

## A GLASS FLOAT LINE SIMULATION: MODELING METHODOLOGY AND APPLICATIONS

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### ABSTRACT

A glass float line begins as a continuous process, liquid glass in a furnace, being pulled down a cooling conveyor in a continuous ribbon of glass. The process then becomes discrete as the ribbon is scored and broken into individual streams. Using some insight, a simulation model is developed that is strictly discrete. Four applications of the model are presented. The first demonstrates how the model assists with the day to day operation of the float line. A second application looks at modifying the control rules which sequence and schedule the glass production. The final two applications show how the model is used to study design alternatives for a future float line.

### 1 INTRODUCTION

A float line process begins with the product in a liquid state. The liquid is drawn down a conveyor as a continuous ribbon of material from the holding vat. This ribbon is cut and separated into panels of various sizes. These panels are transferred off the mainline conveyor to various spurline conveyors. A float line process is used in the production of glass panels, ceiling tiles, and other products. The focus of this paper is a glass float line.

The glass float line process begins at a large glass furnace which melts sands and other materials to form liquid glass. The liquid glass flows from the furnace down a mainline cooling conveyor, forming a continuous ribbon of glass. This ribbon of glass flows continuously from the furnace, 24 hours a day, 365 days a year. Figure 1 is an overhead view of the glass float line.

Downstream from the furnace, the now-cooled ribbon of glass passes under a series of cutters. The cutters score the ribbon according to a cutting schedule and a cutting algorithm. The cutting schedule contains dimensions of glass panels for each route on the float line. The float line modeled contains 14 routes, two for each spurline. Therefore, there are a maximum of 14 glass panel sizes which may be cut during a production run. The cutting schedule also allows the float line operator to set routes as active or inactive. Only glass panels for active routes are cut.

The cutting schedule also contains the standard removal rate for each glass panel. The velocity for each spurline is set as a function of the removal rate for panels routed to that spurline. Because each glass panel may contain a different removal rate, every spurline can be running a different velocity. This factor complicates the development of efficient cutting schedules.

Another complicating factor for developing efficient schedules is the cutting algorithm. The cutting algorithm looks at all the active routes and determines which route to use next. A sequential cutting algorithm causes the cutters to cut panels sequentially from the first route to the last route, and then back to the first route again. A dynamic algorithm creates a more random order to cut glass panels. This order is usually based on the panel removal rates, with the order continuously changing throughout the production run.

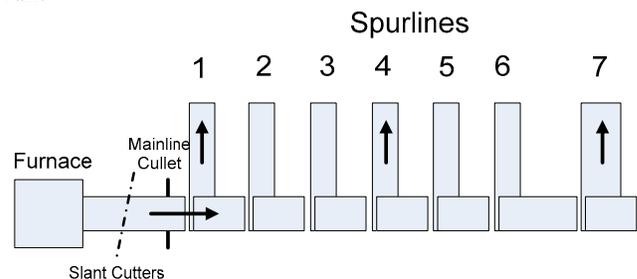


Figure 1 – Diagram of glass float line

Once cut, the panels continue down the mainline until they reach their spurline destination as specified by the cutting schedule. When a panel is approaching its spurline destination, a gate on the mainline lowers and the panel transfers onto the spurline belts. If the belts of the spurline are occupied by another panel, the first panel will wait on the mainline gate until the belts are available. When in position, the belts come up and transfer the panels onto the spurline. When the glass is completely off the belts, the belts become available to accept another panel.

If glass is approaching an occupied gate, the glass will stop on the previous mainline conveyor section. As a rule, only one panel of glass can occupy a section of conveyor at

a time. Glass may continue to back up on the mainline all the way to the mainline cullet chute located just upstream of the first spurline. Glass is then scrapped down the cullet chute until the mainline clears.

Upon leaving the spurline belts, the glass panels travel down to the end of the spurline where workers remove the glass panels. The workers place the panels in crates for storage. This is the end of the float line process.

## 2 THE MODEL

The first major design issue when developing a simulation model of the glass float line is how to handle the combined continuous-discrete nature of the process. Several authors have successfully demonstrated case studies of combined continuous and discrete systems, Akatsuka, et al. (1997), Arer and Ozdemir (1999), Chen and Pidd (2005), and Sezgi, et al. (1993). Fortunately, however with the glass float line, the furnace which produces the continuous flow of glass can be assumed to always produce the proper flow and never experience downtime. The float line personnel explain that the furnace is almost never shut down because of the significant difficulty in restarting the flow of glass. The furnace therefore runs virtually 24 hours a day, 7 days a week, 365 days a year. Thus, in the simulation, the only component that is considered in the model is the float line conveying system itself.

