DEFINITION AND IMPLEMENTATION OF A VISUAL INVENTORY MANAGEMENT SYSTEM

by

Michael A. Kimber

B.S. Mechanical Engineering, Union College, 1993

Submitted to the Sloan School of Management and the
Department of Mechanical Engineering in partial fulfillment of the
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and
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ABSTRACT

Companies today often look to improved inventory management as a means to lower costs and increase their ability to consistently meet customer needs. Research was conducted at Alcoa (Shanghai) Aluminum Products Co., Ltd. (ASAP) in Shanghai, China to determine a framework that might be used to define and implement a visual inventory management system in a foil mill. The framework proposed is founded on 1) understanding the current material and information flows and developing reasons why inventory exists, 2) consolidating rolling and annealing schedules, identifying key specifications, determining necessary inventory levels, and defining a pull system, and 3) creating an environment where people are included in the change process and educated in the principles upon which the visual inventory management system is based.

The framework proposed enabled a pull production system to be implemented at ASAP in the cast shop and rolling area in approximately 6 months. It is anticipated that total WIP and finished goods inventory levels will be decreased from 2000T to 1600T, average coil manufacturing time will be reduced from approximately 19 days to 15.5 days, and delivery performance will be improved.

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Finally, I would like to thank my family and Julie for always believing in me.

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1. Introduction

The research supporting this thesis was conducted at Alcoa (Shanghai) Aluminum Products Co., Ltd. (ASAP) from June 1998 through January of 1999. ASAP was a joint venture established in May 1995 between Alcoa Inc. and Shanghai Light Industry, located southwest of Shanghai, China. The facility produced thin gauge aluminum foil ranging in thickness from 6μ – 400μ. Varying widths and several alloys were offered. Major product applications included food packaging, pharmaceutical packaging, adhesive tape, decorative sheet, fin stock, and cigarette packaging. Customers were domestic and varied in size from large state enterprises to single person operations. Customers ordered bare foil defined by its final gauge, alloy, width, and temper. Almost 1000 finished goods specifications had been established. Coils shipped to customers were referred to as "baby coils" and were derived from larger "parent coils" (baby coils are slit from the parent coils).

Figure 1: Entrance to ASAP

At the time of the research, the plant employed approximately 370 people, including three expatriates. The workforce was diverse, being comprised of farmers and local residents having little education, high school graduates with technical training, and university graduates.

ASAP had casting, rolling, annealing, trimming, and packaging capabilities. Several simplified paths that the product followed are shown in Figure 2.

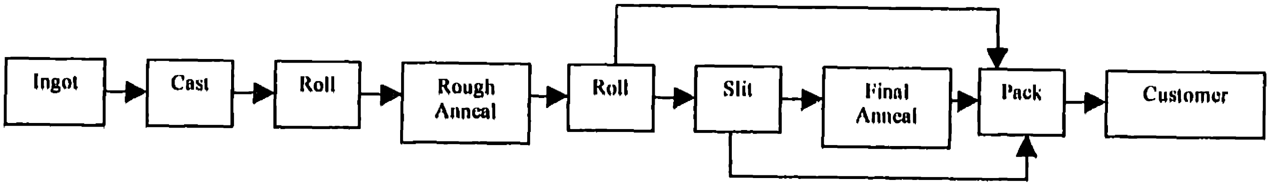


Figure 2: Simplified material flow paths

ASAP faced intense competition within the Chinese market. This was largely driven by a foil capacity surplus among domestic suppliers. As such, ASAP had to position itself to become the natural choice for its customers. To do so, ASAP had to be able to provide timely response to extremely variable demand, at the lowest cost, and with the highest quality. However, ASAP had been unable to meet customer request dates, promising delivery on average 2 days after the original request date (at times 1-2 weeks after the request date). Furthermore, finished goods inventory averaged 600-800T, or almost 18 days of material. Some of the material in the finished goods warehouse was over 1 year old. ASAP found it difficult to respond quickly to customer requirements. Sales forecasts were unreliable. Planning was extremely difficult and required manual management to continually push aside the current schedule in order to meet unforeseen orders. Material flows were extremely complex as coils were assigned and reassigned rolling and annealing schedules. Work in process (WIP) levels averaged one month of material. Almost 20 days were required between casting and packing a coil. Customers gave a mean lead-time of 11 days. In short, a complex material management system that maintained high levels of WIP existed and this system was not capable of providing the flexibility that would ensure consistently meeting demand.

The research conducted at ASAP focused primarily upon the casting, rolling, and rough annealing processes (upstream processes). The resulting thesis proposes that a pull system utilizing a kanban methodology can improve delivery performance and reduce WIP levels and finished goods inventory. The thesis also establishes a framework to implement a visual inventory management system. The elements of that framework are:

1) To describe the current condition and develop reasons why inventory exists.
2) To create the ideal state based on the understanding of the current condition. This ideal state includes
    - redefining and consolidating rolling and annealing process schedules
    - identifying key specifications of in process material

- establishing levels for those specifications using a derivative of the base stock inventory model
- utilizing a pull system design for material flow and scheduling.

3) To provide hands-on education in an environment that works to include people.

While discussing each of these components of the framework, the thesis will offer insights regarding the realities of affecting change both in a manufacturing setting and in the People's Republic of China. It is anticipated that the framework posed will be useful in other environments that utilize similar processes.

Organizational Structure

Alcoa Shanghai's organizational structure was functional. Managers from environment, health and safety (EHS), human resources, purchasing, Alcoa Business System (ABS), manufacturing, customer & supplier relations, quality, finance, engineering, and sales and marketing departments reported to the general manager.

The manufacturing organization included the cast shop, foil shop, maintenance, process development department and planning department – each with its own manager. The foil shop was further separated into the rolling area and the finishing area. Each area had its own supervisor and shifts were coordinated by a lead operator. The cast shop also had a supervisor responsible for daily operations and foremen who had responsibility for their respective shift.

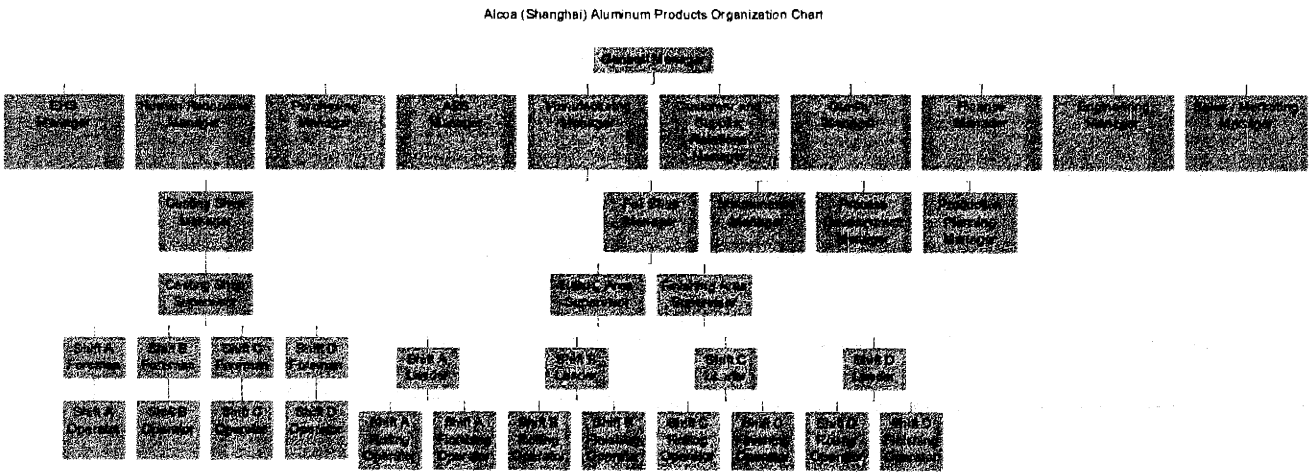


Figure 3: ASAP Organizational Chart

The plant operated seven days a week, 24 hours a day. Operators worked on one of four rotating shifts. A simplified organization chart is shown in Figure 3.

1. The Current Condition

The current condition is a description of the situation that a manufacturer faces today (Alcoa, 1998). It is a snapshot of processes, material, information, people, relationships, systems, customers, and suppliers. It is a snapshot that describes their interactions. It is something that should be understood well and made visible. It is helpful to draw the current condition so that it can be easily communicated and accepted by all employees. While there are no formal guidelines that dictate what should be included in a current condition description, it is helpful to think about those things that would most clearly illustrate a need for change.

1.1 Alcoa Shanghai's Current Condition

1.1.1 Current Condition Diagram

The current condition diagram is a pictorial summary of the information and images that have been collected in trying to understand the current condition. The current condition diagram at Alcoa Shanghai included material flows, information flows, WIP, and finished goods inventory levels (both an average over a six month horizon and a snapshot of those levels that existed on a single day), cycle times, and shop layout. It was intentionally confusing to emphasize the complexity of the current condition. Verbal phrases were included to help describe ASAP's current situation. It was as important to highlight both what was done well and points for improvement and change. It is also important to recognize that the diagram should be very personal to each unique situation and it should be used to help communicate some of the reasons why change is necessary. A diagram alone is useless unless it is taught, contemplated, and hopefully related to by the employees. Figure 4 defines the symbols used in the current condition diagram. Figure 5 is the current condition diagram at ASAP as of September 15, 1998.

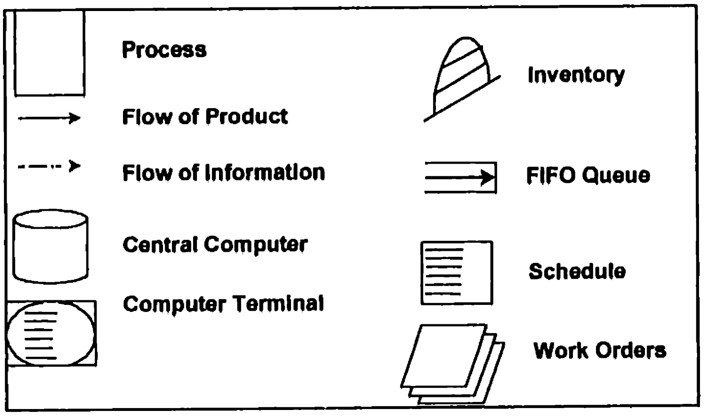


Figure 4: Legend of symbols used in the current condition diagram (Alcoa, 1998)

