OVERALL EQUIPMENT EFFECTIVENESS IMPROVEMENT
A CASE FOR RETROFITS

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Abstract - *For many manufacturing operations, the capital investment in equipment is one of the most important decisions that management has to make. Many considerations come into play when evaluating core strategies such as repairing, upgrading, or out-right replacement of the equipment. In many cases, the most effective investment answer is an electrical control system upgrade to existing equipment. But when is it right for you? It is the goal of this discussion to explore this topic and provide the audience with guidelines that can be used in evaluating their own equipment. This paper will be presented with examples applicable to continuous web converting equipment; however, the overall evaluation process and plan are closely related to nearly all manufacturing applications. The main topics of discussion will include:*

- *Defining Overall Equipment Effectiveness (OEE)*
- *Evaluating OEE*
- *Availability, Performance and Quality Losses*
- *Productivity Improvement Opportunities*
- *Availability, Performance and Quality Gains Through Retrofits*
- *Retrofit ROI – Cost vs. Downtime*
- *The Who, What and When of Retrofitting*
- *Conclusion*

I. DEFINING OVERALL EQUIPMENT EFFECTIVENESS

When considering a strategy for achieving maximum efficiency from a production facility, one of the most important elements to consider is the production equipment. By increasing equipment effectiveness, a facility can increase the throughput and quality of product with less downtime and scrap. Although simply stated, it involves a greater depth of detail. To begin with, it is essential to understand the equipment, and to successfully evaluate the equipment problems.

When investigating equipment effectiveness, most manufacturers begin by evaluating the Overall Equipment Effectiveness (OEE), a quantitative measure of the yield of a machine. The OEE value of the equipment quantifies productivity into three major categories: availability, performance, and quality, taking into consideration the losses encountered within each of those categories.

OEE = Availability * Performance * Quality

To begin an OEE evaluation, an overall assessment of availability, performance and quality, must take place. Then, a more detailed investigation is needed to uncover specific problems and losses encountered in each of theses areas. Next, options must be reviewed to determine a proper course of action to correct the inefficiencies. Finally, a return on investment (ROI) must be calculated to justify the decision.

In general there are three options available to manufacturers looking to increase their OEE. They are:

- Fix the existing machine by implementing basic maintenance corrective actions
- Upgrade the existing equipment with new components
- Purchase new equipment.

Evaluation is essential for making the proper decisions regarding machine effectiveness. It will not only dictate the result of equipment productivity, but also the economic implications for several years to come.

II. EVALUATING OEE

As previously stated, the OEE quantifies productivity into three major categories, availability, performance, and quality.

Machine availability is the most obvious requirement. Without a machine, there is no performance or quality. Questioning why and when the machine is unavailable will help guide the evaluation into a more detailed investigation.

$$\text{Availability} = \frac{(\text{Planned Production Time} - \text{Unplanned Downtime})}{(\text{Planned Production Time})}$$

Machine performance is measured by how fast product is being made. Simply stated, it is the speed at which the machine runs.

$$\text{Performance} = \frac{(\text{Cycle Time} * \text{Number of Products Processed})}{(\text{Production Time})}$$

Producing a quality product is the objective of every manufacturer. Increasing speed and availability of the machine is useless if the final product is scrap.

$$\text{Quality} = \frac{(\text{Number of Products Made} - \text{Number of Products Rejected})}{(\text{Number of Products Made})}$$

The evaluation of all three components - availability, performance and quality - and their interrelation will determine the best solution for increasing the OEE of the machine. The next several sections will take a closer look at each factor, and its associated losses. By understanding the losses, and their impact on the machine, one can gain a clearer picture the overall machine performance.

III. AVAILABILITY LOSSES

In a perfect world, a machine would be available 24/7/365. However, this is only an ideal perspective, from which one can measure true machine availability. There are several real factors that affect availability; some of which are planned, and some unplanned. Planned downtime includes vacation, holidays, and scheduled maintenance. Unplanned downtime includes equipment failures and set-up and adjustments. It is possible to factor in the planned downtime; however it is the losses due to unplanned downtime that can negatively impact machine availability.

Equipment Failure or Breakdown. Equipment failure is a major cause of production downtime. In order to decrease this loss, it is necessary to have an active preventative maintenance program, which will help to diminish any unforeseen failures. This will insure that the machine is evaluated at regular intervals and serviced according to the findings.

