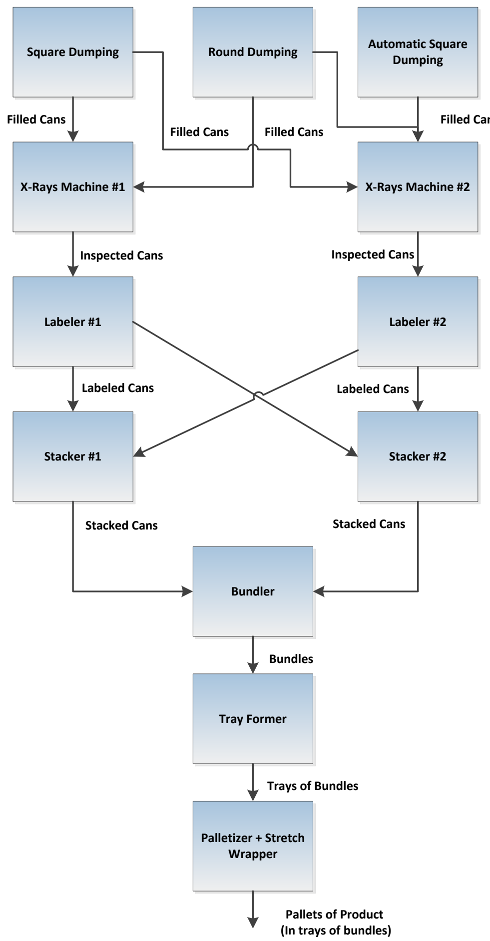

Figure 2

Packaging Line 7 Process Flow

Theoretical Concepts of Alternatives to be Developed

This section is aimed to provide a general understanding of the theoretical concepts used in this project. It describes the DMAIC methodology, which is the overall methodology followed in the project. Then it describes the 4M Process Improvement Methodology, this is the tool used to analyze the data and localize the root causes of the problem. It also describes the formulas used to calculate the efficiencies of the packaging line. Lastly, it discusses the Line Design V-Model Methodology, used to improve the design of the packaging line and therefor its efficiency.

DMAIC: In order to meet the proposed objectives, this project will use the Lean Six Sigma methodology. Lean Six Sigma is a philosophy aimed on process improvement. It is derived from Toyota Production System and is focused on maintaining a continuous flow of product, eliminate waste, and improve customer satisfaction. Lean Six Sigma is based on the combination of the concepts of Lean Manufacturing and Six Sigma principles, using DMAIC strategy. DMAIC is an acronym that has five phases: Define, Measure, Analyze, Improve, and Control.

A project is selected for improvement by the DMAIC methodology based on a review of business performance [1]. The Define phase defines the problem that needs to be solved. The Measure phase collects the facts that describe the process to be improved. The Analyze phase allows you to identify root causes of the problem. The Improve phase implements solutions to address the root causes of the problem. Finally, the Control phase allows for the sustainability of the gains and further improvements.

4M Process Improvement Methodology: In order to reduce losses in a production system, the allocation losses is essential. This allocation should be made using a systematic approach. This project uses the 4M Methodology to identify production losses. The 4M Methodology uses the factors of Machine, Man, Method, and Material to understand the root cause of the problem that is generating the losses in a process. The four factors of the 4M Methodology are described as follows:

- **Man:** These are the human factors that can contribute to the production losses. Some of these could be: Inadequate Standard Operating Procedures (procedures could be too complex to follow; activities are too difficult to be executed or does not have margin for error; visual aids are missing on key areas); Lack of proper tool or equipment to perform the job; Unfavorable workplace environment; Inadequate qualifications of worker to do the job.

- **Machine:** The equipment in a process must be fit for its purpose in terms of capacity and capabilities. Equipment should be in working order. The amount of jams and unplanned equipment stoppages should be minimized with the correct equipment design, operation, and maintenance among other factors.
- **Material:** Materials supply should be of adequate quality and quantity. Storage and handling of materials is essential to preserve these two characteristics. The flow of materials, from supplier to the production line and going to the customer in form of the final product should be oriented in a manner that achieves a zero defect target.
- **Method:** Standardized sequence of steps should be established and followed at all times. These steps should promote a safe work environment and be proven to be efficient and effective in achieving their purpose. The physical conditions of the work area should also be adequate to maximize the work flow and allow workers to perform their work efficiently.