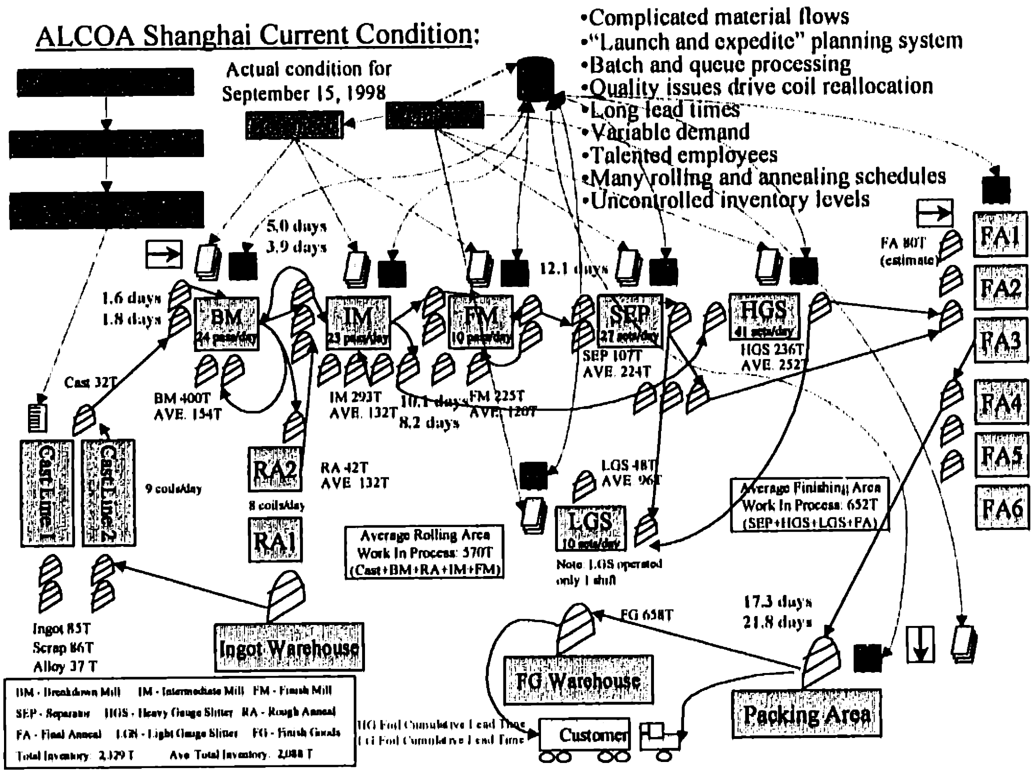


Figure 5: ASAP's current condition diagram

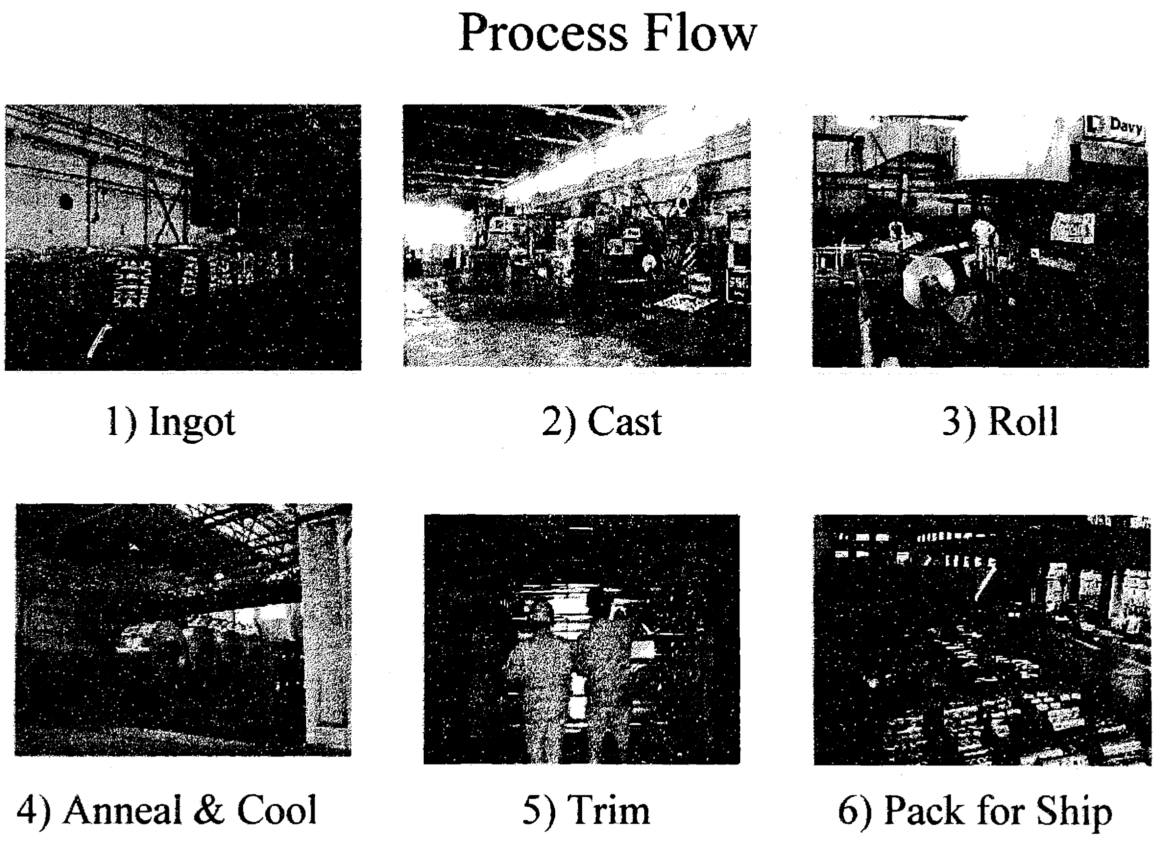
Figure 5 illustrates the material flow from the ingot warehouse through the finished goods warehouse and ultimately to the customer. Solid arrows indicate the possible direction of material flow. Note that there is both forward and "backward motion". Tombstone symbols are representative of WIP (parent coils or baby coils on storage racks) and finished goods inventory levels (packaged baby coils) and the levels are quantified for each process. For example, the breakdown mill (BM) on average had 154T (approximately 20 parent coils) of WIP. On September 15, 1998, the BM WIP was 400T. Total inventory levels for the shop were 2,088T and 2,329T for average and September 15, 1998 levels, respectively. Cumulative cycle times are shown. For example, those coils in process after the finish mill (FM) were cast approximately 12 days prior.

Information flows are also shown on the diagram and are represented by a dashed (dotted) line. From the diagram, it is shown that the daily cast shop schedule was derived ultimately from the 1998 Monthly Revised Operating Plan and work orders for the BM, intermediate mill (IM), and FM were obtained from unallocated orders in the Foil Business System database.

Information flows and material flows will be described in further detail.

1.1.2 Material Flows

Figure 6 illustrates the processes utilized at ASAP to make thin gauge foil.



1) Ingot
2) Cast
3) Roll
4) Anneal & Cool
5) Trim
6) Pack for Ship

Figure 6: ASAP's process flow

In the cast shop, pure aluminum ingot obtained from a local supplier was loaded into a melting furnace and flowed into a holding furnace. The material was alloyed and cast into a 6 x 1320mm to 6 x 1560mm sheet that was coiled. The coil was removed when its weight reached 8-9T and was cooled for approximately 24 hours.

The rolling area of the foil shop reduced the thickness of the coil through a series of passes on as many as three successive rolling mills. The breakdown mill (BM) was capable of reducing foil from 6 to 0.180mm. The intermediate mill (IM) handled foil between 0.270 to 0.022mm. Finally the finish mill (FM) could reduce foil from 0.032 to 0.006mm. With each pass, a new product specification was created. The coil's thickness, length, and perhaps width had changed. Multiple passes were usually required on each mill, however not all final product specifications were rolled on all three mills.

Because each pass introduced stresses into the material (each pass generated a reduction in thickness of ~ 50%), it was necessary to anneal the material in one of two rough annealing furnaces (RA). This usually occurred during BM passes as the cumulative percent reduction quickly approached 90% after only three passes. After annealing, the cumulative reduction was reset to 0% and it was possible to continue rolling to thinner gauges without significant breaking in the coil.

When the foil had reached its designated thickness, it was placed on one of three trimming machines. The finishing area of the foil shop cut the coil (the parent coil) into widths desired by the customer. Heavier gauges (above 0.030mm) were trimmed to size on the heavy gauge slitter (HGS). Lighter gauges were trimmed on either the light gauge slitter (LGS) or separator (SEP). A given coil could be trimmed to multiple widths, depending on how that coil's original width was allocated by the planner. Furthermore, the large coil could be only partially used and returned to a rack for trimming at a later time.

After slitting, the smaller baby coils were placed in one of six final annealing furnaces (FA) or sent directly to the packing area, depending upon the temper (how soft or hard the material is) requirements specified by the customer. Those coils that were annealed were transported to the packing area when cooled. In the packing area, the baby coils were prepared for pickup by the customer or sent to the finished goods warehouse, as not all coils had a designated customer. Coils could be boxed or placed in plastic sleeves. A material flow diagram is shown in Figure 7.

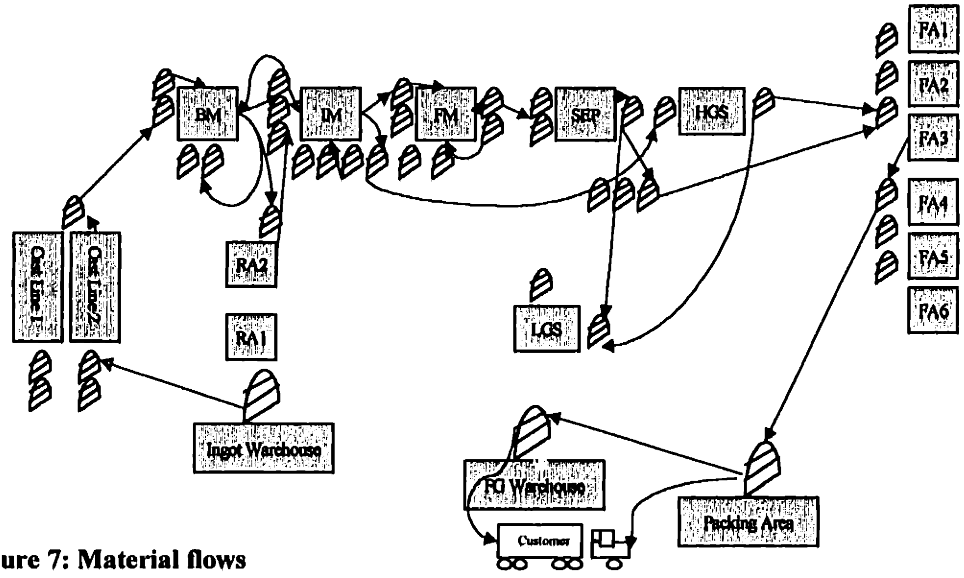


Figure 7: Material flows

While the flow was seemingly simple, the nature of the process required that individual coils be removed and returned to a given machine multiple times. For example, on the BM, there were certain passes that required the coil to be removed from the machine and cooled before rolling could continue. In addition, a coil processed on the BM was rough annealed after the second or third pass. After cooling, it was returned to the BM for one or more additional passes.

Also, reliability constraints added complexity to the flow. For example, should the FM break down, it was possible to run FM passes on the IM. Quality problems such as bands and lines caused the coil to be removed from the machine for review and later returned to the machine when a new application had been specified.

Finally planning changes sometimes required that coils be pulled from the machine between passes to allow more critical specifications to be processed. The coils were placed in racks and returned to the appropriate machine when time or need permitted.

1.1.3 Planning, Scheduling, and Information Flows

1.1.3.1 Operating Plan

Alcoa Shanghai developed a master operating plan in October for the following year. The plan was initially created by the sales department and described as a "shoot from the hip" estimation for the following year's demand. Currently sales does not yet have a systematic approach to understanding what product applications customers will require and when. The idea of a customer in China is still relatively new. Recently, however, the sales department has begun to understand and embrace the need to monitor customer needs and actively pursue establishing new ones.

The forecast was based upon the current market, history (in reality memory) of the existing customer base, and gut feel. Most customers had little idea what their needs would be for the following year.

Both process and manufacturing departments reviewed the forecast to see if production was capable of making the plan. Requests could be made to level certain specifications. In addition, the influence of targeted process improvements was considered. By December, the operating plan was completed. This plan was used to predict ASAP's financial performance for the coming year.

During the operating year, a monthly revised operating plan was created for each month. This was based upon more recent information provided by the sales department around the 15th of the previous month.

1.1.3.2 Casting Shop

The planning department created a monthly casting schedule based upon the revised operating plan for that month. Alloy, width, and final application were specified. The schedule considered material already in process in the rolling and finishing areas and finished goods not allocated to a specific order. Often those applications for which the required tonnage was greatest were cast first.

From planning's schedule, a more detailed production and maintenance plan was created for the shop by its supervisor. Operators were provided daily task sheets.

Four different alloys were cast at ASAP: 1050, 1145, 1200, and 1200 with high iron content (1200 Fe+). Five different widths were cast: 1320 mm, 1400 mm, 1480 mm, 1510 mm, and 1560 mm.

1.1.3.3 Rolling Area

After a parent coil was cast, its quality report was reviewed and a final gauge, width, and application determined. Different applications had different quality requirements. For example the surface finish requirements for decorative sheet were more stringent than for adhesive tape.

Each mill was provided a daily task sheet by the rolling area supervisor. At the BM, coils were typically processed in groups of four as only four coils were able to be loaded into each of the RA furnaces. Coils within each batch were typically of the same alloy, width, gauge, and final application. Those groups that were most immediately needed by the IM, FM, or finishing area were given priority. It was desirable to keep the IM and FM busy. In addition, attention was given to ensure that the RA furnaces were loaded and running, as they were a perceived bottleneck. Occasionally, coils were processed as received from the cast shop if no task sheet had been provided.

The RA furnace operator loaded the furnace on a first come, first served sequence. Usually BM operators had prepared loads for each of the RA furnaces.

Priority at the IM and FM was largely determined by what was required in the finishing area. Here too, coils were batched in groups of four.

1.1.3.4 Finishing Area

Unlike the cast shop and rolling area, the finishing area was planned primarily by customer orders. Customer orders were firm (written contract) or verbal. At the beginning of each month, the planning department received a list of current orders for that month and their corresponding need dates. The planning department would then assign manufacturing dates after reviewing rolling and finishing area WIP reports and a finished goods inventory listing. The planning department resubmitted the current orders list with the manufacturing dates for approval by the sales department. At this time, a determination had been made regarding those orders that must be processed and those that could be filled from finished goods.

A report was provided to the finishing area planner that indicated the orders that must be processed through the finishing area. Using the report, the planner began to identify suitable parent coils to fill the customer orders. The planner manually maintained a list of coils in the finishing area noting alloy, gauge, width, and quality. Orders were processed by promised manufacturing date. Daily task sheets were given to each of the three finishing area machines;

LGS, HGS, and SEP. The sheets informed the operator of the parent coil sequence to be followed, the slitting plan, and the number of baby coils to be produced from each parent.

For those orders where a suitable parent was unavailable in the finishing area, the rolling area supervisor was notified and a coil expedited.

1.1.3.5 Planning and Scheduling Information Flows

Figure 8 illustrates the planning and scheduling channels at ASAP.

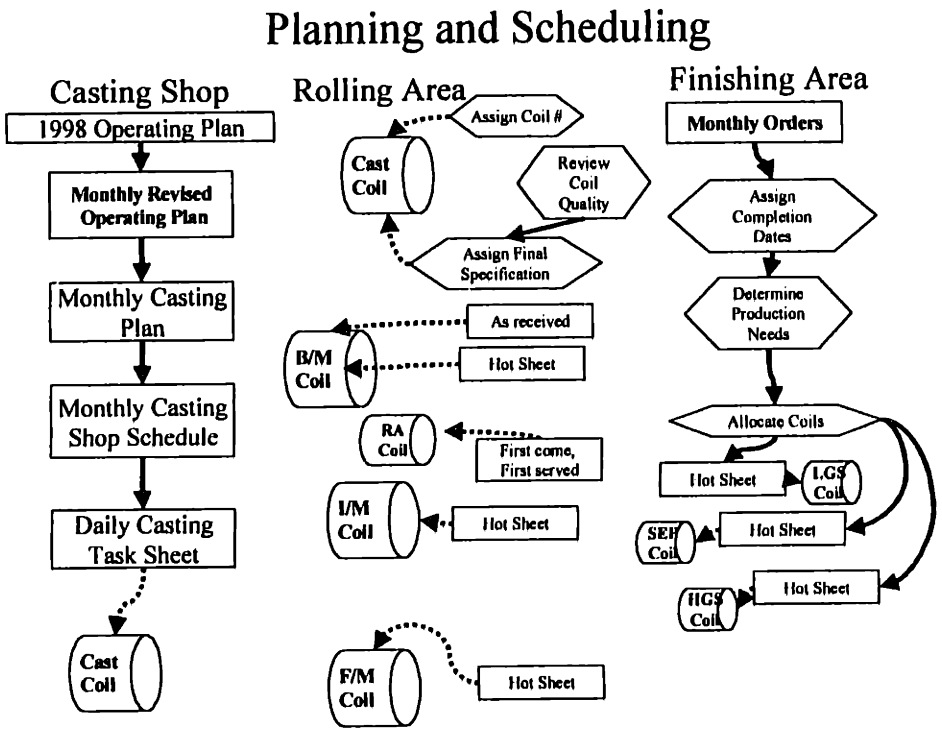


Figure 8: Planning and scheduling

1.2 Rolling and Annealing Process Schedules

1.2.1.1 Schedule Definition

Rolling and annealing process schedules were assigned to each parent coil after it was cast, at the time that final gauge, width, and application were designated. A schedule is an instruction that defines the rolling sequence to be followed, the annealing gauge, and the annealing process. There were two distinct annealing processes: a high temperature and low temperature anneal. The schedule defined was largely dependent upon the final gauge and final application.