Set-ups and Adjustments. Set-ups and adjustments, along with calibration, are needed to prepare the machine for an impending production run. If there is a good deal of product change, the time required to perform these tasks can be quite significant.

IV. PERFORMANCE LOSSES

Machine performance refers to the net production time during which products are produced. The more the machine produces, the greater the OEE. However, speed losses and small stops will inhibit the overall performance. If not recognized and addressed, these losses can cause the machine performance to be less than optimal.

Speed losses. Speed losses are categorized by any situation where the machine is not running at its optimal speed.

Small Stops. Small stops are losses due to short periods of time in which the machine is shut down for minor adjustments such as cleaning.

V. QUALITY LOSSES

If the product coming off a line is not “saleable”, then it is considered scrap, and the entire process has been wasted on product that will never make it to the consumer. It is important not to lose sight of quality when evaluation the OEE. Availability and speed often take a front seat, and quality is left behind. The key to remember is that without a good product, the rest of the operation is a white elephant. In general, quality losses are generated during start-up while the machine is ramping up, during adjustment, or during normal production, as rejected product due to process instabilities.

Losses During Start-up. Losses during start-up are typically attributed to the system ramp up when the process and machine parameters are coming into specification. Unless all of the process parameters are within their tolerance, scrap material is being produced. Such typical parameters are ovens coming up to temperature, the line speed, and tensions stabilizing during and after the ramp up period. The quicker these parameters can be bought into their tolerance band, the less scrap will be produced.

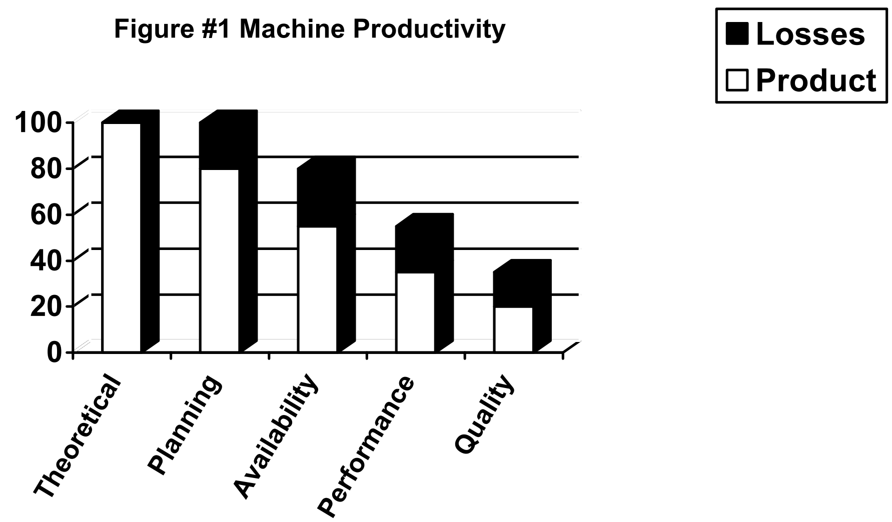
Losses During Production. During production, scrap is sometimes produced predictably, such as a splice going through a machine. Other times it is produced unpredictably, such as a process parameter going out of specification, or a web handling control issue, resulting in a web break.

VI. PRODUCTIVITY IMPROVEMENT OPPORTUNITIES

A thorough assessment of the components and their losses will yield a comprehensive understanding of how the OEE can be increased, ultimately resulting in increased yield. The actual productivity of a machine, P_r, is a value that is derived from equipment OEE * the planned production time (planning factor).

One of the most obvious ways to allow more products to be shipped is through a speed increase. Typically, this is feasible through improvements that are made in the process, through the chemistry, rheology, or other technological improvements. Keeping in mind that many of these advances were not available when the machine was initially installed, there may be many opportunities to increase machine productivity. The machine productivity chart in Figure 1, shows that the value of the theoretical productivity = 100%.

Figure #1 Machine Productivity



In many cases, productivity improvement can be greatly increased by upgrading existing equipment. Typically, the productivity of industrial machinery can be increased by as much as 33% by retrofitting existing rolls and drive trains. However, it is extremely important to note that the mechanical system must also be evaluated to ensure that it is capable of handling the stress incurred by the increased machine speed.

