Implementation of Lean Manufacturing in a Coating and Laminating Operation

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Introduction

Lean manufacturing is not a new concept, but often a poorly implemented one. Many production managers are tasked by their upper management to implement lean manufacturing with little idea what this task entails. Sometimes with only a course or two under their belt.

The lean manufacturing concept is often referred to as the "Toyota Production System" or (TPS). While companies like Toyota and individuals such as Taiichi Ohno are often credited with the invention of lean manufacturing concepts, I believe that the original lean manufacturing concepts pre-date Toyota's implementation and should really be credited to early manufacturers in the U.S., such as Ford. Someone once asked Taiichi Ohno of Toyota, the TPS creator, what inspired his thinking ? He responded that he learned it all from Mr. Ford's book.

Typical film converting operations have been around much longer than the recent interest in the implementation of lean manufacturing, but many operations are loathe to implement such a concept. Often bits and pieces of the concept are employed with little benefit. In order to achieve significant gains in areas such as cost/scrap reduction and factory efficiency, one must take a wider scale approach to implementing lean manufacturing.

This paper describes the application of lean manufacturing to a coating and laminating environment, specifically a window film production operation. This application applies to any multi-ply, multi-pass converting operation. The approach is unique, and a ground up approach was employed.

Methodology

Most mature converting operations tend to increase capacity by increasing line speed, or adding duplicate machines that match their current coating and laminating equipment. While this can increase capacity in the short term, it does nothing to improve efficiencies or reduce costs or waste. Adding duplicate equipment can significantly increase fixed costs due to the large capital investments for typical converting lines. Adding manufacturing capacity while reducing the inherent waste in the manufacturing process should be equal priorities.

A lean manufacturing approach can yield significant cost savings and throughput, while making the total manufacturing operation much more efficient. It is important to note that many companies do not have the facility space or are not willing to risk the capital investment with a new ground up approach to lean manufacturing.

A classic implementation of lean manufacturing attempts to reduce waste in the process. The most common wastes are as follows:

- Overproduction
- Waiting
- Transportation / Motion
- Inventory
- Excess Processing
- Defects

Overproduction can be defined as "production ahead of demand," or excess of supply over demand. This can be caused by poor forecasting, push vs pull production methodology, production processing and scheduling limitations, and unknown or variable process yields.

Some converting operations have limitations on how production lines can be scheduled, and try to limit changeovers. For example if a converter has one or two production lines and must run 3 or 4 passes through the production lines in order to complete the product, then the production line must first run a certain volume of work-in-process (WIP) and store it for the next process pass while changing over the equipment to complete the next process pass.

Unknown or variable yields at the final processing step can create product shortages due to lower than anticipated yields. Over time production managers tend to err on the conservative side in order to make the order or shipment and not fall short. This causes them to schedule and produce excess material, "just in case".

Push vs. Pull production and poor forecasting create the same over-production waste. Anticipating demand based on past orders received, and long term forecasts creates waste. Demand driven manufacturing reduces wastes by limiting overproduction. While Demand driven manufacturing is ideal from a inventory management perspective, it is difficult to implement unless lead times can be significantly reduced.

Waiting can be defined as "waiting for the next production step" or time spent not adding value. One of the best ways to identify this waste is to map out the current state value stream. The value stream is simply a flow chart that illustrates the entire production process, including process steps, idle time and lead times. The map is usually one page and shows the entire flow from order receipt to final delivery. Evaluation of this map leads to potential approaches to streamline the process. Typical waiting losses are incurred at the end of each process step, due to change-overs, production equipment scheduling limitations, or line speed miss-matches. Some value stream maps will quickly illustrate that most of the lead time in your production flow is due to waiting for the next process step, or process pass.

Transportation can be defined as "moving products when not adding value". If your production process includes multiple passes through a number of different machines you will waste a lot of time moving product from one production area the next, or moving product into and out of production to warehouse locations from storage. This can be caused by poor facility lay-out, multiple independent process passes and multiple manufacturing facilities at different locations.