Main Product Application	As Cast Width (mm)	Final Thickness (mm)	Alloy	Passes							
				BM				IM			FM
				1	2	3 / RA	4	5	6	7	8
Food Package	1400	0.0090	1145	2.50	1.10	0.50	0.20	0.090	0.045	0.022	0.009
	1400	0.0100	1145	2.50	1.10	0.50	0.20	0.090	0.045	0.022	0.010
Cable Shield	1480/1320	0.0120	1145	2.50	1.10	0.50	0.20	0.100	0.050	0.025	0.012
Pharmaceutical Foil	1320	0.0160	1145	2.50	1.20	0.60	0.27	0.130	0.070	0.035	0.016
	1400/1320	0.0200	1145	2.50	[illegible]	0.50	[illegible]	0.095	0.045		0.020

Table 1: Rolling and annealing schedules for three product applications

Table 1 is a sample of schedules for three different product applications. Schedules at ASAP were grouped by product application. As shown, 0.012mm cable shield foil was cast of 1145 alloy and rolled from 6 to 2.5mm (pass #1), 2.5 to 1.10mm (pass #2), and 1.10 to 0.50mm (pass #3) on the BM. When the coil was 0.50mm, it was rough annealed, cooled, and returned to the BM where the gauge was further reduced to 0.20 mm (pass #4). The parent coil was then rolled on the IM for passes #5, #6, and #7. A final pass was rolled on the FM that reduced the coil from 0.025mm to its final gauge of 0.012mm.

1.2.1.2 Actual Rolling and Annealing Schedules

While rolling and annealing schedules were defined after a coil was cast, they were not necessarily adhered to. Table 2 illustrates some examples of schedules used to roll coils to 0.0065mm.

Cast Width	Final Gauge	Alloy	Temper	Cast Gauge	BM Exit Gauge	IM Exit Gauge	FM Exit Gauge
* 1510/1400	0.0065	1145	M	6	0.27	0.032	0.0065
1520	0.0065	1145	M	6.08	0.60	0.032	0.0065
1410	0.0065	1145	M	6.01	0.27	0.032	0.0065
1410	0.0065	1145	M	6.1	0.48	0.038	0.0065
1410	0.0065	1145	M	6.08	0.50	0.038	0.0065
1420	0.0065	1145	M	6.3	0.55	0.032	0.0065

Table 2: Comparison of defined and actual schedules

Deviations from the defined schedule (*) were due to mill changes, quality issues, and order changes. Mill changes were attempts to balance the rolling load that each mill saw. For example, the IM was capable of rolling some passes normally reserved for the BM. Quality issues created the need to reassign a coil's intended final application. Should pinholes exist in a coil that had been allocated for a final gauge of 0.0065mm, it was necessary to replace that coil and it was likely that the replacement coil had been designated for a different final gauge and application and already rolled through several passes accordingly.

Order changes drove a similar response as material quality problems. That is, should an unexpected need arise for 0.0065mm foil, coils that were of sufficient quality, but different application, would have their final gauge reassigned to be 0.0065mm.

The nature of the schedule assignments and reassignments yielded a significant number of in-process specifications. Casting practices yielded nine as-cast specifications (alloy and width). Over 150 specifications (alloy, width, gauge, and RA process) existed through the RA furnaces and BM and almost 250 upon exiting the IM. There have been 130 specifications historically between the FM and finishing area.

1.3 Importance of Defining the Current Condition

1.3.1 Understand the Environment

Taking the time to understand the current condition is invaluable in that it allows the opportunity to step back from existing biases of the environment, namely the plant and its suppliers and customers. People often enter a manufacturing facility having a specific role and unintentionally localize their thinking. Inevitably, stories and stereotypes develop for those things outside of their localized thinking.

It is naturally difficult to think in terms of systems. However by doing so and attempting to understand the current condition, components of the manufacturing system are exposed and questions arise. An appreciation can result for what other people do and its consequences, the challenges they might have, and the information they receive. This appreciation enables people to challenge what they have heard or assumed because they have seen it for themselves.

1.3.2 Identify Reasons for Change

In order for change to occur, there must be a reason for it. Change for the sake of change cannot be sustained because people don't know why it is necessary. Solutions may be generated without first understanding what the underlying issues or problems are.

Understanding the current condition makes the underlying issues more visible because an attempt is made to disregard biases. By being vulnerable, unassuming, and admitting how little is known, the system opens itself and interactions become clear. The reasons for change can be found in the interactions between the components of the manufacturing system: information – people, machine – people, material – machine, etc.

1.3.3 Build Trust, Credibility, and Relationships

Assessing what the current condition is can be difficult. There is initial distrust because people's (the group driving change) motives are unclear, their methods are unknown, and the outcomes are not guaranteed. People enjoy stability and security and become uneasy when that is challenged. The threat of any kind of change is a challenge. The exercise of coming to grips with the why and how things "are what they are" in itself starts to bring about some very positive results. People are forced to be with other people that they probably do not know very well. There can be a bond established because these people become visible and part of each other's lives. Asking questions, listening and learning is perceived as caring. This is how trust grows and credibility becomes established. Relationships when trying to affect change are perhaps the most important element to ensuring that the change is: 1) the right kind of change and 2) that it will last.

1.3.4 Begin to Include People

The mechanics involved with creating relationships and understanding the current condition make people feel like they are a part of something. They are involved because they are able to demonstrate and talk about what they do. They are involved because they are able to answer questions. They are involved because other people's thoughts are shared with them. When people feel included they become a mountain of ideas. They are willing to share. And they are willing to listen too. Too often there is a failure to include people early enough in a change process, yet there is an expectation that they will be willing to participate in something in which they have no ownership.

1.4 How to Define the Current Condition

1.4.1 Ask Questions and Listen with Both Eyes and Ears

As indicated previously, defining the current condition can be challenging. There are no formal records and there is no single source of information. People must be actively sought out. For they, as a community, are the true sources of information. The current condition is understood by taking the time to ask questions. Often it is necessary to ask those questions in various ways. This is particularly true when communicating through a translator as in China. Questions may be understood in very different ways than intended. It is important to constantly test that understanding. Furthermore, actively listening with both eyes and ears is essential. People often share a lot through their expressions. Also being very aware of the physical surroundings can yield information - by watching how machines operate, noticing the dust on parts, and looking for dates on communications, for example. Puzzling observations help construct the current condition.

1.4.2 Be There and Admit What is Not Known

Those things that are less frequently seen can be more difficult to understand. The manager's office, the shop floor, and a customer's operation are places where "things happen" and a great deal can be learned. However, the learning may only come by assimilating and participating with each of those environments. Furthermore, it is helpful to be there at different times of the day. Differences in how things are perceived exist not only between roles in the manufacturing system ("management" and "workers"), but between different working shifts as well.

People who are willing to collect information by being where value is added are more readily accepted as equals and in fact "no different than anyone else". Operators for example are impressed by those willing to work and learn in their environment. It shows commitment and endurance and it demonstrates too that their work is important and valued. Finally, admitting what is not known or understood appears to generate respect and a willingness to assist in helping understand the current condition.

1.4.3 Wear a Different Pair of Shoes

While listening and asking questions are powerful ways to understand why and how people do what they do, actually doing the work is perhaps even more powerful. For example, at ASAP it was helpful to use the sales and WIP reports to attempt to create "hot sheets" for each machine as a planner would. The exercise was done with a planner to verify that their thought process was understood. It was found that forgetting ones own biases and preferences while completing the task was very difficult.

1.5 What to Look For

As previously indicated, there are no specific "rules of thumb" when characterizing a current situation. Each environment poses its own unique issues and considerations. Some questions that might be helpful are:

- "How do people know what to do and when to do it?"
- "How is material transformed?"
- "Where is value added?"

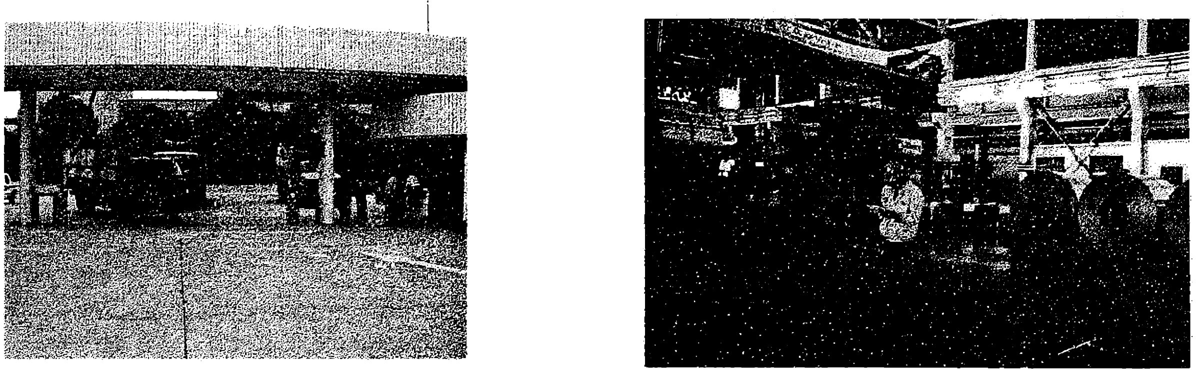
Answers to these questions will naturally lead to further questions.

1.6 The Power of Pictures

Photographs can be an effective means to describe the current condition because they are unbiased. Like diagrams, they are helpful in communicating the need for change. Some photographs of ASAP's current condition are shown in Figure 9.

Finished goods warehouse.

WIP inventory.



Customers often pick up orders at the end of the month.

Planning is difficult.

Figure 9: Photographs defining ASAP's current condition

2. Why Inventory Exists at ASAP

Prior to developing a pull system, it is helpful to understand why inventory exists. In formulating the current condition, an understanding of why inventory exists is developed. Inventory is often thought of in negative ways, however, inventory in itself is not bad. It is a messenger of underlying problems. Arbitrarily removing inventory without first addressing those problems can disrupt operations. Inventory falls into one of three general categories:

1.) Pipeline stock covers demand over the time it takes to replenish inventory that has been consumed.
2.) Buffer stock buffers against demand uncertainty.
3.) Safety stock protects against the inability to consistently supply material in the needed quantity, of the necessary quality, at the right time.

It is important to distinguish between these three inventory types when determining inventory levels, as then it is known what the primary driver is for those levels. The following section examines some of the reasons that inventory existed at Alcoa Shanghai.

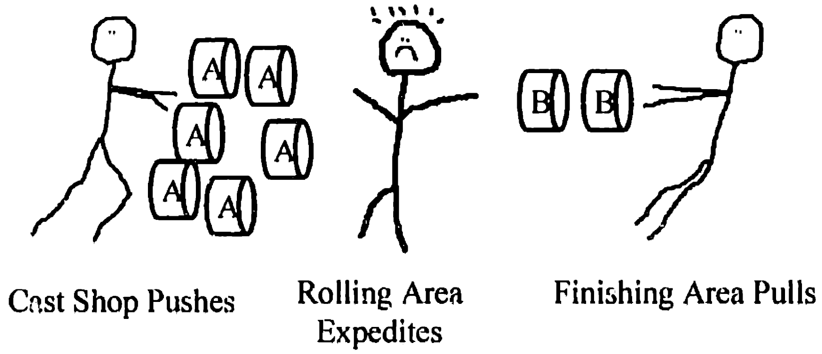
2.1 Management Systems

2.1.1 Planning and Scheduling Policies

ASAP maintained what is referred to as a "launch and expedite" planning system. That is upstream, the cast shop was scheduled by a forecast while downstream, the finishing area was driven by a pull of customer orders. Because customer orders did not always match the forecast, there was a constant conflict between what the finishing area needed and what the casting shop had provided. Caught in the middle of the conflict was the rolling area. The rolling area was forced to be reactive to both its upstream and downstream neighbors. Each machine was given a task sheet or "hot" sheet, that was used to expedite certain specifications through the rough anneal and rolling operations, to the finishing area. Planning the rolling area was extremely difficult and required constant replanning. Coils were frequently removed from a mill to allow "hot" coils to be rolled. Ultimately those removed coils sat in racks for long periods of time until they too became "hot".

The danger in forecasts is that they are usually wrong. There was a risk that what the cast shop pushed into the rolling area would not be needed by the finishing area right away, allowing work in process to accumulate, as shown in Figure 10.

Figure 10: Push vs. pull



Planning departments are often noted for their heroes - individuals who at the last minute are able to find clever solutions to problems. Everyone looks to them when material quality, machine breakdown, or order change issues arise. Alcoa Shanghai had two such heroes in the planning department. While critical to maintaining the day to day operations, heroes actually allow problems to keep resurfacing because people know that somehow an expeditious solution will be found and there is no incentive to determine what the problem is and correct it. Also, heroes work intuitively – a difficult skill to teach. It is often difficult for others to find similar expeditious solutions to production emergencies.

2.1.2 Performance Measurements

Performance measurements are a necessary tool to allow people to get a sense of how they are doing. Unfortunately, these measurements also have the effect of influencing certain kinds of behavior that actually will cause unnecessary buildup of material (Knight, 1992).

Runtime is frequently measured in shops that have large investments in their capital equipment. It is felt that by running the equipment, the cost of the equipment is somehow recovered. Ultimately the equipment is run regardless of need simply to keep the machine busy.

Another common measurement is the productivity of a machine or shop. For example at ASAP, productivity was measured in tons per shift on the FM. Cast shop productivity compared actual production to production levels defined by the forecast. In each case, there was an incentive to produce as much as possible. Rather than considering downstream needs, areas locally optimized and consequently often overproduced.

The sales organization at ASAP was measured by the foil tonnage it sold on a monthly basis. There was extreme pressure to ensure that product was available, should a potential sale exist. Arrangements were made with planning and manufacturing to produce certain product specifications in the hope that a customer would later be found.

Finally, the planning and manufacturing departments were measured by their ability to meet a promise date. There was incentive to maintain a cushion of material to ensure that these dates are met. Often "employees are not taught the impact of inventory. However they are taught the impact of delivery performance." (Knight, 1992)

2.1.3 Organizational Structure and Physical Layout

The functional and hierarchical organization of ASAP caused "walls" to be built around each layer within a functional group (Knight, 1992). Information flow was difficult in this environment and few relationships developed between internal customers and suppliers. This too caused people to locally optimize in that they did not perceive the needs of internal customers and were not exposed to the ultimate consequences of their actions.

The physical layout of the plant also contributed to build up of work in process. At ASAP, the cast shop and rolling areas were located in two separate buildings. Should the BM fail, it was unlikely that the cast shop would notice the breakdown and react to it. Furthermore, if quality problems arose there was a failure to communicate those issues to their source when they were found.