The float line begins with a continuous ribbon of glass, this ribbon is scored across its width with slant cutters soon after the glass ribbon cools and becomes solid. The glass between each score is called a "stream". After the ribbon has been scored, the ribbon passes over a snap roller which breaks the ribbon into the individual streams. The streams are then separated as the streams transition from a conveyor at one speed to one running at a faster speed. This "pulls" a gap between the streams. Thus individual streams of glass are formed and are the basis of entities for the discrete simulation model. Therefore the simulation model is started at the slant cutter and is a strictly discrete model.

To model the creation of the streams of glass at the slant cutter, the time between creation becomes a function of the distance between the leading and trailing edges of the stream being cut and the velocity of the conveyor. The cutting schedule and sequencing algorithm determine the order in which streams are cut, and thus the width of the stream. The schedule and sequencing algorithm are discussed in more detail below.

From this point, the stream entity travels down the mainline over several speedup conveyors and through some horizontal cutters which score the steam into two or more brackets or panels. The speedup conveyors pull successively larger gaps between the entities. Once a stream approaches its designated spurline, the entity is routed down a tilt down conveyor. If the tilt down conveyor is

not free of its previous stream, the approaching stream will halt on the previous zone of the mainline. Conceivably, successive streams can be halted until the mainline backs up to the mainline cullet chute. If so, following streams will be sent to the cullet as scrap until the mainline begins to clear. In the simulation, this logic is handled with a series of resource seizing, queuing and routing.

Once the stream entity has entered the spurline, the brackets or panels which makeup a stream are separated with another snap roller. The stream entity is then converted into multiple bracket entities. The number and time between creation of these entities is also a function of the cutting schedule and the speed of the spurline conveyors. The panel entities continue down the spurline conveyor and are disposed at the end of the spurline. In total, the simulation consists of 29 resources, 74 conveyors, and 123 stations. In addition, over 600 parameters have been defined in the simulation, describing anything from conveyor speeds to the cutting schedule.

## 3 SELECTED APPLICATIONS

Listed below are four applications of the glass float line simulation model. The first application demonstrates that the simulation can be used to manage the day to day operations. While the other three applications are engineering design type analyses.

### 3.1 Analysis of Cutting Schedules

A primary function in the daily operation of the glass float line is to develop effective cutting schedules. An effective schedule is one that balances the workload for each of the removal operators, produces little to no scrap, and minimizes the number of active spurlines in an effort to reduce operating costs. There are obvious tradeoffs for each of these objectives. For example, if too few spurline routes are activated, then the mainline conveyor will backup, resulting in an excessive amount of mainline scrap. The unlimited number of cutting schedules and the dynamics of the system caused by panel removal rate and cutting algorithms, make the scheduling of this process an ideal candidate for simulation.

In order to demonstrate how the simulation is used to analyze cutting schedules, a typical cutting schedule analysis session is provided. The analyst begins with the cutting schedule presented in Figure 2. Note that there are 11 active routes for this cutting schedule. The analyst must also input the float line operating parameters as shown in Figure 3. The conveyor speeds are a function of the glass thickness and "speedup" factors. In addition to the conveyor speeds, the cutting algorithm and simulation run length are also specified.

Float Line Cutting Schedule					
Route #	Width (in)	Length (in)	Active	Brackets/Stream	Unload Time (sec)
72	100	200	1	1	10
71	0	0	0	0	0
62	50	42	1	2	10
61	45	46	1	3	10
52	70	35	0	2	0
51	70	35	1	2	10
42	70	35	1	2	10
41	70	35	1	2	10
32	15	30	0	9	0
31	15	30	1	9	5
22	20	45	1	7	5
21	22	40	1	6	5
12	70	35	1	2	10
11	70	35	1	2	10

Figure 2 – Float line cutting schedule

Operating Parameters			
Tons / Day	475.00		
Ribbon Width (in)	150.00		
Glass Thickness (in)	0.09		
Lehr Speed (in/min)	541.31		
Cordwood Conveyor Speed (in/min)	622.51		
Speedup Conveyor Speed (in/min)	3000.00		
Drive #1			
Spurline	High (in/min)	Low (in/min)	
1	1000.00	420.00	
2	1000.00	264.00	
3	1000.00	180.00	
4	1000.00	420.00	
5	1000.00	420.00	
6	1000.00	300.00	
Drive #2			
Spurline	High (in/min)	Low (in/min)	Drive #3 (in/min)
1	1100.00	462.00	462.00
2	1100.00	290.40	290.40
3	1100.00	198.00	198.00
4	1100.00	462.00	462.00
5	1100.00	462.00	462.00
6	1100.00	330.00	330.00

Figure 3 – Operating parameters

Results of the simulation run are shown in Figure 4. The primary measures of performance are the spurline utilization, the % edge trim, % mainline scrap, and % conveyed to spurlines. Spurline utilization is a measure of the activity level of the unload operator. If the operator is constantly busy, the utilization is 1.000. If the route is inactive, the utilization is 0.000. Utilization is calculated by dividing the actual time between bracket unloads by the standard unload time specified. Edge trim is the amount of glass cut from the edges of the ribbon of glass and scrapped. Mainline scrap is created when too few spurlines are set active.