To reiterate, machine availability is effected by losses in equipment failure or breakdown and set- up adjustments. Machine performance is effected by speed losses and small stops. Quality is effected by losses during start up and production. Based upon this understanding, it is now a question of how to increase gains, decrease losses, and improve the overall process of the machine. The following sections will explore how this can be effectively achieved through retrofits.

VII. AVAILABILITY GAINS THROUGH RETROFIT

One variable that can greatly alter the availability calculation is unplanned downtime. It is considered to be the “Black Hole” which is often overlooked. As previously mentioned, this can also be categorized as losses in two major categories, equipment failures and set-up and adjustments. Many times, modifications can be made to existing equipment that can help reduce the amount of losses that affect the availability of a machine, and at the same time be extremely cost effective.

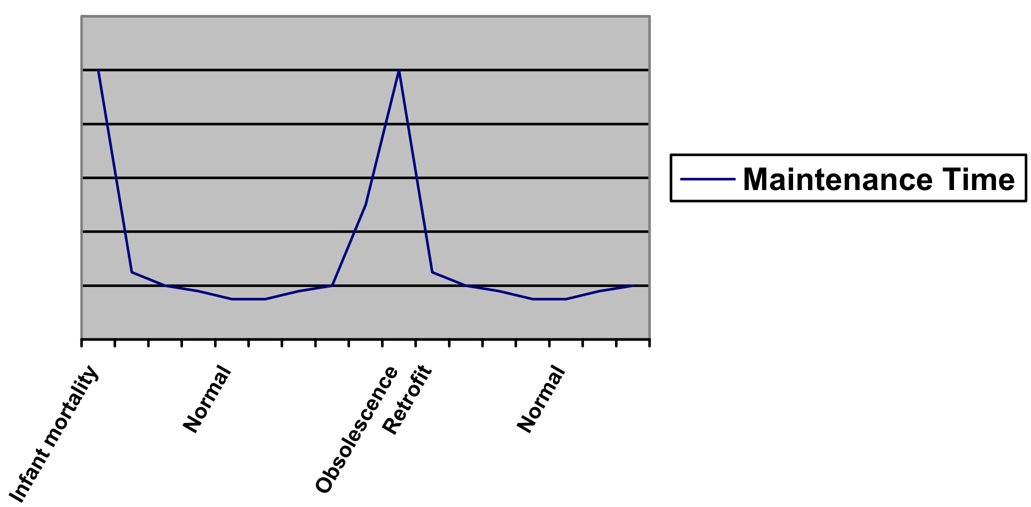
Decreasing Losses Due To Equipment Failures. As equipment gets older, maintenance requirements increase. With most mechanical components, this is not an issue, as a majority are mature technology that does not rapidly change, meaning that spare parts are readily available. However, this is not the case with all machine electronics.

While many sensors (limit switches, thermocouples, etc) are the same mature technology, other more advanced sensors, (ultrasonic sensors, beta gages, etc) are not, and are evolving rapidly. The latter is true of Programmable Logic Controllers (PLC's) and drives. AC drive technology for example, has seen many major manufacturers release new models every 18 months as more advanced technology becomes available. Although this provides capabilities and features that were not possible before, it also creates a challenge with regards to maintaining the equipment.

In the life cycle of equipment, there comes a point where the maintenance of electronic equipment becomes disproportionate, primarily due to obsolescence and the lack of availability of spare parts (Figure 2). According to a Fortune 50 converter, it is expected that in a 45-year average equipment life cycle, there will be 3 major controls retrofits to address obsolescence.

For example, optimization of process parameters can be accomplished through a modern PLC system that will provide a better means of controlling the process. For example: cascade control of dryer air temperatures based on web temperature.

Figure 2 Control System Lifecycle



Decreasing Losses Due To Set-up Adjustments. Set-ups and adjustments, along with calibration, are all part of preparing the machine for an upcoming production run. As indicated earlier, this can be a time consuming task if there are several product changes. Additionally, older electronics can exacerbate this situation by increasing the required change over time. For example, on older analog drive and control systems, there can be great amount of drift that requires constant calibration. In addition, limitations due to the lack of availability of multiple or down 'loadable' parameter sets, will limit the tuning flexibility of the drive.

