SUSTAINABLE BIOMATERIALS

Vacuum Drying: Potential for 4/4 red oak flooring lumber?

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December 4th, 2014

Introduction

Increasing global competition, high stumpage and energy prices, and the slowing housing market have challenged the U.S. hardwood lumber industry.

Implementation of continuous improvement programs like lean manufacturing.

Vacuum drying has the potential to reduce drying times, reduce batch sizes and have product quality comparable or superior than conventional drying.

Objective

1. Determine by the use of feasibility analysis (cash flow, net present value, and internal rate of return) differences between conventional and vacuum drying for 4/4 red oak lumber

2. To determine the impact on the work in process (WIP) and cycle time for a flooring manufacturer when vacuum drying technology is compared to conventional drying technology

Terms for the Project

- Conventional
  - Air drying 42 days and conventional steam kiln for 12 days
  - Green to target (8%) in 54 days
- Vacuum Drying
  - Green to target (8%) in 8 days

Base line

Solid Wood Flooring

Simple production line flow

Produced unfinished and prefinished 2.25” and 3.25” red and white oak flooring

Conventional and Vacuum drying costs

- Data was gathered from:
  - Companies that sell drying equipment
  - Companies using the different drying technologies
  - Literature

Cost Accounting Methods

- Boulet and Ouimet (1968)
- MacMillen and Wengert (1978)
- Fortin (2010)
- Reeb (2011)
- Redman (2011)

Feasibility Methods

- Engalichev and Eddy (1990)
- Holmes and Bilek (1983)
- Govett et al (1996 and 2006)

Data

Fixed Costs	Variable Costs
1. Buildings ($)	1. Forklift wage ($/yr)
2. Kiln (including, auxiliary equipment, boiler, installation) ($)	2. Lumber graders ($/yr)
3. Stickers ($/MBF)	3. Wage for kiln operator and yard supervisor ($/yr)
4. Pile roofs ($/MBF)	4. Fuel cost ($/ton)
5. Pile bases, bolsters ($/MBF)	5. Electrical cost ($/kWh)
6. Temporary road construction (includes drying alleys) ($/MBF)	6. Raw Material Cost ($/MBF)
7. Fences ($)	7. Average price of lumber ($/M bm)
8. Lighting systems ($)	8. Maintenance of kilns and boiler ($).
9. Drainage systems ($)	9. Maintenance and repair of yard ($)
10. Sprinkler systems ($)	10. Snow removal ($/yr)
11. Air drying area (include space between the piles) ($/Acre)	
12. Road area ($/Acre)	
13. Area for buildings, kiln, boiler, etc. ($/Acre)	
14. Land value ($/Acre)	

Data

Other important parameters for cost determination	
1. Annual interest rate (%)	17. Air drying time (weeks)
2. Tax rate to be applied to the total of taxable values (%)	18. `Final Drying time (hrs)
3. Insurance rate applied to the total of insurable values (%)	19. Volume air dry yard (Mbf)
4. Average drying degrades based on lumber value (percent as decimal)	20. Initial MC (%)
5. Average daily volume of lumber on yard and in kilns on any given day (M bm)	21. Final MC (%)
6. Total capacity of kilns	22. Thermal loss (%)
7. Number of Kilns	23. Wood basic density (Kg)
8. Operational year	24. Specific heat of hardwood (KJ/(Kg*oC)
9. Annual throughput (Mbf/yr)	25. Specific heat of water (KJ/(Kg*oC)
10. Run times	26. Heat of Vaporization (MJ/kg)
11. Klin cycles per year	27. Specific gravity at FSP
12. Average length of kiln run (include loading and unloading time)	28. Water density (kg/m3)
13. Number of fans	29. Energy to heat wood (KJ)
14. Fan rating (kW)	30. Energy to heat water (KJ)
15. Annual electrical usage attributed to drying (kWh/yr)	31. Energy to vaporize Water (KJ)
16. Fuel consumption (hog waste) (tons/day)	32. Total BTUs/charge used for drying
	33. Total tons/charge used for drying