Efficiency Calculation Methodology: Efficiency calculations are based in actual throughput which has been estimated using the delta between the Theoretical Available Time (TAT) assuming no losses ("Zero Downtime") vs. Actual Available Time (AAT) considering the Downtime Losses. The formula is illustrated below;

$$\text{Machine Efficiency (ME)} = \text{Actual Throughput} / \text{Theoretical Throughput} \quad (1)$$

Where:

$$\text{Actual Throughput} = \text{AAT} \times \text{Machine Speed} \quad (2)$$

$$\text{Theoretical Throughput} = \text{TAT} \times \text{Machine Speed} \quad (3)$$

While;

$$\text{Line Efficiency} = ME_1 \times ME_2 \times ME_3 \ldots. \times ME_n \quad (4)$$

Line Design Methodology – "V Model": The line design methodology used in this project to evaluate operation of Packaging Line 7 begins by identifying the critical machine (CM). The critical machines for Packaging Line 7 are the Labelers. In general, an appropriate line design will comply with the following requirements:

- Adequate product accumulation (cans) before and after the CM to avoid stoppages of this machine center due to micro-stops in upstream and downstream equipment.
- Machine Centers before and after the labeler should have the capacity to modulate their speed over the CM speed. This over speed will avoid stops in the CM due to micro-stops related machine centers located before and after.
- Centralized Line Control. A centralized line control in place will control the machines and conveyors speed to provide a smoother and continued line operation achieving higher line efficiencies.

The schematic shown on Figure No. 3 summarizes the concept explained above.

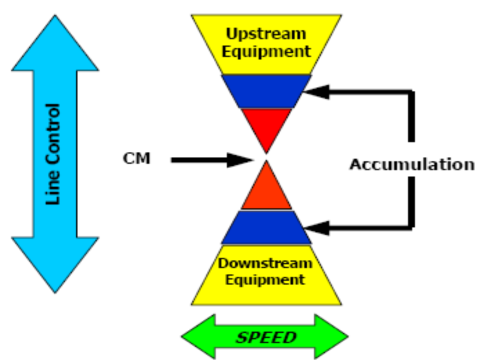

Figure 3
Line Design Methodology – "V Model"

Based on the above concept, an appropriate line design for Packaging Line 7 will have a V-Graph as shown on Figure No. 4 (for reference only). Please note that the CM is identified as the Labelers, while the line has over-speed capabilities to avoid stops in the CM due to micro-stops related machine centers located before and after.

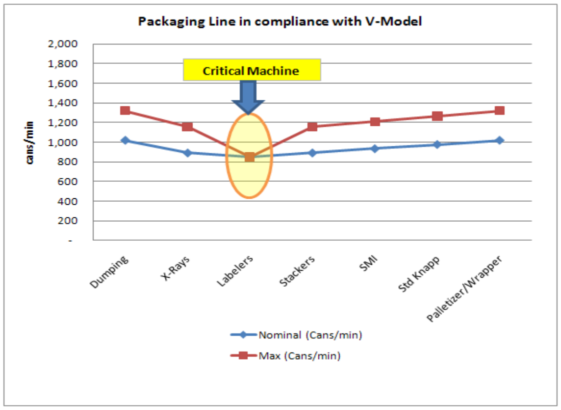

Figure 4
Packaging Line 7 V-Model Example

METHODOLOGY

This section provides an overview of the methodology and procedure to be applied in this project in order to achieve the objectives of the project.

Description of Project Development Steps

The project methodology to be used is DMAIC improvement strategy coming from Six Sigma principles. DMAIC is an acronym that has five phases: Define, Measure, Analyze, Improvement, and Control.