2.2 Customer Demand Variability

While demand is unpredictable regardless of geographic location, it is particularly so in China due to the fact that relationships between customers and suppliers are still being defined. Neither party has experience in sharing information. Determining what kinds of information are valuable and how to use it is not obvious. As a result, planning and sales both worked to buffer against demand variability by increasing inventory levels. This inventory is termed "just in case" inventory. "Just in case more is needed!" or "Just in case a customer comes along!"

Currently in China, contracts, verbal or written, are not necessarily binding. As such there is no guarantee that a customer will arrive to pick up material requested at the time originally agreed upon. This can be due to the fact that they are unable to pay for the material or in other cases there is no longer a current need.

2.3 Operating Systems

Operating systems are defined as those parameters, limitations, policies, and rules that describe or dictate how work is done. They can be physical or prescribed and tend to govern the flexibility of the manufacturing process.

2.3.1 Setup Times and Batch Processing

Long setup times are often offset by running large batches. At ASAP roll changes on the rolling mills, tip and alloy changes in the cast shop, and knife realignments in the finishing area were perceived as costly and efforts were made to maximize the time spent between these changes. This often resulted in longer runs of a given specification, even if there was not a demonstrated requirement for the specification. Interestingly, setup times are often seen as fixed and a consequence of machine design. For example, to avoid a lengthy roll change due to roll heating, coils were processed in a specific pattern. An increase in coil width between successive passes required a roll change because the current rolls would cause marking due to the uneven heating within the roll. Thus it was desired to continue running coils of the same or smaller width for the next pass through the mill. The potential to reduce roll change time was not considered.

In some cases equipment is designed to handle batches of material. For example, the RA furnaces were designed to anneal four coils at a time. The melting furnaces in the cast shop were capable of holding 25T of melt, or approximately three coils.

2.3.2 Lead-times

When lead-times are long, there is a need to cover demand over the replenishment time and similar to setup times, replenishment times are often viewed as fixed. The longer the lead-time, the greater the amount of inventory that people prefer (and need, although preference seems to be in excess of need) to have on hand. There is no perceived cost to them to have additional material.

2.3.3 Rolling and Annealing Schedules and Specifications

As indicated in section 2.1.3, a significant number of in process specifications resulted from the rolling and annealing schedules utilized at ASAP and a tendency to periodically reassign those schedules when necessary. Manually managing such diversity of WIP inventory was extremely difficult. Some coils inevitably became "lost".

2.3.4 Process Rules

There are certain rules that are developed over time that are perceived to be the most efficient way of doing things and perhaps at one time they were and still may be. Regardless, process rules should be periodically re-examined to ensure that those rules are necessary. For example the final anneal (FA) furnaces often sat idle as they waited for a furnace rack to be adequately filled with baby coils. FA process requirements were such that only certain baby coil specifications could be grouped together on the same rack. Over 25 different annealing processes existed. As a result, there was an accumulation of partially filled racks because there was little flexibility in combining loads. In another example, coils were cast in large batches by the cast shop. While there was some need for the specification cast, it was not uncommon to have some coils that were not immediately used downstream.

2.4 Supply Variability

Supply variation is a measure of a supplier's ability to consistently provide the right specification, at the correct time and in the necessary quantity. Should there be significant variation, there is a need to buffer against inconsistent supply with on-hand material. Two sources that contributed to variation of supply at ASAP were material quality issues and unexpected machine downtime.

2.4.1 Product Quality

Maintaining high levels of material quality throughout the casting, rolling, and annealing process were critical to providing foil having mechanical and physical properties suitable for a customer's final application. For example, a coil of foil allocated to be rolled to 0.006mm could not contain any inclusions when cast, as pinholes would result when the product was rolled to thinner gauges. Knowing that it was likely that some coils would contain inclusions, planning cast additional material to be used for 0.006mm orders. Those coils with quality issues were usually set aside for some time until a suitable application was identified (i.e. an order came along), or the material was signed off as acceptable for the original application.

In some cases, material quality is seen as driven by the machine. When a machine is running well, there is incentive to keep it running, because good product is being produced, regardless if there is current demand for the product. At ASAP, there was hesitation in stopping either cast line if the coils cast had a high level of quality. This was because "the settings were just right and might not be repeatable."

2.4.2 Machine Reliability

Machine downtime also contributes to accumulation of WIP. At ASAP, the BM was notorious for developing hydraulic leaks that forced the machine to go down. It was something that the planning department was unable to predict, only anticipate. As such, the BM often continued to roll foil for RA and IM, even if there was an adequate queue before each machine. The belief was that it was better to have excess coils than risk starving either machine.

2.5 Because It Can

Inventory existed at Alcoa Shanghai because it could. That is, the physical layout of the plant was able to accommodate a large number of coils. For example the racks between the BM and IM were capable of containing over 50 coils. It was common practice to put coils on the floor as well. People will utilize space if it exists.

2.6 Historical and Cultural

China is emerging from a state economy to one driven by market forces. For forty years, industries were given annual production quotas by the Chinese government. To meet those quotas was a source of nationalistic pride. While the transition to a market economy has been swift, attitudes still remain that believe in the long term merits of stockpiles of inventory. One competitor for example was extremely proud of the square footage of its finished goods warehouse.

3. The Ideal Condition

The ideal condition is derived from the current condition. After having developed an appreciation for how and why things "are what they are", it is necessary to ask the question, "Where to go?" The ideal condition is the answer to that question. The ideal condition is a simple description of the processes and flows that will help achieve some improved state. At Alcoa Shanghai, the ideal condition was a pull system that utilized kanbans to signal production. Similar to the current condition, the ideal condition should be presented in a visual way so that it can be easily communicated and understood by others. Note though that the ideal condition must be dynamic as it will be necessary to make adjustments when internal and external conditions change (Alcoa, 1998).

Defining the ideal condition is not obvious, as it is not entirely clear what is possible. It is helpful to start with the basic elements of the manufacturing system and look for opportunities. At ASAP, significant attention was given to the rolling and annealing schedules currently in practice.

3.1 Redefining Annealing and Rolling Schedules

3.1.1 Realities of Schedule Development Over Time

Schedules at ASAP were defined by product application. For example, when a customer indicated that it required 0.080mm foil to be used as food packaging, there were mechanical and physical properties that the foil must satisfy. An appropriate schedule was then defined to meet those requirements.

Schedules were created over time as specific needs arose. The consequence of this kind of evolution is that schedules are optimized in consideration of a single gauge and product application. What is lost is the power that a group of schedules potentially possesses. The power is that significant portions of schedules may be shared and the number of upstream specifications reduced. Schedules must be created such that the entire group of schedules is optimized.

3.1.2 Opportunities for Consolidation

3.1.2.1 Alloys

As noted in section 2.1.3.2, ASAP cast four alloys: 1050, 1145, 1200 and 1200 Fe+. Because 1050 and 1145 were chemically similar, it was proposed that these alloys be consolidated into a single alloy. While there was some discussion that 1050 was the alloy originally specified by a customer, it was later disclosed that when 1050 is unavailable, 1145 is readily substituted with no complaint.

3.1.2.2 Cast Widths

As noted in section 2.1.3.2, ASAP cast five different widths: 1320mm, 1400mm, 1480mm, 1510mm, and 1560mm. Some alloys were cast in multiple widths. It was proposed that each alloy be cast in a single width. Originally, it was believed that having multiple cast widths would enable ASAP to better utilize parent coils when slit into individual baby coils and increase their recovery rate (material that is good product / material input).

In reality, while the finishing area planner attempted to optimize material usage, the parent coil's width was not a primary consideration. Primary considerations were: 1) alloy and gauge and 2) coil quality. The planner was usually unable to wait for a coil having a more suitable width to enter the finishing area.

Furthermore, orders should be thought of as random until a more extensive demand history could be constructed. The widths required for a given specification over one or more days were not entirely known. As such, over a period of time in the finishing area, it was likely that overall recoveries for single widths would be similar to those recoveries realized when there were multiple widths offered. This was because there was "no guarantee" that the arrangement of daily orders would allow any of the widths to be optimized.

3.1.2.3 Specification Growth

The number of in process specifications in a foil mill can grow very quickly. Planning and managing material throughput may also become increasingly complex. Reducing the number of specifications as early in the process as possible is advantageous in that it quickly simplifies material management.

Consider a foil mill that casts two alloys (A and B) each in two different widths (1 and 2) and the coil cast may be rolled similarly in each alloy and width to one of two gauges (a or b).

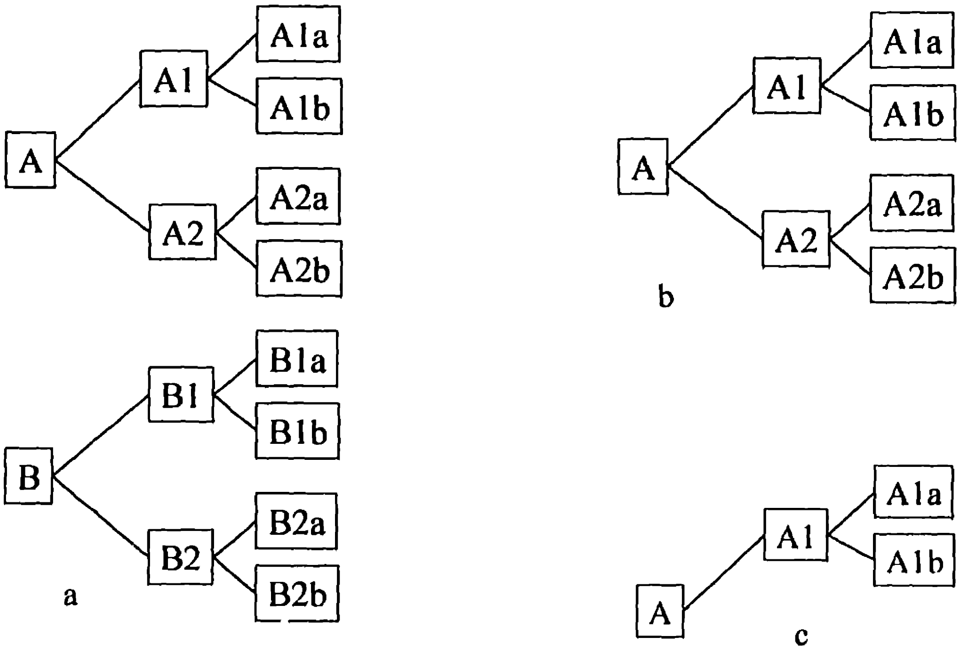


Figure 11: Specification growth

By the third band in Figure 11a, the two alloys together have already proliferated into 8 different specifications. This is only after the first pass through the rolling mill. Figure 11b demonstrates that if the B alloy is no longer cast, only 4 specifications result after the first pass. Furthermore, if alloys are cast in only one width, only 2 specifications exist after the first pass through the rolling mill as shown in Figure 11c. Such an exercise is only possible if A1a and A1b are capable of satisfying those same customer requirements as all 8 original specifications. The experience at ASAP has been that this is often the case, with little additional scrap and simplified planning and material management.

3.1.2.4 Process Groups

The importance of optimizing the rolling and annealing process schedules as a group rather than on an individual basis was emphasized in section 4.1.1. In order to begin to think about treating the existing schedules as a system, it was necessary to categorize the schedules in terms of process groups rather than by application. A process group is defined by schedules that have the same rolling process to rough anneal, the same rough anneal process, and the same rough anneal gauge. By looking at individual schedules in this way, opportunities for schedule consolidation (through the process groups) became much more evident. Table 3 includes a sample of rolling schedules from process groups 2 and 3.

Main Product Application	As Cast Width (mm)	Final Thickness (mm)	Alloy	Passes							
				BDM				IM			FM
				1	2	3 / RA	4	5	6	7	8
	Process 2										
Food Package	1400	**0.0090**	**1145**	2.30	1.10	0.50	0.20	0.090	0.045	0.022	0.009
	1400	**0.0100**	**1145**	2.60	1.10	0.50	0.20	0.090	0.045	0.022	0.010
Cable Shield	1480/1320	**0.0120**	**1145**	2.40	1.10	0.50	0.20	0.100	0.050	0.025	0.012
Pharmaceutical Foil	1400/1320	**0.0200**	**1145**	2.50	1.10	0.50	0.20	0.095	0.045		0.020
	Process 3										
Pharmaceutical Foil	1320	**0.0160**	**1145**	2.60	1.20	0.60	0.27	0.130	0.070	0.035	0.016

Table 3: Schedules defined by process groups

A total of 15 process groups existed for the schedules used at Alcoa Shanghai. Immediate questions arose in that it appeared possible to somehow incorporate process groups. For example in Table 3, it seemed possible to include process 3 into process 2. Such questions were appropriate because it was likely that 0.016mm pharmaceutical foil's original schedule was defined irrespective of other schedules that would yield similar mechanical properties. The process and planning departments determined that processes 2 and 3 could be consolidated as shown in Table 4.

Main Product Applications	As Cast Width (mm)	Final Thickness (mm)	Alloy	Rolling and Annealing Schedule							
				BM				IM			FM
				1	2	3 / RA	4	5	6	7	8
Food Package	1510	0.0090	1145	[illegible]	[illegible]	0.50	[illegible]	0.095	0.045	0.022	0.009
	1510	0.0100	1145	[illegible]	[illegible]	0.50	[illegible]	[illegible]	[illegible]	[illegible]	0.010
Cable Shield	1510	0.0120	1145	[illegible]	[illegible]	0.50	[illegible]	[illegible]	[illegible]	0.025	0.012
Pharmaceutical Foil	1510	0.0160	1145	[illegible]	[illegible]	0.50	[illegible]	[illegible]	[illegible]	[illegible]	0.016
	1510	0.0200	1145	[illegible]	[illegible]	0.50	[illegible]	[illegible]	[illegible]		0.020

Table 4: Schedule consolidation

Table 4 illustrates how groups of schedules may be consolidated into a single process group. Note that the 0.016mm foil's schedule has been modified. Testing was conducted to ensure that the changes made would not influence the foil's quality or properties. Note too that the 1145 alloy is now cast as a single width, 1510mm.

Modifying annealing gauge, annealing process, and rolling schedule made other opportunities for consolidation possible, reducing the total number of process groups from 15 to 7.