Drying Costs

Total Costs ($)	Company A		Company B	
	Conventional Drying	Vacuum Drying	Conventional Drying	Vacuum Drying
Investment Costs	$4,627,142	$8,148,062	$3,948,742	$7,084,780
Operational Costs	$341,000	$147,500	$341,000	$147,500
Maintenance Costs	$49,425	$29,925	$49,425	$29,925
Energy Costs	$138,320	$116,058	$184,577	$102,131
Raw Material Cost	$16,061,500	$12,698,231	$14,673,750	$11,174,443
Total	$21,217,387	$21,139,776	$19,197,494	$18,538,779

Vacuum drying capital investment represented 66% -67% more than conventional drying

Feasibility Analysis

- Cash flow was performed for a period of 20 years.

- Cash flow (Keowon et. al 2006):
  - 1) Operating → sales growth/year
  - 2) Investing →assets + depreciation
  - 3) Financing Activities → bank loan and interest rate

- NPV

$$NPV = \sum_{t=0}^{n} \frac{R_t - C_t}{(1+i)^t} - C_0$$

Where
i: is the interest rate;
t: is the year;
n: is the economic life of a system
R_t: is the revenue earned
C_t: is the cost of a system in year t
Co: initial investment

- IRR

$$IRR(X) = min_{d>0}\{E[NPV(X, D)] = 0\}$$

where,
IRR(x) = Internal rate of return
E= discount rate
NPV= net present value

Cash Flow Company A

Cash flow	year 0	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
(+) Sales		15,300,000	15,912,000	16,548,480	17,210,419	17,898,836	18,614,789	19,359,381	20,133,756	20,939,106	21,776,671
(-) Costs		15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506
(-) tax		625	49,585	100,503	153,458	208,532	265,808	325,375	387,325	451,753	518,759
(-) interest		144,000	128,349	111,289	92,693	72,424	50,331	26,249			
(-)Amortization		173,905	189,556	206,616	225,212	245,481	267,574	291,656			
Net cash flow	-3,948,742	-283,035	280,005	865,566	1,474,550	2,107,894	2,766,571	3,451,595	4,481,925	5,222,847	5,993,406

Cash flow	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20	year 11
(+) Sales	22,647,738	23,553,647	24,495,793	25,475,625	26,494,650	27,554,436	28,656,613	29,802,878	30,994,993	32,234,792	22,647,738
(-) Costs	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506	15,264,506
(-) tax	588,444	660,917	736,288	814,675	896,197	980,980	1,069,154	1,160,855	1,256,224	1,355,408	588,444
(-) interest											
(-)Amortization											
Net cash flow	6,794,788	7,628,225	8,494,999	9,396,444	10,333,947	11,308,950	12,322,953	13,377,517	14,474,263	15,614,878	6,794,788

Cash Flow Company B

Cash flow	year 0	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
(+) Sales		15,300,000	15,912,000	16,548,480	17,210,419	17,898,836	18,614,789	19,359,381	20,133,756	20,939,106	21,776,671
(-) Costs		12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602
(-) tax		199,895	248,855	299,773	352,728	407,802	465,078	524,645	586,595	651,023	718,029
(-) interest		144,000	128,349	111,289	92,693	72,424	50,331	26,249			
(-)Amortization		173,905	189,556	206,616	225,212	245,481	267,574	291,656			
Net cash flow	-8,111,657	2,046,599	2,609,639	3,195,200	3,804,184	4,437,528	5,096,205	5,781,229	6,811,559	7,552,481	8,323,040