- **Define Phase:** This phase consists in the definition of the problem statement, scope, and goals. It will establish a project charter and conduct a kick-off meeting with site leadership and team members in order to communicate the scope and objective of the project as well as establishing ground rules.
- **Measure Phase:** The objective of this phase is the collection of relevant data and evaluation of current packaging line operations to identify issues and key aspects limiting its performance. An assessment of the packaging line will be performed while the line is under normal operation. The assessment will emphasize on the collection of data that includes current and nominal speeds, sources of downtimes and downtime durations, as well as process and materials flow. This phase will develop detailed charts to help the team understand the packaging line performance.
- **Analyze Phase:** The goal of this phase is to identify possible root causes that are limiting the performance of the line. Efficiency and associated calculations (i.e. machines and conveyors speeds and throughputs) will be made as part of this phase. The 4M Process Improvement Methodology will be used as a tool to allocate and layout the efficiency detractors of the packaging line.
- **Improvement Phase:** This phase consists in developing and implementing a solution based on the analysis performed on the previous phase. During this phase meetings will be held with site leadership in order to communicate the possible solutions, this will include a detailed description of the alternatives as well as implementation costs and expected benefits. The decision of the improvements to be implemented will be made based on the information shared on those meetings. Although previous phases of the methodology will cover aspects related to methods and procedures, improvements under the scope of this project will focus mainly on those related to automation and engineering techniques. Measurement of the improvements will be made to assure project goals have been meet before initiating the next phase.
- **Control Phase:** The purpose of this phase is to ensure the sustainability of the improvements made during the previous step. This phase includes the design and documentation of the new controls and procedures that will help achieve the sustainability of the new process. Some of the tools to be implemented during this phase are a process map of the new process, engineering layouts, operation and maintenance manuals, and spare parts list. Training on the operation and maintenance of the new process will be provided to operators, maintenance personnel, and key administrative personnel as deemed necessary. Also, training will be provided for the tracking of the line

efficiency so that any drift back to previous results can be addressed in a proactive manner. Other automation aspects of the new process destined to preserve the performance of the new process, like the management of software security and backups, will also be addressed as part of this phase. During this phase the responsibilities of the improvement team will be shifted to the appropriate teams that will be responsible for the sustainability of the new system.

ANALYSIS AND RESULTS

This section details the analysis performed in order to implement the process improvements and the results obtained from the improvements implemented.

Data Presentation

Downtimes for Efficiency Calculations: In order to calculate the line efficiency, we first determine the base variables for this formula; TAT for the "Theoretical Available Time" for production and AAT for the "Actual Available Time" for production which is equal to TAT minus Downtime.

TAT Calculations: The TAT is based in the predetermined theoretical available time for production minus the planned downtime. The calculation presented on table number 1 is based in observations during the line audit and information provided by site representatives.

Table 1
Theoretical Available Time Calculations

Theoretical Available Time Calculations		
Total Available Time Shift	8 hrs	480 mins
Planed Downtimes		
Period	1 hrs	60 mins
Change Overs	0.5 hrs	30 mins
Theoretical Available Time (TAT)	6.5 hrs	390 mins

The above estimated TAT value (390 minutes) is used throughout this analysis as the baseline for the available production time to manufacture good products as we have assumed for the purposes of this project that quality criteria is 100%.

AAT Calculations = (TAT-Downtime): The estimated downtime impact as presented on this project is based on the downtime analysis performed on each of the machine centers during the line audit. Each machine center was monitored for a predetermined amount of time in order to record the downtime events establishing the duration and it's percent weight. For the purposes of this project, the percent weight for each of these events has been extrapolated to estimate the downtime for each event for the interval of one (1) shift (TAT = 390mins).

The major efficiency hitters were found to be the following:

- Stacker # 2: (16.7% Downtime Impact)
- SMI: (15.9% Downtime Impact)
- Labeler # 1: (8.2% Downtime Impact)

Machine Speeds for Efficiency Calculations: In order to complete the efficiency calculations, the maximum speeds were either calculated or noted on each equipment during the line audit. However, it is to be noted that the actual line throughput will be limited for each Production Scenario dependent on individual machine over speeds capabilities and its percentage over-speed to the critical machine. From the above, the actual line throughput for some of these scenarios will be "clamped" to actual throughput achievable due to limitations on Dumping and/or EOL equipment.

Packaging Line 7 Efficiency Calculations: Table Number 2 summarizes the efficiencies calculated for production scenario #5 of Packaging Line 7. Similar numbers where obtained for other production scenarios (i.e. Production Scenario # 1: %55, Production Scenario # 2: %57, Production Scenario # 3 %57, and Production Scenario # 4: %57).

It is to be noted, that the machine efficiency calculation is based on the maximum speed (theoretical throughput) for each machine center.