ASAP did not produce pharmaceutical foil, food packaging, or cable shielding. Instead, ASAP produced bare foil of a certain alloy, gauge, and width that had specific mechanical properties that made the foil suitable for certain applications. As such, it was important to think in terms of process, not application. While clearly the sales and marketing team interacted with the customer and spoke the language of application, it was critical to then define the application in terms of a process that would yield those properties that were desired. By having a focus on processes, schedules could be better designed to minimize the complexity that customization introduced and maximize the power of sharing similar upstream processes.

3.1.3 Establishing Proliferation Points

A proliferation point is defined as a position in the value chain after which there is a substantial increase in the number of specifications. The term may also be applied to rolling and annealing schedules as a point after which a given in-process specification may be rolled to multiple other in-process or final specifications. The ability to capture and manage proliferation points within process groups is key to inventory management and establishing a pull system. Two examples of proliferation points are shown in Figure 12 and Table 5.

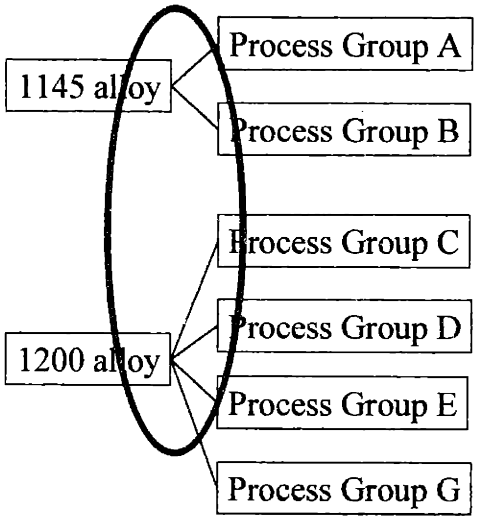


Figure 12: Proliferation of alloys

Figure 12 illustrates the proliferation of two alloys into process groups. The 1200 alloy for example proliferates into 4 distinct process groups and ultimately 30 final specifications. Table 5 shows proliferation within a process group.

Main Product Applications	As Cast Width (mm)	Final Thickness (mm)	Alloy	Rolling and Annealing Schedule							
				BM				IM			FM
				1	2	3 / RA	4	5	6	7	8
Food Package	1510	0.0090	1145	2.50	1.15	0.50	0.20	0.095	0.045	0.022	0.009
	1510	0.0100	1145	2.50	[illegible]	0.50	0.20	0.089	0.045	0.022	0.010
Cable Shield	1510	0.0120	1145	2.50	[illegible]	0.50	0.20	0.095	0.052	0.025	0.012
Pharmaceutical Foil	1510	0.0160	1145	2.50	[illegible]	0.50	0.20	0.095	[illegible]	0.019	0.016
	1510	0.0200	1145	2.50	1.15	0.50	0.20	0.095	0.045		0.020

Table 5: Proliferation within a process group

0.200mm is a proliferation point for the process group in Table 5. From this point, a single specification, a 0.200mm 1145 coil, may be rolled to any of 5 final specifications. Redefining ASAP's rolling and annealing schedules was done so such points would be created. That is, upstream rolling and annealing processes were made similar to generate downstream proliferation points within each process group. It was hoped that the points could be postponed as far downstream as possible. Most proliferation points within ASAP's proposed schedules occurred between the BM and IM.

3.2 Determining Inventory Levels

Redefining and consolidating rolling and annealing schedules was necessary before establishing strategic inventory positions. Once those schedules were created, it was possible to determine where in process inventory should be located and in what quantity.

3.2.1 Identifying Key Specifications

Key in-process or final specifications are those specifications that are most critical to maintaining the ability to consistently meet customer (internal or external) needs. In other words key specifications are those specifications of which some level of inventory should be maintained. Specifications at proliferation points are usually key specifications because they are inputs to multiple downstream specifications. Key specifications also occur at points where there is a physical disconnect in the process flow (Alcoa, 1998). For example, a physical disconnect existed between the BM and IM. A coil was physically removed from the BM and placed on the IM. Most times that coil first waited in queue before being run on the IM. Finally, key specifications occur at points where it is necessary to decouple against long lead-times in order to be able to cover demand over the replenishment period. While the cast shop and rolling area were physically disconnected, there was also incentive to maintain inventory between them due to the long lead-time associated with the casting process.

Using these guidelines, it is possible to identify potential key specifications. However, it is often not feasible to hold inventory for all key specifications, particularly when there are many different specifications. While a specification may fall within one or more of the criteria above, it is important to also have some appreciation for the level of demand associated with the specification. If there is little consistent demand for the specification, it is perhaps not worthwhile to maintain inventory for that specification. It is also important to consider the financial value that the specification contributes over some time horizon. For example, at ASAP significant product proliferation occurred between the rolling and finishing areas. The finishing area slit parent coils into different widths (there was no further rolling). Hundreds of different widths were possible. However, it was not desirable to carry inventory prior to the finishing area for all possible final gauges, as many were not frequently used. In order to determine the "critical" key specifications, a Pareto diagram, shown in Figure 13, was constructed to highlight those specifications through the rolling area that contributed most to ASAP's monthly sales revenue. The diagram shows that less than half of the specifications contributed over 90% of the revenue realized each month.

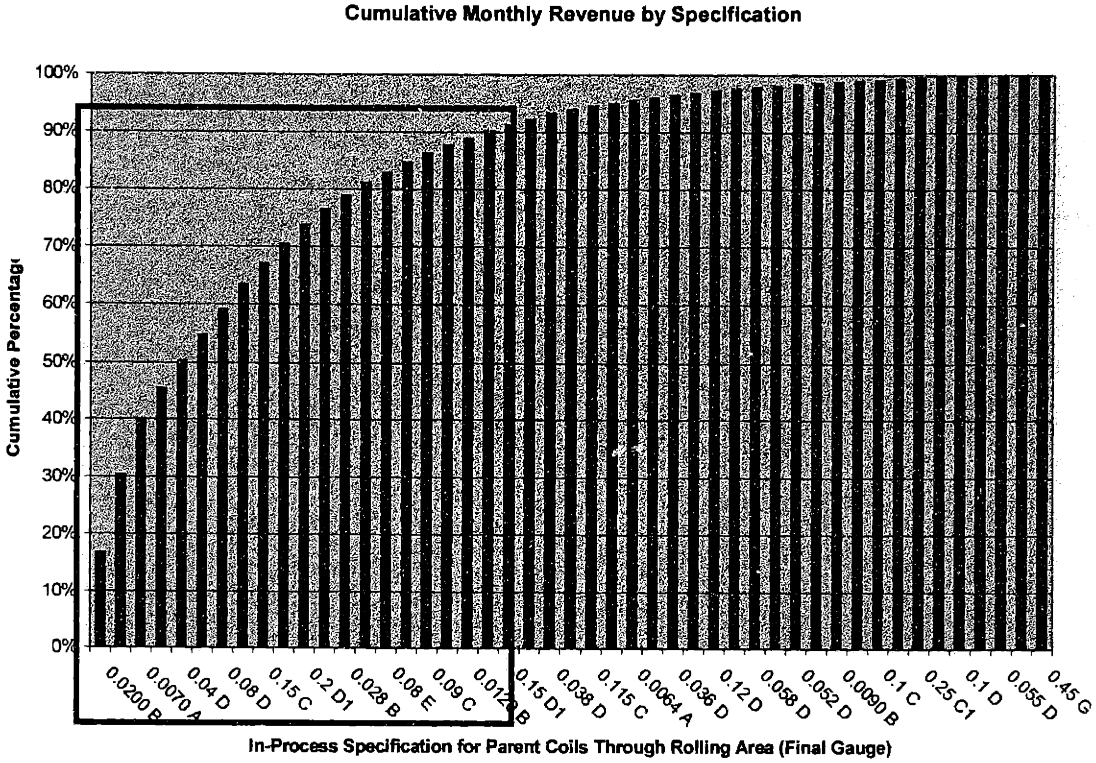


Figure 13: Cumulative percentage of monthly revenue

For example, the baby coils produced from 0.020mm (process group B) parent coils generated approximately 17% of the average monthly revenue. Clearly, this specification was financially critical and inventory was maintained for the specification.

3.2.2 Determining Store Sizes

Inventory held of a key specification is called a store. A store has a physical location in the factory and a calculated size (Alcoa, 1998). The store size is the summation of the calculated pipeline stock, buffer stock, and safety stock needed for the key specification.

$$\text{Store Size} = \text{Pipeline Stock} + \text{Buffer Stock} + \text{Safety Stock}$$

Equation 1: Store Size

The store calculation should be kept simple when first determining inventory levels. Much of the benefit in trying to introduce changes regarding inventory management systems comes not from the sophistication or accuracy of the calculation itself, but from the discipline that is achieved

- through the exercise of understanding the current condition and why inventory exists

- by redefining rolling and annealing schedules and preventing deviations from those schedules
- and by maintaining a known level of work in process.

Inventory levels may be recalculated if it is found that the levels are too high or low. Because detailed information regarding customer demand variability, yield variability, and machine down and repair times might not be known, a simple derivative of the base stock inventory model is developed to calculate store sizes.

3.2.2.1 Calculating Pipeline Stock

Pipeline stock, assuming constant demand, ensures that the customer has a continuous supply of material. The pipeline stock required for a key specification is dependent upon the average daily demand for that specification and the time to replenish the specification. The replenishment time is the total time needed to replace the inventory from the time it was used. Equation 2 may be used to calculate pipeline stock:

$$\begin{aligned}&\text{Pipeline stock} = \mu * R \qquad \text{where},\\&\mu = \text{specification's mean daily demand}\\&\text{R} = \text{average replenishment time (days)}\end{aligned}$$

Equation 2: Pipeline stock (Graves, 1998)

It is helpful at first to use conservative estimates of replenishment time. Estimates should consider both processing time and queue time.

3.2.2.2 Calculating Buffer Stock

Buffer stock is used as a countermeasure to customer demand variability. It protects the supplier from sudden changes in customer demand over the replenishment time. When customer demand is not constant, pipeline stock alone will not prevent stockouts. When calculating buffer stock, it is first necessary to characterize customer daily demand by determining its mean (μ) and standard deviation (σ). The mean demand is the same average daily demand used when calculating pipeline stock requirements. It is often difficult to determine the variation in daily demand or to characterize an appropriate statistical distribution. In such situations, assuming $\sigma = \mu$ and daily demand follows a normal distribution is adequate. The accuracy of the calculation is not critical. Benefit comes from the fact that there is a demonstrated understanding that demand is variable and that the variation must be considered when sizing the store. Buffer stock can be calculated using Equation 3, assuming a normal demand distribution.

$$\text{Buffer stock} = Z\sigma\sqrt{R}$$

where, R = replenishment time
σ = standard deviation of daily demand
Z = the service level factor

Service Level	0	1	2	3
Fill Rate	50%	84%	97.7%	99.9%

Equation 3: Buffer stock (Graves, 1998)

Note that when using Equation 3, there is a tradeoff between fill rate (the probability that a customer need will be satisfied) and buffer stock level. Doubling the service level from 1 to 2 increases the fill rate almost 14% but it also doubles the buffer stock level. Satisfying variable demand comes at a cost.

3.2.2.3 Calculating Safety Stock

Safety stock is a precautionary measure against equipment breakdown, material quality problems, or other reliability issues that might prevent timely replenishment of cycle stock or buffer stock to the store. The need for safety stock stems from the fact that internal and external factors exist that make supply variable.

Calculating safety stock levels is not straightforward and can become mathematically complex. However a more intuitive approach may be used to estimate what those levels should be for a key specification. Safety stock may be thought of as inventory that is used to cover variable demand over the replenishment time for the specification given that there is some percentage of the pipeline stock and buffer stock that will not be available. Or more simply, safety stock is material that covers those times "you cannot make what you want to make, when you want to make it." Equation 4 is proposed to estimate safety stock levels:

$$\text{Safety stock} = (1 - \text{Reliability factor}) * (\text{Pipeline stock} + \text{Buffer stock})$$

Equation 4: Safety stock

The reliability factor is the frequency that good product is produced when attempted. For example, at ASAP it was estimated that the rolling area was able to supply good foil approximately 80% of the time desired. In other words, 20% of the time mill failure or quality issues prevented timely supply of the foil to the downstream customer. Thus, according to Equation 4, the safety stock maintained for the specification should be determined by 0.20 * (pipeline stock + buffer stock).

3.2.2.4 Calculating the Store Size

The store size equation given in Equation 1 may be written mathematically as:

$$\text{Store size} = (\mu * R) + (Z\sigma\sqrt{R}) + (1 - F) * ((\mu * R) + (Z\sigma\sqrt{R}))$$

where,

μ = average daily demand
R = replenishment time
Z = service level factor
σ = standard deviation of daily demand
F = reliability factor

Equation 5: Mathematical equation for store size

3.3 Pull System

Having established process rules, identified key specifications, and determined store sizes, it was possible to begin to develop a pull system to drive material and information flow at ASAP. The following section defines a pull system and illustrates the advantages of such a system.

3.3.1 The String

"Try to push a string and it piles up. Pulling a string makes it lean." (Black, 1998)

The analogy of a string when explaining the difference between a push and pull inventory system is helpful. While a push system is a hope for future demand, a pull system is a reaction to present demand (Nahmias, 1997). When one pushes a string, the tendency is for the string to bunch in an uncertain way. It is a guess as to whether the string will bunch up (inventory buildup) or down (inventory backlog). When planning by forecast, material is pushed in large batches into the factory, however it is not certain that demand will exist, only anticipated. Multiple production schedules are used, perhaps one for each machine. Confusion, planning heroes, and "hot jobs" can often characterize a push system. A push system is difficult to control because it is at the mercy of external factors. At Alcoa Shanghai, the casting and rolling areas were characterized by a push system.