U-shaped production flow is very important to reducing excess transportation. Ideally raw material should enter at one end and finished product ready for delivery at the other end of the U. Materials should ideally be handled once. WIP rolls are not moved into and out of storage racks a number of times.

Inventory can be defined as "all components, WIP and Finished Goods (FG) not being processed". The creation of Work in Process or WIP, is one of the largest contributors of inventory waste. It is product you can't sell, it commits raw material, and takes up storage space in your facility. In some cases finished goods are not in their final form, and still have one more conversion step, before they can be shipped or released for sale.

Once created, the raw materials used are gone, and can not be reassigned to more pressing deliveries. This reduces operations flexibility to respond to higher priority orders when raw materials are in short supply. If manufacturing errors or defects are created during WIP production it may remain undetected until too late in the process to be able to meet delivery dates. This is one form of hidden scrap.

Excess Processing can be defined by "poor equipment design that creates excess activity." The converting process is full of waste caused by excess processing. This can be as simple as not integrating processes but running serial processes on specific, limited functionality equipment. Winding and rewinding large rolls of film is excess processing that creates waste with every start-up and with losses at the end of the roll or core due to damaged goods.

By creating equipment that can combine multiple processes into one or two steps, a significant amount of waste can be reduced. You will always know what you have in terms of quality at the end of the line. You see it in its final form. You are not creating large rolls of WIP or FG that can create large hidden yield losses when finally inspected and converted to a product for sale.

Defects can be defined as "the time, material losses, and effort spent inspecting for and fixing defects". Multiple inspections of product as it goes through multiple manufacturing steps creates waste due to the time and effort spent reinspecting the same product. If you wait to inspect the product when it is complete, the material has reached its highest value due to all the processing that has taken place. You will now scrap the material at its highest value. Some converting operations incur the highest yield losses at this step.

Inspecting the product as it runs allows you to make corrections on the fly to reduce losses. Winding large rolls of film then sending it off for inspection is a waste of time, effort and money. The material may have been 1st quality before winding it on the core, but due to winding errors such as a bad core start, incorrect tensions or tension taper, winding defects are produced that create waste and scrap. Films tend to be intolerant to winding errors which can quickly become the largest contributor to the scrap losses.

Mistake proofing machines and product designs reduces operator errors when making product. Operators should be enabled to take ownership of their process and provide their own self inspection. Who is more equipped to inspect the film than the person who knows the materials inside and out ?

Results

We took a ground up approach to designing a lean manufacturing facility to produce window film. This enabled us to design the equipment to optimize the process, and layout the facility to optimize production flows.

Typical window film manufacturers use multiple coating lines (2 or more) and cascade the WIP rolls through the different machines running unique processes in order to minimize change-overs. Other manufacturers with limited capital investment rely on one machine to perform all the required processes. They will typically run a number of large WIP rolls through a process before stopping, cleaning up, and changing over to a new process and re-running the same WIP rolls through the machine again to add the next process step to the material. This creates large amounts of WIP rolls, start-up & end-of-roll scrap, and can create hidden defects in the film.

Each WIP roll is approx. 10,000 – 20,000 ft long. Three to four unique process passes are required for typical window film production. Each process pass can be run on either the same equipment after a change-over, or different machines. For example: the first process may be a film lamination of two discrete films, followed by a second process on a different machine that applies and cures the scratch resistant hard-coat, followed by a third process on a different machine that applies the pressure sensitive adhesive and laminates silicone coated PET liner or protective layer. The fourth and final step is to unwind, trim the edges, and inspect and cut down a large roll of material, generally 8,000 – 10,000 ft long. During the inspection process the final 100 ft long roll for sale is produced for the customer.

This long repetitive process creates large amounts of waste, a longer than required lead time for the product, and variable production yields.