Summary of Results		
Route #	% Spurline Utilization	# of Brackets Removed
11	0.316	96
12	0.316	96
21	0.475	288
22	0.554	336
31	0.534	324
32	0.000	0
41	0.316	94
42	0.316	94
51	0.316	96
52	0.000	0
61	0.474	144
62	0.316	96
71	0.000	0
72	0.158	48
Average Utilization	0.372	
Total Edge Trim for Run (sq ft)		6197.92
Mainline Scrap for Run (sq ft)		0
Total Glass Capped (sq ft)		26687.5
Total Glass (sq ft)		32885.42
% Edge Trim		18.85
% Mainline Scrap		0
% Conveyed to Spurlines		81.15

Figure 4 – Summary of results with 11 active routes

In reviewing figure 4, the analyst noted that the average spurline utilization was very low, 37.2%. The analyst decided to reduce the number of active routes to 8. Figure 5 presents the simulation results with the 8 active spurlines. The average utilization increased to 69.2% and no scrap was generated.

The analyst decided to further reduce the number of active routes to 6. The results are presented in Figure 6. The spurline utilization fell to 50.4% and 35.88 % of the glass was scrapped at the mainline cullet. This indicates that not enough spurs were in use and the mainline backed up. The backup created a bottleneck at spur 1, causing spur 2 and spur 6 to become starved at times, reducing their utilization.

Summary of Results		
Route #	% Spurline Utilization	# of Brackets Removed
11	0.707	210
12	0.707	210
21	0.706	426
22	0.824	497
31	0.000	0
32	0.000	0
41	0.706	212
42	0.706	212
51	0.000	0
52	0.000	0
61	0.707	213
62	0.471	142
71	0.000	0
72	0.000	0
Average Utilization	0.692	
Total Edge Trim for Run (sq ft)		3460.55
Mainline Scrap for Run (sq ft)		0
Total Glass Capped (sq ft)		29399.87
Total Glass (sq ft)		32860.42
% Edge Trim		10.53
% Mainline Scrap		0
% Conveyed to Spurlines		89.47

Figure 5 – Summary of results with 8 active routes

### 3.2 Comparison of Cutting/Sequencing Algorithms

As mentioned in the Introduction, cutting algorithms look at all the active routes and determine which route to use next. During this study, the float line in production was using the sequential cutting algorithm. A sister plant uses a dynamic cutting algorithm. While using the simulation to compare these two algorithms, a third algorithm was conceived. This new algorithm has been coined the modified-dynamic algorithm. All three algorithms are presented below.

Summary of Results		
Route #	% Spurline Utilization	# of Brackets Removed
11	0.898	268
12	0.899	268
21	0.319	186
22	0.372	217
31	0.000	0
32	0.000	0
41	0.000	0
42	0.000	0
51	0.000	0
52	0.000	0
61	0.322	96
62	0.215	64
71	0.000	0
72	0.000	0
Average Utilization	0.504	
Total Edge Trim for Run (sq ft)		3754.43
Mainline Scrap for Run (sq ft)		11800.07
Total Glass Capped (sq ft)		17334.04
Total Glass (sq ft)		32888.54
% Edge Trim		11.42
% Mainline Scrap		35.88
% Conveyed to Spurlines		52.71

Figure 6 – Summary of results with 6 active routes

#### Sequential:

- 1) Cut streams for all active routes, in order from spurline 7 to spurline 1.
- 2) Repeat steps 1 to 2.

#### Dynamic:

- 1) Initialize a clock for every active spurline to 0. These clocks increment one unit for every elapsed second.
- 2) Find the spurline with the greatest clock value and cut all active routes for that spurline.
- 3) Reset the clock for the spurline chosen in step 2 to minus the stream removal time<sup>1</sup> for that spur.
- 4) Repeat steps 2 to 4.