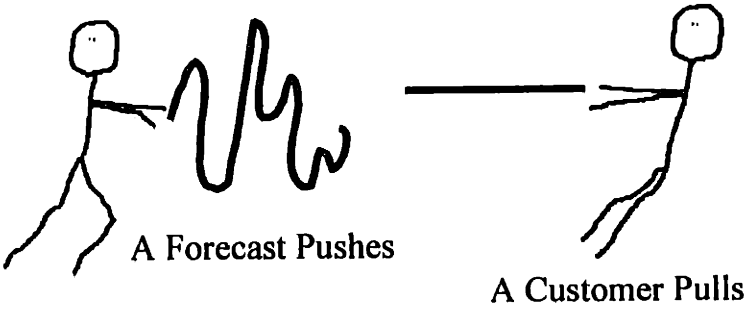


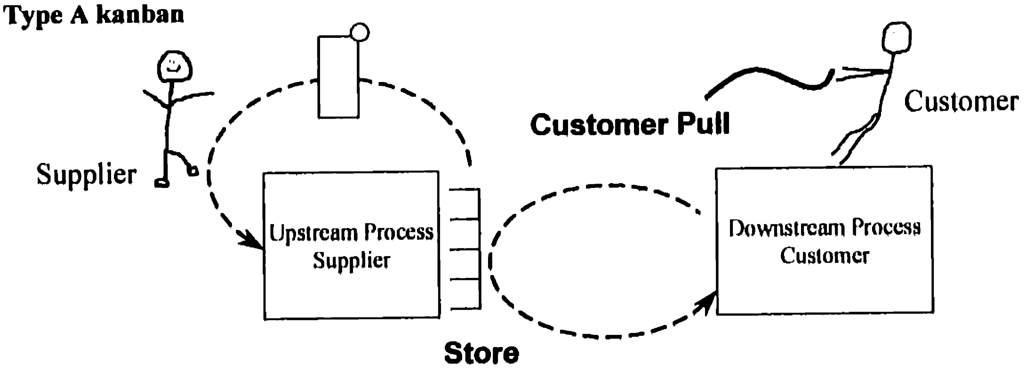
Figure 14: Pushing and pulling a string

When a string is pulled, there is certainty in the direction that the string will move. The string is predictable and easier to control. In a pull system, the system only reacts to external factors (customer demand) and inventory levels remain more consistent as the system itself adjusts to changes in demand. In a pull system there is only a single plan to replace what the customer has used. This necessitates that clear customer and supplier roles are established through the plant (Alcoa, 1998).

3.3.2 Pull System Mechanics

A common means to achieve a pull system is through kanban. Kanban is a production instruction or signal that by Japanese translation means ticket. Kanban is a visual means to achieve pull and is the method utilized by Toyota's Production System. In a kanban system, each part is accompanied by a ticket that in some way describes the part. In a Type A system, a downstream customer directly pulls a part from its store and the ticket is returned to the upstream supplier as signal that it must replenish that part (Alcoa, 1998).

Figure 15: Type A kanban



In a Type B system, instead of having material on-hand in a store, a downstream customer may directly send a production instruction to its upstream supplier as a signal to produce the given specification (Alcoa, 1998).

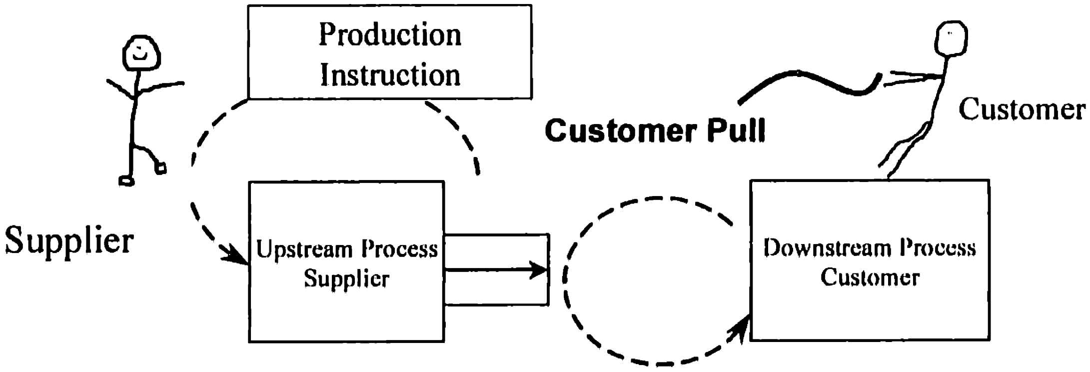


Figure 16: Type B kanban

A Type A system is often utilized for a few key specifications. It typically cannot accommodate a high number of specifications. The advantage of a Type A system is that the lead-time associated with delivering the specification to the customer is very short (Alcoa, 1998). There is a cost in that it is necessary to hold inventory. A Type B system is capable of handling many specifications as no inventory is held. However the lead-time in providing these specifications to customers is longer than in a Type A system (Alcoa, 1998).

3.3.3 Advantages of a Pull System at ASAP

The primary advantage of a pull system lies in the fact that it introduces a high level of discipline into the production process. Instead of continuously juggling production schedules, the schedules are clear and fixed. Kanban cards and special work instructions at a workstation define the manufacturing process. Priority is determined by the kanban's position on a board. At ASAP, it was not possible to adjust the rolling and annealing schedules for a given coil. Once a kanban had been matched to a coil, the rolling and annealing instructions specific to that kanban were followed without exception. Furthermore, a coil could not be bumped from its position in the production schedule. No longer was it possible to expedite coils, although flexibility could be designed into the system to accommodate emergency situations.

The discipline of a pull system also promotes improvement behavior. At ASAP because it was not possible to reallocate a coil should quality issues develop, it became imperative to focus on the causes of those issues. Furthermore, because the fundamental principles of a pull system do not allow prioritization, there was a need to better understand customer requirements on a more frequent basis.

Unlike a push system, a pull system incorporates stores of key specifications, strategically placed throughout the process. Material is available upon demand from the store. Those stores are consistently replenished as material is used. Through ASAP's pull system, because large batches of a single specification were not processed at once, there was less probability that significant inventory would remain during periods of low demand. Furthermore, should a quality problem be identified downstream, it was not likely that large amounts of that specification need be set aside or scrapped.

A pull system enables employees to become involved in the decision making process. While a pull system does not eliminate the need for planning, it does shift daily coordination responsibility to those who know material flows best – the operators. Because of the visual nature of the system, operators are able to load and unload their machines and distribute material without outside involvement. Also, it is essential that operators directly participate in the initial design of the system, as they are knowledgeable about the most efficient way to manage the complexity introduced when multiple specifications are processed across several machines.

A pull system in itself does not reduce inventory levels. Instead it exposes the underlying issues causing inventory to exist and creates a sense of urgency to address them. Because it requires active participation from all employees, it builds confidence and promotes decision making and problem solving. And finally, the discipline in following processes and maintaining production schedules smoothes throughput, reducing the quantity of stagnant WIP.

3.3.4 Material Flow

A pull system was established at ASAP in both the casting shop and rolling area of the foil shop. Namely, stores containing coils of critical key specifications were located at three points:

- between the cast shop and BM
- between the BM and IM
- prior to the finishing area.

The rules outlined in sections 4.2.1 and 4.2.2 were used to identify critical key specifications and determine appropriate levels for those specifications, respectively. Table 6 summarizes the specifications included at each of the stores.

Table 6: Summary of specifications contained in stores

Store Location	*Description of Specification*
Between the cast shop and BM	As-cast coils of three alloys (3 specifications)
Between the BM and IM	Coils through the BM, belonging to one of 6 process groups (7 specifications)
Prior to finishing area	Key coils rolled to final gauge (19 specifications)

The finishing area machines pulled material through the rolling area. Figure 18 and Figure 19 illustrate the flow paths taken by coils as they are successively pulled by downstream customers. Figure 17 defines the symbols used to describe the pull system and ASAP's ideal condition.

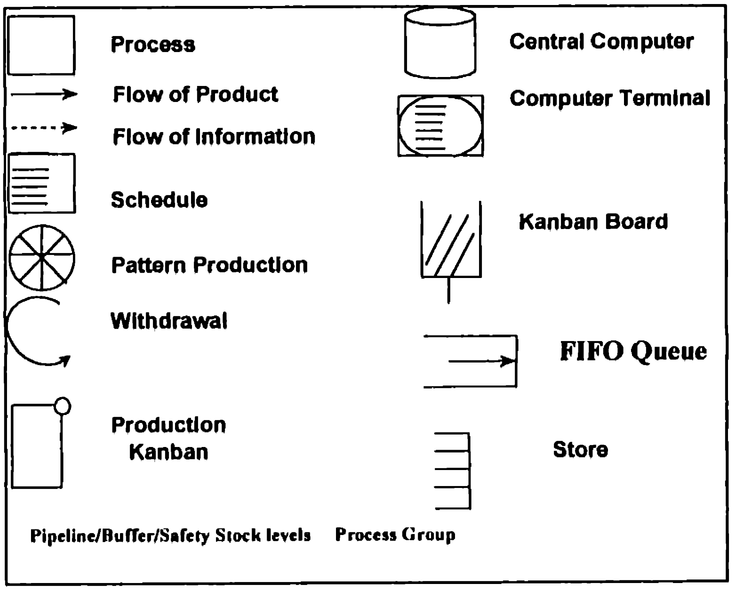


Figure 17: Legend of symbols used in the ideal condition diagram (Alcoa, 1998)

Figure 18: Pull system between the finishing area and BM

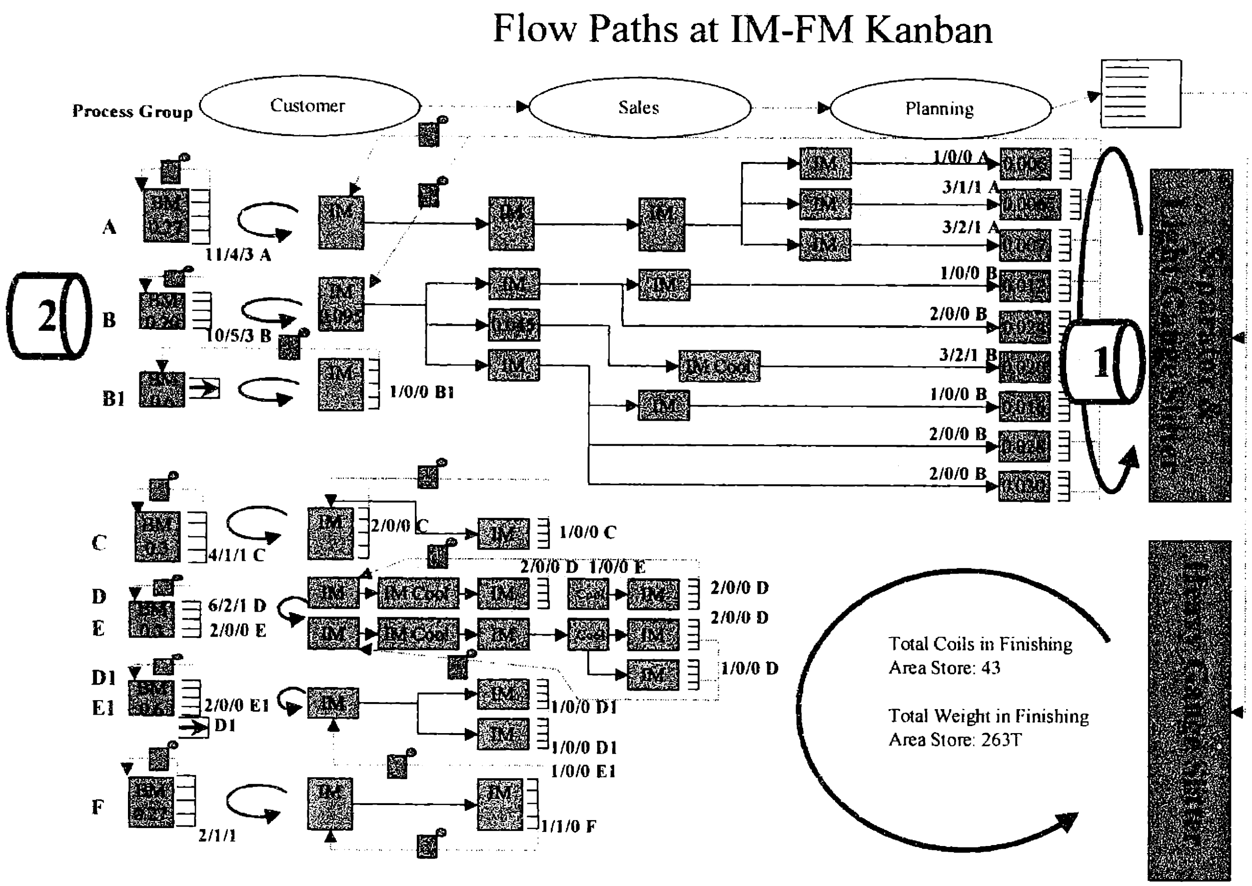


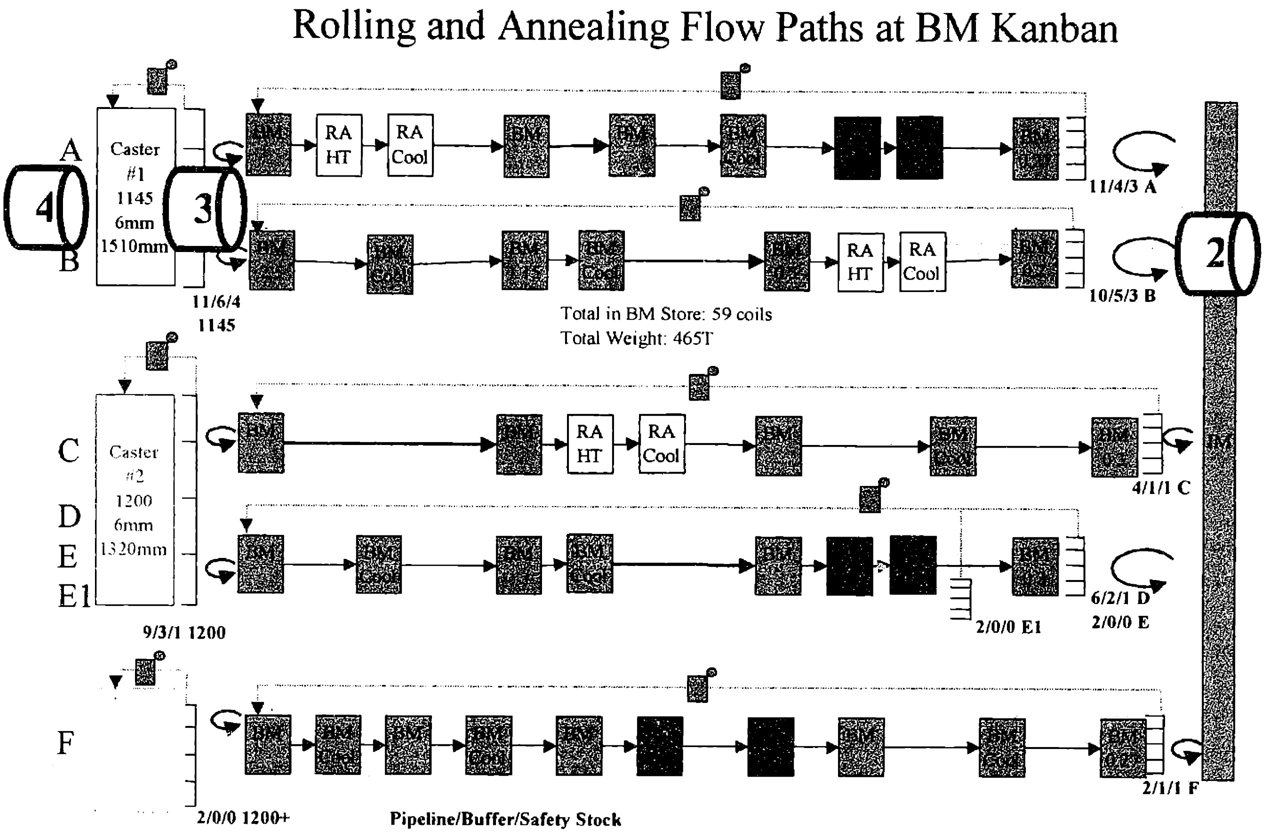
Figure 18 illustrates the kanban system between the finishing area and BM. Two stores have been established: 1) for coils rolled to their final gauge and 2) between the BM and IM. A 0.020mm coil pulled by the separator or light gauge slitter is used as an example. The separator or light gauge slitter is given a schedule that is based upon customer orders. When a coil is pulled from the 0.020mm store (Coil #1), the kanban accompanying that coil is returned to the IM. Receipt of the kanban by the IM is an instruction to replenish the 0.020mm store. The IM then pulls a 0.200mm, process group B coil (Coil #2) from the store between the BM and IM. While the IM rolls the coil pulled to 0.020mm (0.200mm to 0.095mm, 0.095mm to 0.045mm, cool, 0.045mm to 0.020mm), the kanban from the 0.200mm is returned to the BM.