If you could combine these processes into one continuous process, then huge cost savings, and lead time reductions could be realized. By eliminating several of these process steps, end of roll wastes can be eliminated each time the roll is wound then unwound. The uncertainty of film tensions, and film shrinkage between process passes, which cause excessive film curl is eliminated. The uncertainty of what the film quality will be when the product is complete, is reduced significantly.

Digital cameras should be used to grade the film and alert the operators of any defects or 2nd quality material. The film inspection should be done in real time as the material is made. In order to reduce scrap any corrections to web tension, and/or coating head settings, can be made on the fly. This method of inspection eliminates post production inspection at slitting / rewinding. The digital camera uses a rule based system to determine quality, not 10 - 30 individual inspectors with their own interpretation of the quality standards.

The lean manufacturing process required a very unique manufacturing line. One that had not been built before for this industry. The equipment was designed to contain the following capabilities:

- Dual position unwinds with flying splice capabilities
- Multiple coating stations capable of applying from 1 to 25 microns of dry coating
- Lamination stations
- On-line digital inspection stations
- Slitting station for edge trim and center cuts
- Rewinder capable of continually rewinding 100' roll on 3” dia. cores.

The overall facility layout was designed to produce a U-shaped production path:

1) Raw materials enter the production facility at one end of the building are received, and go into a warehouse location.
2) Raw materials are moved to production.
3) All processes are performed on the product and rolls ready for sale leave the production area at the other end of the building.
4) Finished product is staged in pallets at the end of the production line.
5) Completed pallets are moved to a warehouse location.
6) Completed pallets or roll orders are pulled from the warehouse and shipped.

Inventory Reduction:

There are no WIP rolls created during manufacturing, and raw materials are typically not returned to the warehouse from the production area, but consumed entirely. WIP rolls can take up large amounts of warehouse space and can contain hidden defects. If you can design a process to eliminate WIP, you have already saved a significant amount of money in inventory reduction, and eliminated the scrap created by this process.

Yield Improvements:

If you look at a hypothetical factory yield calculation for a window film facility you will see the following:

Current State of Four Process Pass Window Film Manufacturing

	Pass #1	Pass #2	Pass #3	Pass #4	Final Yield
Average Process Yields / pass	0.95	0.95	0.95	0.85	0.73
Material Value	0.20/sq ft	0.25/sq ft	0.30 /sq ft	0.32/sq ft	
$ loss per 10,000 ft roll /pass	$500.00	$594.00	$677.00	$2,058.00	$3,828.00

While the use of tandem coaters is nearly universal in window film production, it does little to reduce the overall process scrap. Typical scrap reductions are 12% - 15% vs a 75% - 85% reduction with a lean manufacturing approach.

Three Process Pass (tandem coater) Window Film Manufacturing

Manufacturing Approach	**Yield Pass #1**	**Yield Pass #2**	**Yield Pass #3**	**Yield Pass #4**	**Final**
Lean Process Yields / pass	0.95	N/A	0.95	0.85	0.78
Material Value	0.20/sq ft	N/A	0.30/sq ft	0.32/sq ft	
$ loss per 10,000 ft roll	$500.00	N/A	$713.00	$2,166.00	$3,379.00

Lean Window Film Manufacturing

Manufacturing Approach	**Yield Pass #1**	**Yield Pass #2**	**Yield Pass #3**	**Yield Pass #4**	**Final**
Lean Process Yields / pass	0.95	N/A	N/A	N/A	0.95
Material Value	0.32/sq ft	N/A	N/A	N/A	$0.32
$ loss per 10,000 ft roll	$800.00	N/A	N/A	N/A	$800.00

There are actually several fiscal benefits to the new lean manufacturing approach:

1) Scrap reduction per roll cost savings.
2) Increased sales revenue per roll from material that would have been scrap.