Modified-Dynamic:

- 1) Initialize a counter for every active spurline to 0.
- 2) Find the active spurline with the smallest counter value and cut all active routes for that spurline.
- 3) Increase the counter for the spurline chosen in step 2 by the stream removal time<sup>1</sup> for that spur.
- 4) Repeat steps 2 to 4.

$$^1 \text{Stream removal time} = \text{Max}_i \{(rm_i + rt_i) * n_i\}$$

$rm_i$  - standard time to remove panel  $i$

$rt_i$  - time to rotate panel  $i$

$n_i$  - number of panels per stream  $i$

$i$  - an element of the set of active routes for the stream.

To compare the three cutting algorithms, 4 typical cutting schedules were defined. Two performance measures are of interest. The first performance measure is the maximum difference in spurline utilization between active spurlines. The second performance measure indicates the percentage of scrap glass generated on the mainline. Table 1 shows the results of this analysis.

Table 1 – Comparison of cutting algorithms

Max. Variation in Spurline Util.				
Cutting Schedule	Number of Active Spurlines			
	Sequential	Dynamic	Modified-Dynamic	
1	6	0.370	0.361	0.007
2	5	0.442	0.425	0.004
3	4	0.288	0.278	0.005
4	3	0.471	0.146	0.015
Percent Mainline Scrap				
Cutting Schedule	Number of Active Spurlines			
	Sequential	Dynamic	Modified-Dynamic	
1	6	0.0%	0.0%	0.0%
2	5	5.9%	7.2%	0.0%
3	4	8.7%	7.8%	0.0%
4	3	27.9%	5.9%	2.5%

The modified-dynamic cutting algorithm significantly outperforms both the sequential and dynamic algorithms for all cases reviewed. For most cases, the modified-dynamic provides an almost perfect balance in utilization. This allows for fewer spurlines to handle the furnace load

without generating scrap. This also results in higher worker morale because of balanced workloads.

### 3.3 Cost Penalty Analysis of 4 vs 5 Spurlines

A third application of the float line simulation was to help the glass plant with an engineering design and cost study. The plant was in the process of studying the purchase of another float line, a multi-million dollar study. Because 4 spurlines could handle any cutting schedule, one major point of discussion was whether to pursue a 4 or a 5 spurline configuration. The measure and cost of interest was how much lost production could be expected with each configuration.

To assist with this study, the first consideration was to estimate the expected downtime of a spurline. The plant's technical estimate was that a line could be expected to be in operation 90% of the time, allowing 10% for planned and unplanned maintenance activities for this 24 hour a day operation. The simulation was then loaded with a 64 day production schedule and run with 5 active spurlines. The reported measure of interest is the percent of mainline scrap. The same 64 day production schedule was then simulated with 4, 3, 2 and 1 active spurline(s). Using the Binomial probability function, and the estimate of a 90% uptime rate for each spurline, the probability of having 5, 4, 3, 2, 1 or 0 spurlines in operation is calculated. These probabilities are used in conjunction with percent mainline scrap generated from the simulation runs to calculate an expected scrap rate for the 4 and the 5 line configuration.

The result of the calculations is that there is a 3.07% expected loss in production due to mainline scrap with the 4 spurline configuration. With the 5 spurline configuration, there is a 0.62% expected loss in production. Management felt the additional 2.45% loss in production of the 4 spurline configuration was unacceptable, and opted for the 5 spurline configuration.

### 3.4 Comparison of Upstream –vs- Downstream Scrap Strategies

In addition to studying the benefits of 4 vs 5 spurlines, plant management was also interested in determining the benefit of moving the mainline scrap conveyor to the end of the mainline. For the current float line, if glass is approaching an occupied spurline gate, the glass will stop on the previous mainline conveyor section. Glass may continue to back up on the mainline all the way to the mainline cullet chute located just upstream of the first spurline. An alternative is to position the mainline cullet chute at the end of the mainline. In this configuration, if a stream of glass destined for a spurline arrives while that spurline gate is occupied, then the stream will bypass the spurline and continue down the mainline to the cullet chute.

The mainline cullet was relocated in the simulation. The same 4 vs 5 spurline study from section 3.3 was performed with this new mainline cullet configuration. With the new configuration, there is a 2.46% production loss for the 4 spurline configuration and a 0.47% production loss with the 5 spurline configuration.

#### 4 CONCLUSION

A glass float line is modeled as a strictly discrete simulation model using numerous conveyors, stations, resources, and feed and speed parameters. This simulation can be used on a daily basis to assess the quality of various cutting schedules. The simulation can also be used for engineering design studies to determine how various spurline, mainline scrap, and cutting algorithms impact the operator workload, and production losses.

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#### AUTHOR BIOGRAPHIES

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