Table 2

Efficiency Calculations

Machine Center	Actual Throughput (Trays/Shift)	Theoretical Throughput (Trays/Shift)	Machine Center Efficiency
Production Scenario #5			
Round + New Square Dumping Area	21,048	21,645	97%
X-Ray #1	9,458	9,750	97%
X-Ray #2	9,750	9,750	100%
Labeler #1	8,209	8,938	92%
Labeler #2	8,938	8,938	100%
Stacker #1	17,577	17,875	98%
Stacker #2	7,448	8,938	83%
SMI	22,959	27,300	84%
Standard Knapp	29,557	31,200	95%
Palletizer + Wrapper	17,144	17,472	98%
Total Line Efficiency: 56%			

Statistical Analysis of Results: Nominal and Maximum Throughput of production scenario #3 and production scenario #5 of Packaging Line 7 are plotted in Figures 5 and 6 in order to locate the machine centers that are limiting the throughput of the packaging line. It has to be noted that, for this analysis, scenario #3 is used in representation of production scenarios with one Dumping Area (i.e. Scenarios #1, #2, and #3) and scenario #5 is used in representation of production scenarios with two Dumping Areas (i.e. Scenarios #4 and #5).

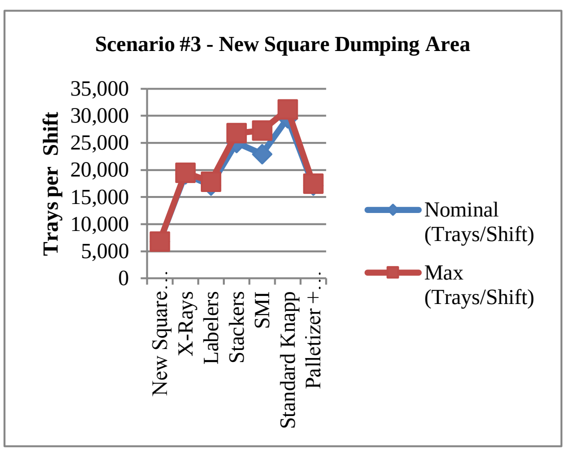

Figure 5
Throughputs Plot for Production Scenario #3

From Figure number 5 it can be seen that the machine limiting the throughput for Scenario #3 is the New Square Dumping at a maximum throughput of 6,825 trays/shift. For this production scenario the Dumping area throughput needs to be increased by around 300% to comply with the V-model. This will avoid micro-stops or starving conditions in the Critical Machine (Labelers).

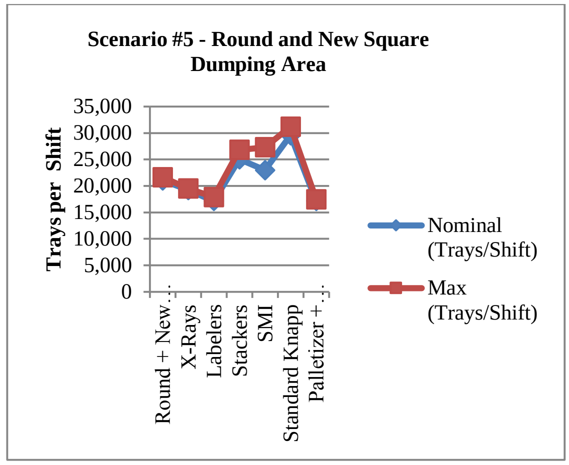

Figure 6
Throughputs Plot for Production Scenario #5

Similar analysis applied to scenarios #1 and #2 reveal that a V-model cannot be achieved with only one Dumping station (i.e. Production Scenarios 1, 2, and 3) active. Both dumping areas need to be active in order to comply with the V-model and avoid micro-stops or starving conditions in the CM (Labelers).

Figure number 6 reveal that for scenarios #5 machine limiting the throughput is the Palletizer / Wrapper at a maximum throughput of 17,472 trays/shift. Although the V-model cannot be entirely completed for production scenarios #4 and #5, the principle can be meet upstream the Critical Machine and up to three (3) machine centers upstream the Critical Machine (i.e. Stacker, SMI, and Standard Knapp). Accumulation conveyors between the Standard Knapp and the Palletizer / Wrapper can compensate for the limited throughput of the Palletizer and Wrapper.

