

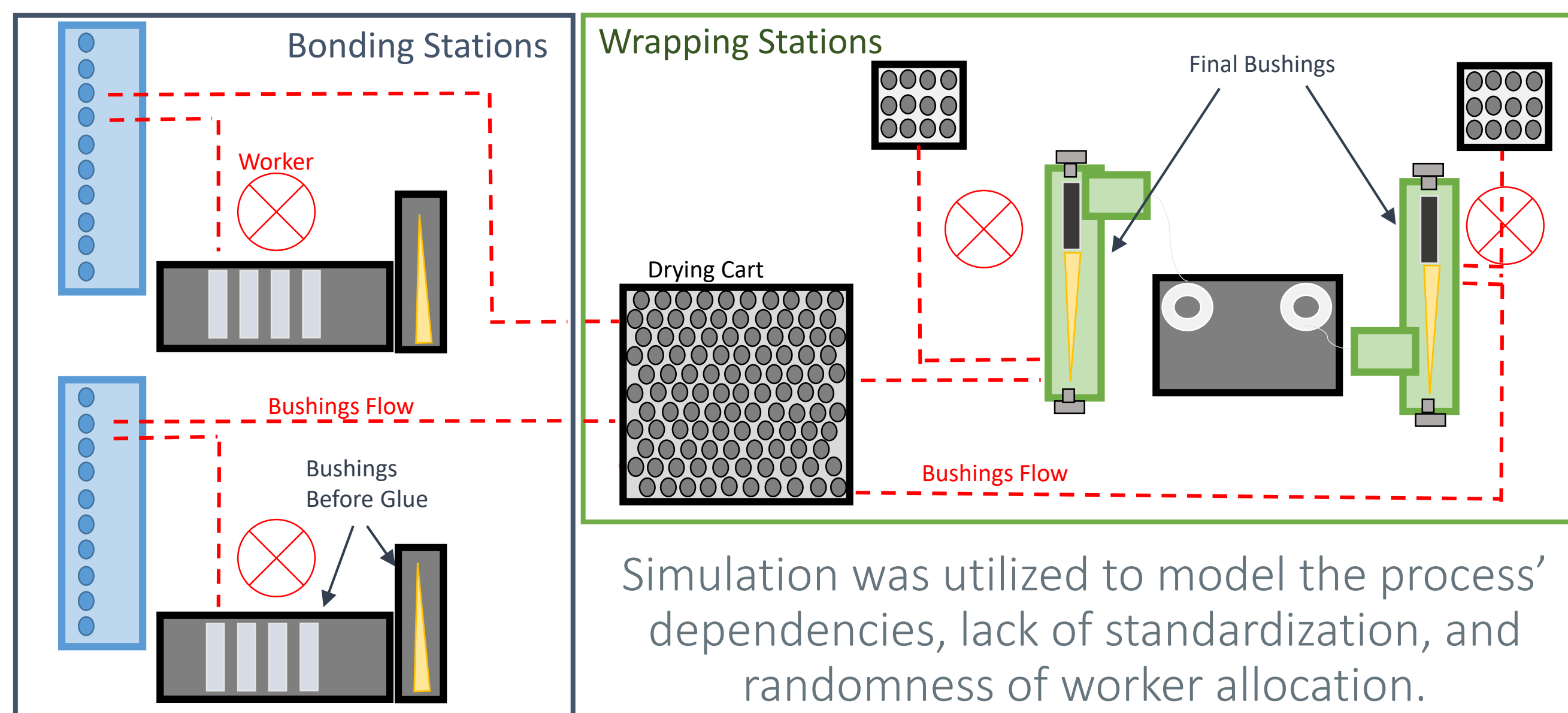
Bushings

What is it?

Bushings are composed of metal tubes bonded to long foam extensions and wrapped in two types of fiberglass. They are utilized to attach and secure the finished blade to the hub of the wind turbine. Bushings can be one of two widths and can number from 64 – 92 per blade.



Data Analysis: Modeling the System with Arena and Monte Carlo



Simulation was utilized to model the process' dependencies, lack of standardization, and randomness of worker allocation.

The min, most likely, and max system times from Arena were run through Monte Carlo and interpolated to fit every staffing scenario across two shifts. **Interpolation for Optimization**

Objective:

Minimize excessive worker hours in the pre-molding process to allow for the productive reallocation of LM employees.

Stakeholders suspected Parkinson's Law may be in effect in the pre-molding area. **Required** (blue bar), **Spent** (light blue bar), **Allotted** (white bar). After preliminary analysis, 6 out of 8 processes were found to possess improvement potential.

Optimization Model

$$\text{Minimize } 7.25 \sum_{i=1}^m \sum_{j=1}^n x_{ij} + 7.25 \sum_{k=1}^p \sum_{j=1}^n y_{kj} + 7.25 \sum_{l=1}^q \sum_{j=1}^n \sum_{r=1}^o A_r z_{lj} + 7.25 \sum_{l=1}^q \sum_{j=1}^n \sum_{r=1}^o B_r z_{lj}$$

$$s. t. \quad x_{ij} \in \{1,0\} \quad \text{for } i = 1, \dots, m \text{ and } j = 1, \dots, n$$

$$y_{kj} \in \{1,0\} \quad \text{for } k = 1, \dots, p \text{ and } j = 1, \dots, n$$

$$z_{lj} \in \{1,0\} \quad \text{for } l = 1, \dots, q \text{ and } j = 1, \dots, n$$

$$\sum_{l=1}^q z_{lj} = 1 \quad \text{for } j = 1, \dots, n$$

$$\sum_{i=1}^m x_{ij} + \sum_{l=1}^q \sum_{r=1}^o A_r z_{lj} \leq 11 \quad \text{for } j = 1, \dots, n$$

$$\sum_{k=1}^p y_{kj} + \sum_{l=1}^q \sum_{r=1}^o B_r z_{lj} \leq 7 \quad \text{for } j = 1, \dots, n$$

$$7.25 \sum_{j=1}^n x_{ij} + 7.25 \sum_{j=1}^n y_{kj} + 7.25 \sum_{j=1}^n \sum_{l=1}^q \sum_{r=1}^o A_r z_{lj} \geq \sum_{s=1}^b H_s \quad \text{for } i = 1, \dots, m \text{ and } k = 1, \dots, p \text{ and } l = 1, \dots, q$$