The set-up and adjustment time can be significantly reduced through the use of automation that can be retrofitted to many older lines. Controllers such as digital drives, tension controllers, and temperature controllers require less calibration due to drifting issues, and are able to handle a higher range of products. Furthermore, Supervisory Control Data and Acquisition (SCADA) systems, have a recipe-based structure, which will allow the machine parameters to be downloaded prior to the next production run. The recipe eliminates the time required for a point-by-point set-up and can simply be acknowledged from a single point of entry at the appropriate time. Due to the accuracy of a computer controlled recipe set-up, the line will not be as likely to generate waste as a result of improper set points.

Through automation, changeover time can also be drastically reduced. For example, changing the machine configuration for multiple web paths can easily be automated, further reducing losses and increasing the availability of the machine.

VIII. PERFORMANCE GAINS THROUGH RETROFIT

Machine performance is directly dependent upon speed losses. This categorizes any situation where the machine is not running at its optimal speed. Although some circumstances may be understood at the time of equipment purchase, and are a conscious decision, others are due to incorrect machine operation. Both conditions merit examination for improvement.

Decreasing Speed Losses. Sometimes process or product requirements may be the factor limiting machine speed. In the web converting industry, and example of this is having a heavy coatweight without enough dryer capacity to run at full speed. This situation may be a direct result of budgetary constraints during the initial purchase. However, it is now worth reassessing. Consider the following:

- Are the assumptions still valid?
- Has the cost of the equipment decreased?
- Is there any new technology that can be used to accomplish the same thing?

It may be discovered that assumptions made during the original decision making process are no longer valid, making it economically worthwhile to retrofit additional equipment to achieve maximum speed.

Decreasing Short Stops. In another circumstance the equipment may not be allowed to run at full speed due to the requirement to slow down or stop to make a splice. More than likely, this machine feature may have operated properly after the machine was handed over, but over time machine performance had deteriorated, raising a myriad of questions, such as:

- Are there parts broken or misadjusted?
- Are the procedures being followed?
- Was the original system not robust enough?
- Did the original design allow for enough latitude?

In any of these cases, the situation is causing lost potential revenue, and needs to be rectified.

Considering these dilemmas, there are many solutions that have proven successful in the web conveyance industry through the implementation of retrofits and upgrades. The results and benefits, are as follows:

- Unwind Splicing Reliability. By converting the splice control from a traditional lap splicer to a predictive unit, the tail length can be minimized. This provides a better splice that can be conveyed through the machine more reliably.
- Unwind/Rewind Diameter Control. One of the most troublesome components in a legacy drive system is reliable diameter calculation. This is due to processor speeds or limitations in the systems firmware. This leads to instabilities ultimately increasing the occurrence of web breaks or missed splices. A new system, using a digital drive, performs this calculation at the drive level eliminating the problems associated with poor diameter calculation.
- Automated Features. Once the entire line is under the control of a single system, higher automation features become possible. For example, automatic nip jumping to allow splices to pass through the line, or sequential line thread with tension loop enabling to allow the line to produce with increased yield.
- Human Machine Interface (HMI). Through the effective use of strategically or centrally placed HMI's, machine functionality can be improved significantly. Centralized control improves the overall efficiency of machine operation. An additional benefit is the centralization of all process data relevant to production. This data can then be passed to the plant wide information systems. Even if the Manufacturing Enterprise System (MES) system is not computerized, a well structured process control system can accept and process this type of information if it is input manually.

IX. QUALITY GAINS THROUGH RETROFIT

Quality losses occur when product coming off the machine is not deemed as saleable product.

Losses during start-up. As previously discussed, losses during start-up are typically attributed to the system ramp up where the machine parameters come into specification. The quicker these parameters can be brought into their tolerance band, the less scrap will be produced. Here, retrofitting a machine with an updated control system can have very positive results. Following are some examples:

- Increased Drive Stability. Advanced DC and AC drives have the capability to perform the necessary calculations for outer loop, such as tension control. In addition, they can digitally control the outer loop at the power converter level. This provides the line with a more responsive system that can accommodate a wider range of substrate and dynamic conditions.