Alternatives Development

Line Efficiency Improvement Recommendations: The detractors that impact Packaging Line 7 efficiency were summarized and ranked. The problems identified were classified as per their allocation, using the 4M Process Improvement Methodology and by their impact to the efficiency of Packaging Line 7. At the same time, possible actions were proposed for a preliminary action plan to be further implemented. The ranking of these opportunities will allow prioritizing its implementation plan. Ranking of the complexity of the recommendations Complexity ranking is based on approximate cost impact as follows:

- Moderate – from $0K to $5K.
- Medium – from $5K to $15K.
- High – from $15K+

Implementation of Solution

From the summary of the detractors it can be seen that a vast majority of the problems observed are caused during product handling on the conveyors and because of lack of integration of the conveyor system with the machine centers. Most of the problems are related to:

- Excessive conveyor backpressure at different areas
- Improper Supply of product from one machine center to another.
- Inadequate spacing between cans at infeed of machines.
- Areas of the Line without proper machine and conveyor controls.

The proposed actions were presented to the site leadership and an action plan was developed to upgrade the existing Line Control System to a Centralized Packaging Line Control System to address all of the aforementioned problems.

An upgrade to centralized Programmable Logic Controller (PLC) was made to provide speed and machine operating signals to each piece of packaging equipment and each "can" conveyor. With a Centralized Packaging Line Control System the line will be capable of operating at higher speeds and greater efficiencies using a common communication network and accumulation recovery systems.

As previously noted, the existing conveyor control system has limited communication to other equipment. The graphic of the V-Model concept illustrates how a Centralized Line Control System can allow the critical machine (CM) to continue to operate provided that a variable speed range exists upstream and downstream. The CMs for Line 7 are the labelers. The machine speeds are controlled upstream and downstream of the CM to ensure that there are always "cans" available at the infeed of equipment and there is always space available at the discharge end allowing a continuous run and flow at the CM. The downstream machines are pulling "cans" away from the CM at a speed that is higher than the typical operating speed of the CM.

As previously noted, the only two production scenarios were implementation of a V-Model is possible are the production scenarios with two Dumping Areas, these are Production Scenarios #4 and #5. Therefore the Centralized Packaging Line Control System will include only these two production scenarios.

Optimal line design is intended to provide "can" accumulation at a location that protects the CM from "micro-stops". Micro-stops are defined as those stops typically shorter than the mean time to repair (MTTR) for most basic machine stops (i.e. simple component jams, "can" label changes, etc.) The Centralized Line Control System monitors the status of each packaging machine and the population of "cans" on the mass conveyors and accumulation systems (if available). Upstream and downstream machines speeds and related "can" conveyor speeds are adjusted accordingly based on population. The result is a smoother running line where packaging machine centers are less susceptible to stops. Less machine stops results in greater operating efficiency and increased throughput.

Conclusion and Recommendations

This section compares results of line efficiency before and after the implementation of the improvements. Also provides the conclusion of the project and as well as recommendations for further improvements.

Results Comparison of Before and After

As per analysis performed it was decided to operate Packaging Line 7 with two Dumping Areas active, meaning that only production scenarios #4 and #5 will be used for production. Therefore all improvements were implemented and tested using only these two production scenarios. Testing of results was performed using a commissioning protocol that measured throughput. Additional product testing was performed to monitor the amount of defects (product) found in the improved packaging line.

Once all improvements were implemented and tested, the new throughput off all machine centers were measured in order to calculate the new efficiencies of the machine centers and the overall new efficiency of Packaging Line 7.

The efficiency of Packaging Line 7 improved from 57% to 88% for production Scenario #4, this represents a 55% percent increase. From figure 7 it can be seen that the most significant improvements were made in the efficiencies of the Labelers, Stackers, and the SMI. These machine centers improved from 92% to 100%, 83% to 98%, and 84% to 95% respectively.