Variables

x_{ij} = Job assignment for first shift for operation i during day j

y_{kj} = Job assignment for second shift for operation k during day j

z_{lj} = Bushings worker allocation l for first and second shift during day j

A_r = Bushings first shift workers

B_r = Bushings second shift workers

H_s = Required resource hours to complete blade demand for operation s

$i = 1,2,3,4$ (1 = Net Sets, 2 = Carousel Glass, 3 = Hand Glass, 4 = Flange Glass)

$j = 1,2,3,4,5$ (1 = Monday, ..., 5 = Friday)

$k = 1,2,3$ (1 = Net Sets, 2 = Carousel Glass, 3 = Hand Glass)

$l = 1, \dots, 9$ (1 = 1 Worker 1st Shift / 1 Worker 2nd Shift, ..., 9 = 3 Workers 1st Shift / 3 Workers 2nd Shift)

$r = 1,2,3$ (1 = 1 Worker, ..., 3 = 3 Workers)

$s = 1,2,3,4,5$ (1 = Net Sets, 2 = Carousel Glass, 3 = Hand Glass, 4 = Flange Glass, 5 = Bushings)

Deliverable:

Decision support tool that provides a recommended worker allocation schedule to the pre-molding supervisor based on weekly blade demand.

Total energy cost, total employee cost, and total man hours are three metrics of the decision support tool's output having the potential to produce weekly savings based on the demand each week.

Carousel/Hand Glass

What is it?



Carousel glass kitting involves cutting large sheets of fiberglass to specific lengths and spooling them onto cardboard cores for implementation onto the blade's mold. A smaller variant of carousel glass, known as "hand glass", is manufactured on a separate, slower machine.

The Power of Extrapolation

If glass roll length and speed of carousel machine is known for any particular cut of glass, the rest can be estimated via extrapolation.

Data Analysis: Accounting for 250+ Cuts per Blade with Refills

Time studies conducted on carousel glass include the time required to: machine the cut glass, replace raw materials for cutting, and reload machine with desired glass types and cut lengths.

Part #	Material	Ply #	Length (cm)	Width (cm)
01001	BAC 4301000M	33	304	55
01002	BAC 4301000M	33	304	55
01003	BAC 4301000M	33	304	55
01004	BAC 4301000M	33	304	55
01005	BAC 4301000M	33	304	55
01006	BAC 4301000M	33	304	55
01007	BAC 4301000M	33	304	55
01008	BAC 4301000M	33	304	55
01009	BAC 4301000M	33	304	55
01010	BAC 4301000M	33	304	55
01011	BAC 4301000M	33	304	55
01012	BAC 4301000M	33	304	55
01013	BAC 4301000M	33	304	55
01014	BAC 4301000M	33	304	55
01015	BAC 4301000M	33	304	55
01016	BAC 4301000M	33	304	55
01017	BAC 4301000M	33	304	55
01018	BAC 4301000M	33	304	55
01019	BAC 4301000M	33	304	55
01020	BAC 4301000M	33	304	55
01021	BAC 4301000M	33	304	55
01022	BAC 4301000M	33	304	55
01023	BAC 4301000M	33	304	55
01024	BAC 4301000M	33	304	55
01025	BAC 4301000M	33	304	55
01026	BAC 4301000M	33	304	55
01027	BAC 4301000M	33	304	55
01028	BAC 4301000M	33	304	55
01029	BAC 4301000M	33	304	55
01030	BAC 4301000M	33	304	55
01031	BAC 4301000M	33	304	55
01032	BAC 4301000M	33	304	55
01033	BAC 4301000M	33	304	55
01034	BAC 4301000M	33	304	55
01035	BAC 4301000M	33	304	55
01036	BAC 4301000M	33	304	55
01037	BAC 4301000M	33	304	55
01038	BAC 4301000M	33	304	55
01039	BAC 4301000M	33	304	55
01040	BAC 4301000M	33	304	55
01041	BAC 4301000M	33	304	55
01042	BAC 4301000M	33	304	55
01043	BAC 4301000M	33	304	55
01044	BAC 4301000M	33	304	55
01045	BAC 4301000M	33	304	55
01046	BAC 4301000M	33	304	55
01047	BAC 4301000M	33	304	55
01048	BAC 4301000M	33	304	55
01049	BAC 4301000M	33	304	55
01050	BAC 4301000M	33	304	55
01051	BAC 4301000M	33	304	55
01052	BAC 4301000M	33	304	55
01053	BAC 4301000M	33	304	55
01054	BAC 4301000M	33	304	55
01055	BAC 4301000M	33	304	55
01056	BAC 4301000M	33	304	55
01057	BAC 4301000M	33	304	55
01058	BAC 4301000M	33	304	55
01059	BAC 4301000M	33	304	55
01060	BAC 4301000M	33	304	55
01061	BAC 4301000M	33	304	55
01062	BAC 4301000M	33	304	55
01063	BAC 4301000M	33	304	55
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01171	BAC 4301000M	33	304	55
01172	BAC			