- Other Digital Controls. The use of digital controllers for temperature and pressure loops will greatly enhance the reliability and predictability of a system. They also provide wider latitude to handle many substrates without changing parameters and allow the system to stabilize faster due to the many advanced control algorithms. The outcome is faster process parameter stabilization.

Rejects during production. It is understood that scrap is a result of both predictable and unpredictable events. Whatever the case, each of these situations can be handled effectively by retrofitting the equipment with the proper systems.

To help reduce predictable scrap, it is important to minimize both the occurrence and the effect of the disturbance. Consider a typical unwind scenario. Mounting larger rolls and leaving less material on the core would have an overall positive effect by eliminating the number of splices required during a production run. This would generally involve at least a drive upgrade, and possibly a new unwind to handle the larger rolls. A well designed unwind will also control the tail length of the splice, minimizing the possibility that a long tail will get caught as it is transported through the process. This reduces the chance of web breaks, reducing the likelihood of unpredictable scrap.

Many times unpredictable scrap is not as apparent as a web break. It may be a dryer temperature that is out of specification, causing a curing problem that is not found until the QC lab checks the roll, or worse yet, when a customer has an issue with the product. To reduce this type of scrap, an aggressive program must be put into place to constantly monitor the parameters of the equipment. This can be accomplished through retrofitting the equipment with proper sensors and control systems to monitor the process parameters.

In the web conveyance industry, as in many industries, these upgrades can correct quality deficiencies by implementing the following procedures:

- Fault Detection. Using the advanced fault finding capabilities that are part of most modern controllers, the up time of a line can be extended. Faults, such as web tension instabilities, are more readily identified. In addition, parts can be replaced before the fault becomes a critical ‘show stopper’ enabling the line to run longer.
- Consistent Process Setpoints. For the product to run correctly, the machine parameters must be set to the proper value for the production run. Although this seems like an obvious statement, it is actually difficult to achieve consistently since there may be dozens, if not hundreds of parameters on the machine that must be set. If they are manually set, there is a good probability of human error. There is also a level of subjectivity that is introduced where one operator or shift likes to run the machine one way versus another shift or operator. This leads to different quality products from shift to shift. An automated solution would be to use a computerized recipe set-up. By using a computerized recipe download, the machine parameters are correctly and consistently downloaded to the machine, providing for uniform product quality settings.

- Web Efficiency. A customer who uses flying splice equipment understands the value of minimizing material left on a core after splice over. A process control upgrade to implement auto splice as a function of diameter can drastically minimize the wasted web.
- Coating Control. By adding a coating thickness gauge/monitor to the process control system the process line can then be operated in a closed loop fashion.
- Labor Optimization. As a result of automation, operator involvement can be minimized in certain areas that have traditionally required a great amount operator interface. Auto splice and alarms generated from the main SCADA computer reduce the need for operators to stand by the line and monitor its status.

X. RETROFIT ROI – COST VS. DOWNTIME

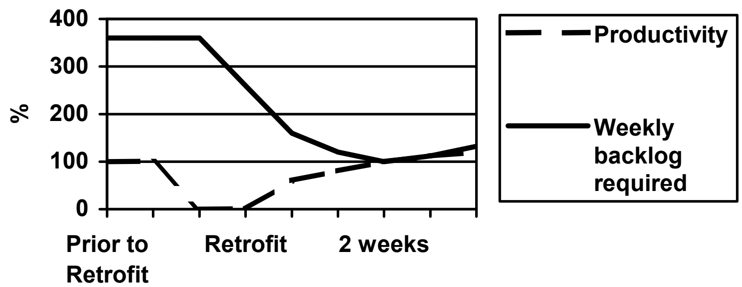
Once a successful retrofit project is identified, a ROI calculation must be made to verify the financial soundness of the project. One of major factors to consider is the trade-off between the costs of the retrofit versus the amount of time that the process will be down. A retrofit project can be designed to either minimize the initial out of pocket cost, or minimize the amount of time the equipment is down.

In order to minimize the capital expense, it may make sense to maximize the use of the original equipment. For example, on a drives retrofit it is not uncommon to reuse old components like the cabinet, sub-panel, and circuit breaker. In performing the retrofit, the line can be brought down, the existing cabinets gutted, the 'good' components remounted with the new drives, and all of the components rewired. This is a very economical solution in terms of capital investment; however, it is accomplished at the expense of production.