Figure 19 shows the material flow from the cast shop through the BM. To replenish the 0.200mm store, the BM must pull an 1145 coil (Coil #3) from the store between the cast shop and BM. The coil is rolled and annealed according to the schedules identified on the kanban (6mm to 2.5mm, cool, 2.5mm to 1.15mm, cool, 1.15mm to 0.5mm, RA, RA cool, 0.5mm to 0.2mm). The kanban

]

from the 1145 coil is subsequently returned to the cast shop to cast a new coil (Coil #4) to fill the vacancy in the 1145 store. Through this system, there is always a fixed amount of WIP, equivalent to the number of kanbans introduced into the shop. Store levels are shown in Figures 18 and 19 adjacent to the stores. For example, the 0.200mm, process group B store from which Coil #2 was pulled contains a total of 18 coils – 10 pipeline stock, 5 buffer stock, and 3 safety stock.

Figure 19: Pull system between the IM and cast shop



3.3.5 Planning and Scheduling

At ASAP, planning became greatly simplified with the introduction of a pull system. Because production was scheduled through the use of kanbans, it was no longer necessary to provide daily work instructions to the cast shop or rolling area. Operators themselves planned the work for their respective machines. Planning however became critical in identifying key specifications, calculating store sizes, and adjusting cycle stock, buffer stock and safety stock levels when necessary. Furthermore, there was an increased need to work closely with sales and process departments to help translate specific customer requirements into schedules that optimized process groups by sharing rolling and annealing processes with other schedules. Also, it was necessary to initiate production for those specifications that were not maintained in stores due to low demand frequency. These specifications had no kanban associated with them and were considered special cases.

3.4 ASAP's Ideal Condition Diagram

An ideal condition diagram was created to show the benefits of consolidating schedules and implementing a pull production system at ASAP. The diagram, shown in Figure 20, is clearer than the current condition diagram in Figure 5. Material flows are less circuitous and inventory "tombstones" have been replaced by stores of key specifications. Only a single schedule is utilized, given to the finishing area machines. The cast shop no longer receives a monthly production schedule based upon a forecast. The BM, IM, and FM are not given daily task sheets. Instead, coils are pulled through the rolling area and cast shop by the finishing machines.

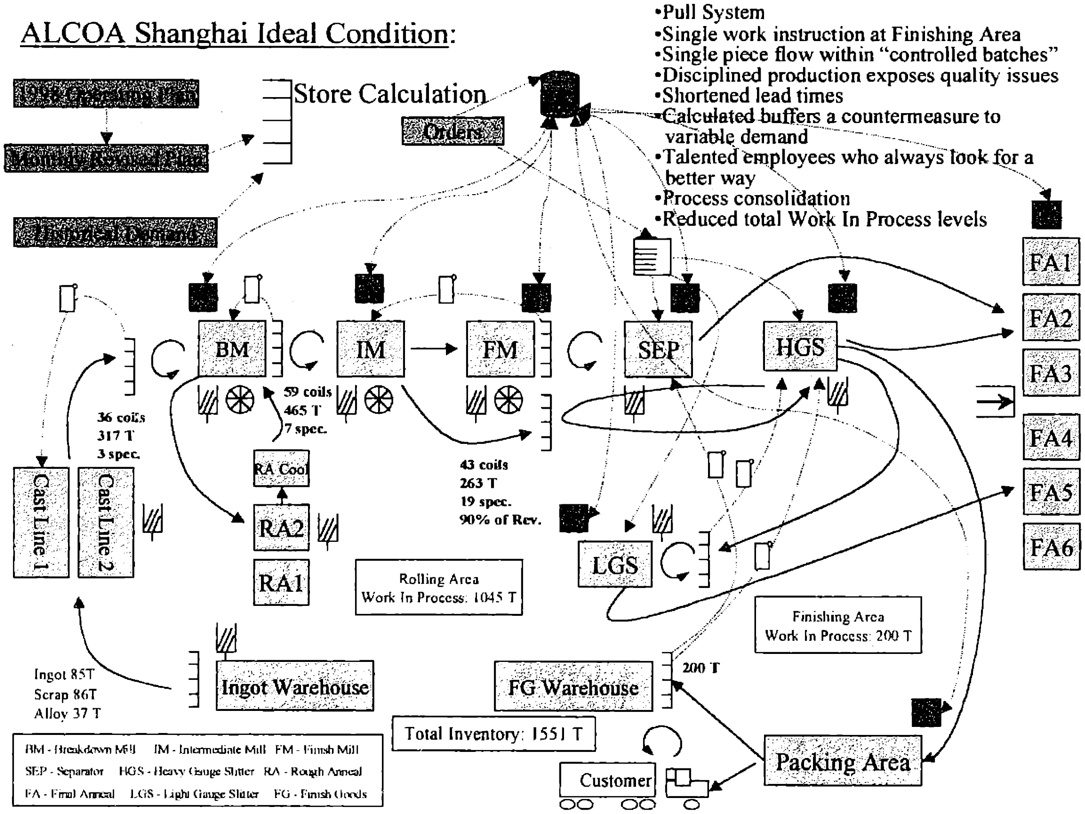


Figure 20: ASAP ideal condition diagram

4. Creating the Visual Factory

While understanding the current condition and defining the ideal situation pose significant challenges, the ability to implement and sustain the ideal condition is the shortcoming of most change initiatives. There can be a failure to recognize the amount of preparation required before change will be accepted by a factory. Painting racks and making kanbans do not in themselves guarantee that production is lean or even visual. These activities are only tactical and may be readily duplicated by competitors. Rather, the principles and emotions associated with the ideal condition must be both understood and embraced by the people who will be impacted by the change that the ideal condition drives. Ultimately at ASAP, implementing a visual inventory management system required a shift in culture and attitude.

4.1 Establishing the Coordination Team

Leadership is key to realizing the ideal condition. Initially a team should be assembled to begin to understand the current situation, define the target state and to educate and train employees. Ideally that team includes some individuals who have familiarity and experience in the underlying principles supporting the ideal condition. The team is solely a coordination team and should not be seen as an implementation team. Implementation itself is the decision and responsibility of everyone.

At ASAP, a coordination team was created while defining the current condition. The team originally consisted of several people including the former purchasing manager, a translator, a newly hired engineer, an assistant to the general manager, the author, and the general manager. A leader from each of the four shifts also joined the group. Participation by the general manager was essential in that it demonstrated that the efforts of the group were fully supported by ASAP. In addition, the shift leaders brought a different perspective to the group and ensured that, as the current condition was understood and ideal condition defined, the coordination team was sensitive to the needs and realities of the shop. Daily morning meetings were held to inform the off shift leaders of the project's progress and to receive questions that might have arisen during the night (Figure 21). The shift leaders communicated the activities and motives of the group to the factory.

Figure 21: Coordination team daily meeting

Soon after the initial team was formed it became apparent that other individuals would be critical to defining and implementing the new production system. Resistance was encountered and it was clear that the resistance was due to the team's failure to include certain key people. For example, annealing and rolling schedules were consolidated without involving the individual directly responsible for those schedules. While his manager had been included, it was this individual that would ultimately be required to verify that the new schedules were acceptable and implement them. The planning manager was initially critical of the idea of the pull system primarily because he had not been educated in its principles or involved in the development of the first kanban system in the cast shop. To ensure that people were better informed, representatives from the planning, process, and information technology departments were asked to join the team. Ultimately team members need to include people who will be affected by the change as well as people responsible for implementing the change. The coordination team too should be comprised of a diverse group of individuals: managers, operators, and staff that clearly understand their role. It is helpful that the group have a single leader to ensure that proper direction of the group's activities is maintained. Finally, the team members must be dedicated full time. Distractions with current work hinder a person's ability to clear biases and generate new kinds of thinking.

4.2 Education and Simulation

A visual factory can only exist if people have been educated about the limitations that the current environment imposes, the basic concepts upon which the ideal condition is built, what the ideal condition is, and how the ideal condition will help them in their work. The education can be formal or informal. For example, it may be as simple as an explanation of why information is being sought regarding an operator's work. Or it may be as complex as a presentation on the sources of manufacturing variability. Most people are interested in what goes on around them. Assuming what people need to know or don't need to know is potentially obstructive to learning, as is underestimating their ability to learn.

Teaching can be a very rewarding experience because it shapes people and influences thought. While there are several modes of teaching, fun hands-on exercises appear to be effective in a manufacturing environment. In these exercises, people seem to be particularly stimulated because they are able to use their intuition, actively participate, and interact with other people. Several games and activities were created at ASAP where employees learned by doing.

A Lego simulation (Figure 22) was developed (Alcoa, 1998) to help illustrate the current condition that existed at Alcoa Shanghai and to demonstrate the benefits that the ideal condition, a pull system, would provide. Three operators manned three workstations in series. A fourth employee acted as a shipper. A simple widget was constructed using Lego's, with each operator contributing successively to the assembly. The simulation was conducted in two phases. In the first phase representing the current condition, material was unorganized and each machine worked to a different schedule. It was common that a workstation lacked the part that it needed to complete its schedule because it had not received the part from the upstream workstation. Furthermore, operators found that they had difficulty delivering widgets to their customer.

Figure 22: Lego simulation

In the second phase, a pull system was introduced and only one production schedule existed. Stores of parts were established between the workstations. An operator pulled the parts needed from the upstream store to replenish the downstream store or to fill customer demand. It was clear that in the second phase, the plant was better able to consistently meet the requirements of its customer. The simulation introduced the idea that there were costs associated with labor, finished goods inventory, and work in process inventory and a simple calculation for profit was performed.

A second game (Figure 23) was created to help employees understand the reasons that inventory exists and to differentiate between the three types of inventory. The game consisted of a flower (customer), raindrops (product), and a cloud (supplier) and considered three environments: 1) constant demand, 2) variable demand, and 3) variable demand with variable supply. The game was played through 10 iterations or "days". Each day, a demand card was drawn indicating the flower's total demand of raindrops for that day. The flower "pulled" available raindrops from the ground (the raindrop store). A supply variability card was also drawn (for those scenarios having no variability of supply, no card was drawn) to indicate the ability of the cloud to produce raindrops on that day. There was a lead-time associated with the production of the raindrops and a signal time to account for the amount of time required to signal the cloud to produce raindrops.

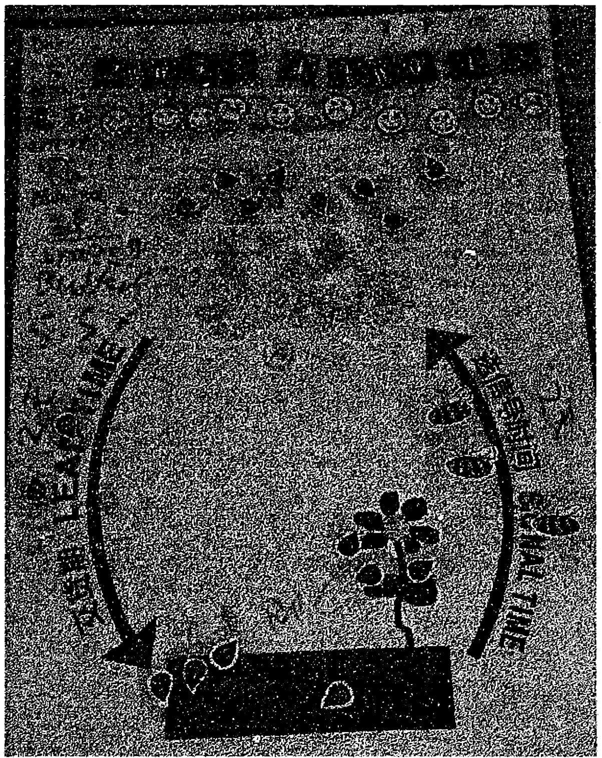


Figure 23: Inventory game

Employees calculated the number of raindrops needed as pipeline stock, buffer stock, and safety stock. Records were kept to monitor the system's ability to meet customer demand.

A final example that used hands-on learning was a demonstration that introduced the advantages of producing in smaller lots (single piece flow) over longer production runs of large batches (Figure 24). During a training exercise, employees were asked to select one of three beverages that would be served to them during their break. Their choices were juice, coffee, or tea. Two employees were asked to prepare and serve the drinks. One employee was asked to prepare each drink individually. Individual order preparation meant pouring the proper drink mix into a glass, adding water, stirring, and serving the order. This was repeated for each order and orders were not grouped. The other employee was asked to prepare each drink type in a batch. Orders were grouped such that all drinks of the same type were prepared together. Furthermore, processes were also batched. For example, when the juice orders were filled, the employee first assembled all of the cups, poured the juice mix into each cup, added water to each cup, and then stirred each mixture. Employees saw that those people whose drinks were prepared on an individual basis received their drinks more quickly.