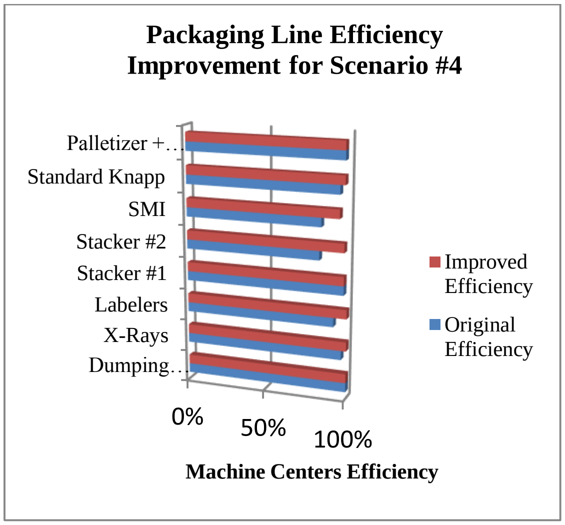

Figure 7
Efficiency Improvement Graph –Scenario #4

The efficiency of Packaging Line 7 improved from 55% to 85% for production Scenario #5, this represents a 55% percent increase. From figure 8 it can be seen that the most significant improvements were made in the efficiencies of the Labelers, Stackers, and the SMI. These machine centers improved from 92% to 100%, 83% to 98%, and 84% to 95% respectively.

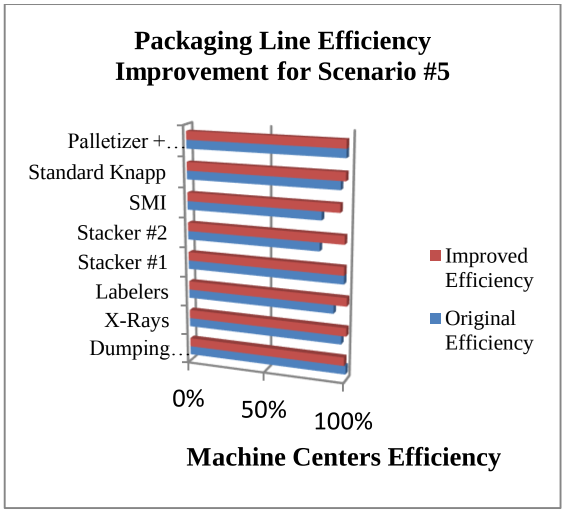

Figure 8
Efficiency Improvement Graph – Scenario #5

CONCLUSIONS

The DMAIC methodology was used for business improvement as a road map for implementing sustainable solutions. This technique allowed the allocation and categorization of opportunities under their impact to efficiency and cost of implementation. A Centralized Line Control System was implemented to allow for better product flow of product on conveyors and at infeed and discharge of machine centers. The new system also allowed for proper synchronization between the conveyor systems and the machine centers. These resulted in an increase of the efficiency of Packaging Line 7 by 55%. This allows for a better utilization of resources and a reduction in waste.

Documentation of the new Centralized line Control System was delivered to the site with the intention to sustain the improved performance of Packaging Line 7. This documentation included the following:

- Process Maps of new process.
- Engineering Drawing new system.
- Operation and maintenance manuals, including spare parts list.
- Backups of new and modified software.

Training on the operation and maintenance of the new system was provided to the site operators, maintenance, and key administrative personnel. Also, training was provided to key administrative personnel for the security management of the new system to help maintain the integrity system. Additionally, training was provided for the correct tracking of the line Overall Efficiency Methods detailed in this project so that any drift back to previous results can be addressed in a proactive manner.

Recommendations to Improve Results: alternatives were developed and classified by impact to efficiency and cost of implementation. These alternatives were presented to site leadership in order to obtain a decision of which ones to implement. The following are some of the alternatives presented as recommendations for further improvements to the efficiency Packaging Line 7:

- Install a New Palletizer - Packaging Line 7 Throughput will be able to increase its throughput by nearly 50%.
- Revise the "Operator's Breaks Schedule" to ensure that the quantity of operators will be available as planned on the Dumping Area.
- Develop Change Over instructions and "Poka-Yoke" for the setup of the Orienter in the Square Dumping Area.
- Use dedicated change parts per can size on the Dumping Area.
- Review design of the Standard Knapp in order to develop a lock mechanism to ensure the synchronization of Collation Area
- Review Forklift Operator responsibilities to determine frequency needed at the packaging line and / or install additional conveyor for pallets accumulation at the discharger in order to reduce stops on the Palletizer/Wrapper.

References

[1] P. Gupta, "Application of Six Sigma Tools" in *The Six Sigma Performance Handbook*, McGraw-Hill, 2004, ch. 3. sec. 5, pp. 98.