If the production line is producing a high value added product, or if downtime is just unacceptably long using the above process, the retrofit may be designed to minimize downtime. In this scenario, new drive cabinets are manufactured with new sub-panel and new circuit breakers, even if the old ones are usable. If space permits, the new drive panels are located on the machine while the process is still running with the old drive system. All new wiring is pulled in new cable trays or other raceways to the point of termination. It is possible for the new control system to be partially commissioned and debugged prior to bringing down the old system. At the point of cut over, the motors are connected to the new drives, start-up is completed, and the process is in production mode in a minimum amount of time. The capital expense of this method is certainly more costly, however, the line is up and running profitable material with minimal downtime.

As indicated earlier, tradeoffs always exist when making any decision to upgrade existing equipment. Downtime is one of the a major considerations, as it will not only impact the amount of lost potential profit, but will also affects product backlog to meet customer demand during that time period. This is compounded by the fact that on a typical rebuild project, there is a short period of time, right after the machine goes back into production, in which it is less productive than prior to machine retrofit. This is largely attributed to the initial learning curve of both maintenance and operation personnel. In many cases the equipment, albeit mechanically the same, is a new design and requires training. Figure 3 shows that a retrofit that takes the machine down for two weeks will typically require about 3½ weeks of backlog to meet customer demand. Again this is a very key issue that must be considered when planning a retrofit project, and deciding between downtime vs. cost.

Figure 3 Typical Retrofit Productivity



XI. THE WHO WHAT AND WHEN OF RETROFITTING

Once the decision has been made to increase yield improvements through process control improvements, selecting partners is extremely important. These partners will be a major contributor to the success or failure of the project. Their skill, knowledge and competency will greatly impact the final results. Therefore, deciding WHO is best suited for the task, WHAT will be accomplished and WHEN it will happen are very vital questions.

It is most essential to stress the importance of having a detailed specification prior to making any decisions regarding upgrading or replacement of equipment. An engineer or consultant who has expertise in the industry can develop this document, and provide valuable insights.

Who. Once a specification has been developed it is best to chose a partner who is experienced in the industry. This is either a systems integrator who specializes in the industry, or, if the line requires major mechanical work, a process equipment OEM who has additional mechanical expertise and process capabilities that will manage the controls portion. In either case, the project can and should be handled on a turnkey basis to prevent any oversight resulting in budget problems.

What. There are many possibilities to examine when improving yield through process controls on existing equipment. Several strategic areas will typically return the most yield for the investment.

- Drives. Typically this is the first component users will improve for increased throughput and higher reliability. Modern digital drives are relatively easy to retrofit to existing machinery, assuming the mechanical equipment can handle it.

- Programmable Logic Controllers. PLC’s are great for retrofitting old high maintenance relay panels and early proprietary controllers. They can be used to replace and integrate many single controller functions, like temperature controllers, into one unit.
- Operator Panels. Operator Interface or Human Machine Interface is a prime rebuild improvement that increases reliability and reduces operator error. An ergonomically designed operator panel will not only make the line more intuitive to run, but will often times regain valuable factory real estate.
- SCADA. SCADA systems, in most retrofits, are considered an add on component that improves the understanding of process. The addition of these systems can be an invaluable tool for averting production of scrap and troubleshooting problems.

When. There are many factors involved in evaluating the benefits of implementing a process control upgrade. It is important to keep in mind that certain lines are more suited to these improvements than others. The following criteria should be closely examined before proceeding with a retrofit plan:

- Line Longevity. When evaluating an older line, a retrofit may become cost prohibitive. Attempting to reengineer the drive train and instrumentation with modern controls may be too expensive.
- Performance Criteria. If the line requires higher performance due to process requirements, production, quality or other critical business purpose, a retrofit may or may not be the right solution
- New Line Inefficiencies. If the line in question is relatively new and is not meeting performance expectations, it may be feasible to improve yield through improved process controls.

XII. CONCLUSION

When trying to improve Overall Equipment Efficiency (OEE), process controls upgrades on existing equipment should seriously be considered.

Many older lines are mechanically sound and their yield could be substantially improved by upgrading the process controls. This upgrade could increase throughput, save resources, improve quality, and/or improve the lines reliability.