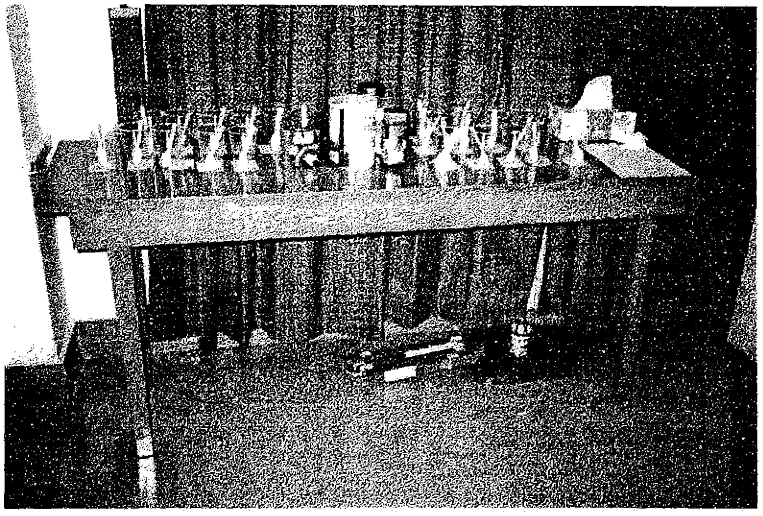


Figure 24: Small batches game

Members of the coordination team conducted most of the training. Because of the number of employees requiring training, it was realized that additional teachers would be necessary. "Train the trainer" sessions were held for representatives from each department. The new trainers became welcome members of the coordination team.

While an attempt was made to provide interactive, hands-on training, as much as possible, it was necessary to include more theoretical training as well. In the more formal types of training, employees attended lectures where the trainer helped people understand the concepts in more detail. Each employee received a handout that described the subject and followed the lecture. Employees were encouraged to take notes. These handouts were accumulated by each employee in a binder distributed at the beginning of the training sessions. The binder then served as a point of reference in the shop for each employee, containing information regarding the basic principles that were the foundation of the visual inventory management system at ASAP.

Figure 25: Training session

4.3 Creating an Environment of Inclusion

When people feel that they are a part of something, they are more apt to want to contribute to its success. Any deviation from the status quo represents a disruption in the shop and is likely not viewed favorably unless steps have been already taken to create an environment where people feel needed and included.

When designing the pull system in the rolling area, the coordination team utilized the expertise of the employees in the area. Simulations were run on scaled models of the shop where operators, using stop watches and small aluminum coils, followed the rolling and annealing schedules and pulled material through the area (Figure 26). Through their observations, the operators established the rules that would govern the pull system. The failure in implementing change is often the result of forcing the change on individuals who never had any input as to what that change should be.

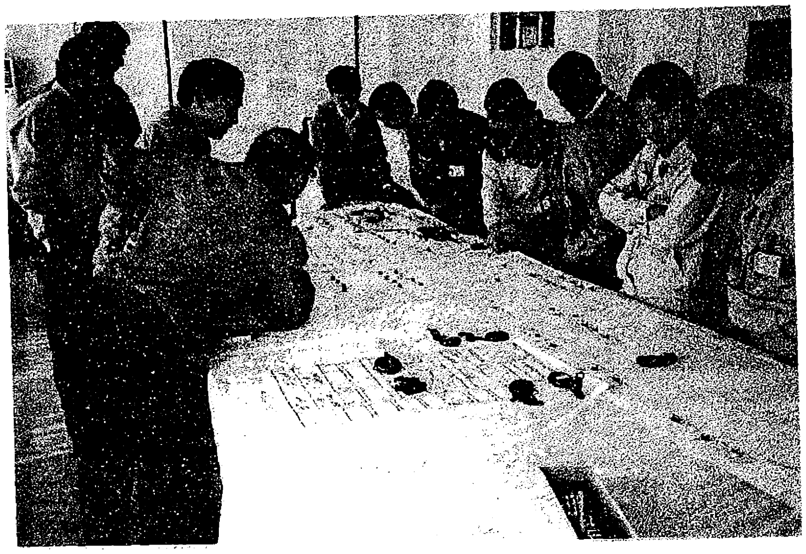


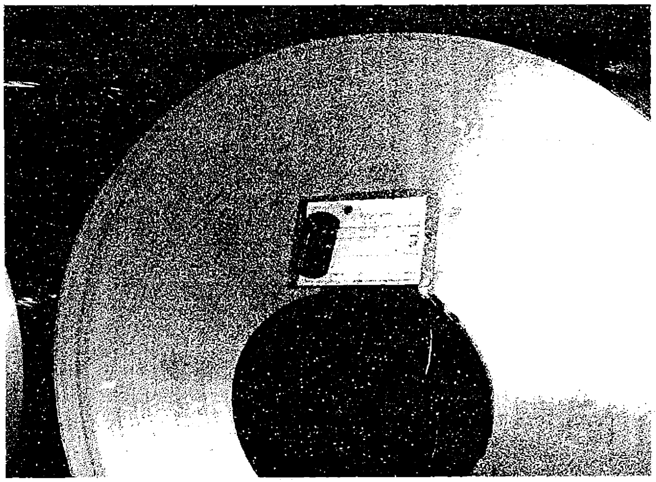
Figure 26: Pull system simulation

4.4 Elements of the Visual Factory

4.4.1 Kanbans

Kanbans were a critical element to ASAP's visual inventory management system in that they provided both material identification and explicit processing instructions. The kanbans were color coded to indicate alloy. They also included the rolling and annealing schedule to be followed and identified the customer and the supplier for that specification. Each coil in the system was accompanied by a kanban. The number of kanbans issued restricted the total WIP level. A kanban and coil are shown in Figure 27.

Figure 27: Coil with kanban



4.4.2 Racks

Racks at ASAP were color coded to indicate alloy (Figure 28). Furthermore, racks were designated to hold only a certain specification. Prior to this, coil specifications were readily mixed in the racks, making locating a specific coil extremely difficult. Racks not designated to hold coils were roped off so they could not be used. Also, coils were no longer allowed to be placed on the floor. Each coil was destined for a rack or machine at all times.

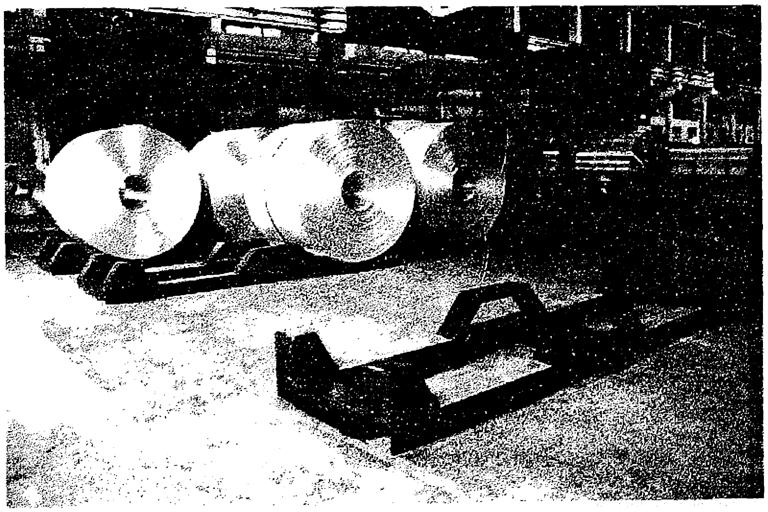
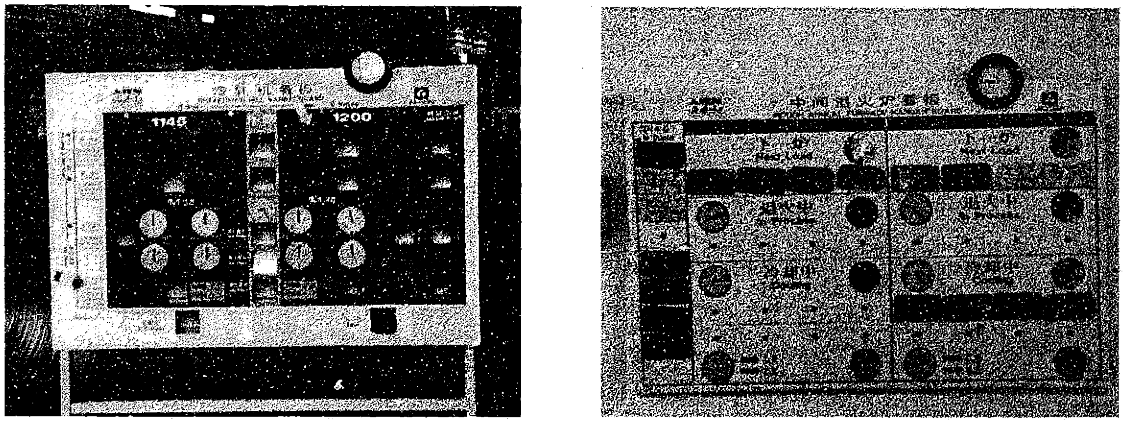


Figure 28: Painted racks

4.4.3 Kanban Boards

Kanban boards were essential to the sequencing of coils at each machine. The boards were largely the design of operators and incorporated production rules that helped to make flow through the machines more efficient. For example, on the rolling mills, it was advantageous to roll coils from a wide specification to a narrow specification to manage roll heating and prevent unnecessary roll changes. BM operators also noted that the final pass on the BM required a different roughness than the other passes and suggested that the final pass kanbans be grouped separately from the intermediate and first pass kanbans. The BM and RA kanban boards are shown in Figures 29a and 29b, respectively.



a

b

Figure 29: Kanban boards

5. Results and Conclusions

A pull system utilizing a kanban methodology was implemented at ASAP in the cast shop and rolling area in approximately 6 months. While the inventory levels in these areas remained unchanged when compared to current levels, the number of stagnant coils dramatically decreased as shown in Figures 30 and 31.

Figure 30: Before pull system

Figure 31: After pull system

The difference between the "before pull system" and "after pull system" figures is due to the fact that the "after" coils have been pulled by downstream machines and replacement coils are in process – in the cast shop, on the BM, in the annealing furnace, or cooling. Because need rather than forecast drives the system, there are fewer coils that remain in the racks for extended periods of time. It was anticipated that total inventory levels would be reduced from 2000T to 1600T. Furthermore, by Little's law (Hopp, 1996), it was estimated that coil manufacturing times would be reduced from 19 days to 15.5 days.

The lasting benefits of a pull system come not from an overall reduction of WIP and finished goods inventory, but from the discipline that the system requires and the active participation of all employees in developing and sustaining it. The reduction in inventory is not the result of the pull system, but rather a consequence of understanding the reasons why inventory currently exists, consolidating rolling and annealing schedules, producing only those specifications that are needed, and following the priority defined by the kanban boards.

Appendix

A. Continuous Improvement

Inventory must exist because of flexibility and reliability constraints inherent to every process. In order to reduce inventory levels, one or more of these constraints must be improved upon or eliminated. Immediately identifying a project to work on is key in beginning to develop the mental framework required to maintain a pull system. By looking for opportunities to eliminate any forms of waste that contribute to constraints such as poor material quality or long lead-times, it is possible to eliminate inventory. Often however, the tendency is to accept flexibility and reliability constraints as given or fixed. By beginning to think critically, employees will be better able to understand and recognize inadequacies in the current condition and recommend improvements for the ideal state.

An Example – Coil Cooling

Coils are most efficiently cooled after rough anneal when forced convection is concentrated in the axial direction of the coil rather than in the radial direction. In the axial direction, the thermal conductivity of solid aluminum is 85% greater than the thermal conductivity in the radial direction (Richard M. Beeler, 1998). This is due to the insulating effects of the air, oil, and oxides between each wrap of the coil. It means that heat is conducted more efficiently in the axial direction than the radial direction. Furthermore, calculation of a Biot number indicated that the heat transfer coefficient of the air is rate controlling for axial cooling. In other words, the resistance to conduction within the solid is much less than the resistance to convection across the fluid boundary layer (Incropera, 1990). Thus, to speed coil cooling after rough anneal, it is not only necessary to cool in the axial direction, but also to find a means to reduce the heat transfer coefficient in the air. The calculation of the Biot number is shown.

Interpreting the Biot number to be the ratio of thermal resistances (Incropera, 1990),

$$Bi = \frac{R_{conduction}}{R_{convection}} = \frac{hL}{k}$$

h = convection heat transfer coefficient, $45\, {}^{W}\!/_{m^2K}$

L = characteristic length, $0.9m$

k = thermal conductivity, $222\, {}^{W}\!/_{mK}$

$$Bi \sim 0.18$$

A team was organized to identify and implement a solution to the coil cooling problem. Cooling accounted for approximately 20% of total lead-time in the rolling area. To reduce this time would imply that calculated pipeline stock levels could be reduced in the stores. The group recognized that while an eight coil cooling station existed for coils to cool after rough anneal, coils were first cooled in an interim location, as the final cooling stations were usually full. At the interim location, coils cooled in ambient air. It was felt that some improvement to these areas could reduce total cooling time. The group proposed that a dedicated high velocity fan be placed on each coil, blowing in the axial direction, as close as possible to the coil. Totally eight fans were installed at two cooling areas in the interim location. It was anticipated that cooling time could be reduced by 10% -15% by this improvement project.

B. Approaching Manufacturing Problems in the People's Republic of China

Likely the author's greatest learning in developing a framework for defining and implementing a visual inventory management system came from the realization that manufacturing problems should not be approached differently because of their geographic location. Manufacturing systems are constrained by similar underlying issues. Methods for identifying and resolving these issues should not be influenced by the location of the system.

It was the author's experience that people are very similar. While clearly language and cultural differences exist, people everywhere have similar needs; people want to learn, to be respected, to be secure and provide for their families, and to do a good job and feel that they are adding value. When introducing change into a manufacturing system, it is helpful to be aware of these needs. It is also helpful to avoid making assumptions about the capabilities of the people ultimately responsible for implementing and sustaining the change.

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