If you look at a theoretical production rate of 8-10 master rolls per day, and a range of yield improvements, you see the following fiscal benefit:

Fiscal Benefits of Lean Manufacturing

Manufacturing Approach	Scrap Reduction / 10,000 ft roll	Extra Sales Revenue/ 10,000 ft roll	Total Daily Benefit
Current State – 4 pass	$0.00	$0.00	$0.00
Tandem Coater – 3 pass	~$ 400 - $ 500	$ 600 - $1,000	$ 1,000 – $ 1500
Lean Manufacturing – 1 Pass	~$ 2,000 - $ 3,000	$ 4,500 - $7,500	$ 6,500 – $ 10,000

Other tangible cost savings are:

1) Cost to carry excess WIP and FG Inventory
2) Reduced machine time cost in the finished product
3) Excess Capital investment and depreciation in duplicate manufacturing equipment.
4) Reduction in Labor costs
5) Reduction in square footage occupied by equipment and personnel
6) Reduction in operation/ utility costs / chemical usage

Throughput:

Current manufactures of window film utilize several coating and laminating production lines, and an array of individually manned slitter/rewinders in order to produce their product for sale. The throughput of the factory is often limited by the slitting and rewinding operation. This is due to generally lower line speeds, but is compensated by employing a larger number of slitters and operators.

If you look at throughput of a factory that utilizes a number of process passes to create the final product, the throughput is a function of the process pass speeds and the number of passes required to complete the product. Looking only at coating and laminating throughput without respect to slitting throughput you find the following three hypothetical cases:

Manufacturing Approaches	No. Coating Lines	Pass No. 1	Pass No. 2	Pass No. 3	24 hr Throughput	Number of Machine Minutes per roll*
Typical Operations	3 coating lines	80	100	150	~ 1200 rolls – slitting losses	~ 3 min + Slitting Time

Manufacturing Approaches	No. Coating Lines	Pass No. 1	Pass No. 2	Pass No. 3	24 hr Throughput	Number of Machine Minutes per roll*
Tandem Coater Operation	2 coating lines	80	150	N/A	~2000 rolls - slitting losses	~ 2 min + Slitting Time
Lean Manufacturing Operation	1 coating line	150	N/A	N/A	~2000 rolls	~ 0.7 min Complete

*Note: Bear in mind that the typical 4 pass manufacturing operation and the tandem coater 3 pass operation have one more pass to go and that is the slitting operation. This will reduce their overall throughput due to slitting yield loses.

Lead Time Reduction:

Multi-pass coating and laminating operations will have production scheduling issues due to process changeovers and the different set-ups required to manufacture the product. This all effects product lead time. If you have to run a single process pass, and either move the material to another line or park the material as WIP in the warehouse, you create long lead times for your material. With a lean manufacturing approach you can utilize a demand or pull production method. Finished products ready for sale come off the production line. If an order requires 134 rolls, you make 134 rolls. No need for overproduction or guessing what the yield loss will be. The warehouse finished goods inventory levels can be kept at minimum reorder points. With Just in time (JIT) raw material inventory, new product can be made and shipped in less than 8 hrs time.

Conclusion:

While there is no one way or perfect way do do things, optimized processes will generally outperform those that are not. Take a hard look at your internal manufacturing processes. Have you made any significant yield improvements in the last view years ? Have you reduced your lead times ? Are your operating costs continuing to spiral upward ? With raw material costs continually rising, yield improvements go a long way toward reducing manufacturing costs, and maintaining a competitive edge in the world market.

The tried and true mentality of always doing it the same way will make a company uncompetitive very quickly. Frankly you will be left behind, while others innovate. There are off shore manufacturers who want to take the US converting business. In order to remain competitive we must think outside the box, try new ideas, and always embrace lean manufacturing concepts.

I found several; appropriate quotes that pertain to this subject, one from Henry Towne, the past President of the ASME.

"We are justly proud of the high wage rates which prevail throughout our country, and jealous of any interference with them by the products of the cheaper labor of other countries. To maintain this condition, to strengthen our control of home markets, and above all, to broaden our opportunities in foreign markets where we must compete with the products of the other industrial nations, we should welcome and encourage every influence tending to increase the efficiency of our productive processes."

What is interesting about this quote is, it was written in 1911, and is just as appropriate today as it was when it was written.

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