Cash flow	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20
(+) Sales	22,647,738	23,553,647	24,495,793	25,475,625	26,494,650	27,554,436	28,656,613	29,802,878	30,994,993	32,234,792
(-) Costs	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602	12,735,602
(-) tax		787,714	860,187	935,558	1,013,945	1,095,467	1,180,250	1,268,424	1,360,125	1,455,494	1,554,678
(-) interest											
(-)Amortization											
Net cash flow		9,124,422	9,957,859	10,824,633	11,726,078	12,663,581	13,638,584	14,652,587	15,707,151	16,803,897	17,944,512

Feasibility Analysis

Scenario	Plant A		Plant B	
	NPV	IRR	NPV	IIR
Conventional Drying	$17,039,064	33%	$17,672,640	37%
Vacuum Drying	$26,553,430	40%	$29,205,867	43%

- Both Conventional and Vacuum Drying for the two case studies are economically feasible at a discount rate of 15%

- Vacuum drying obtained, for the two case studies, a higher NPV and IRR, which means that is more economically feasible and the best scenario for investment than conventional drying.

Why Better?

Costs ($)	Company A		Company B	
	Conventional Drying	Vacuum Drying	Conventional Drying	Vacuum Drying
Raw Material Cost	$16,061,500	$12,698,231	$14,673,750	$11,174,443

- The raw material or inventory cost was a factor that impacted the feasibility analysis between the two scenarios
- Conventional drying raw material costs were 21% and 24% more than vacuum drying for Company A and B respectively.

Objective

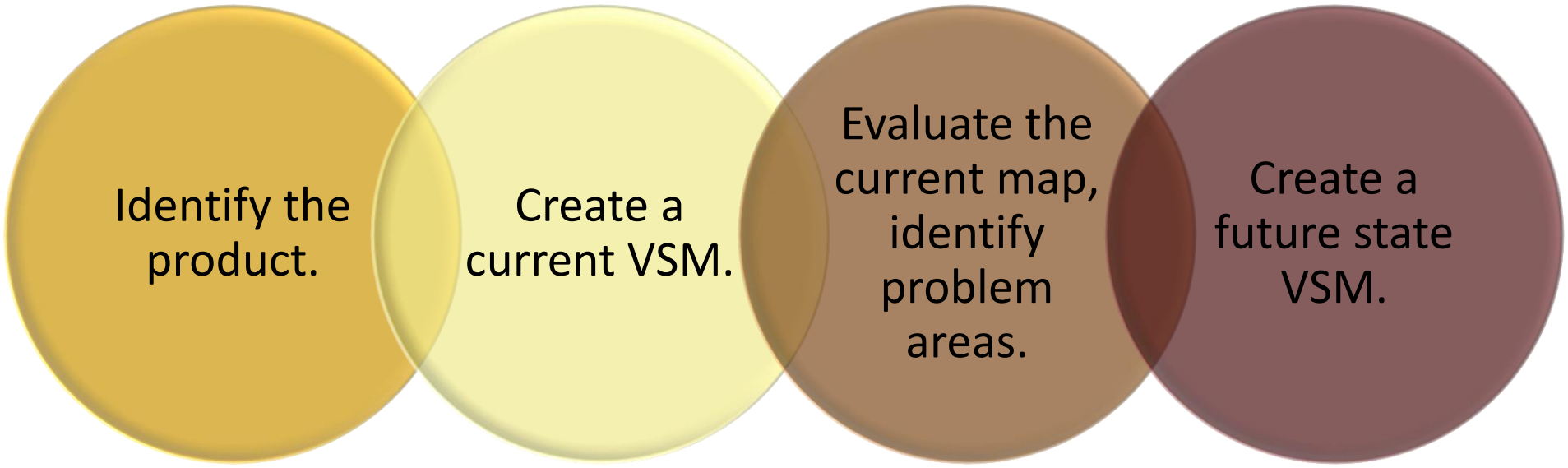
Determine the impact on the work in process (WIP) and cycle time for a flooring manufacturer when vacuum drying technology is compared to conventional drying technology

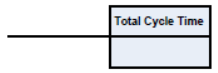
Lean Manufacturing

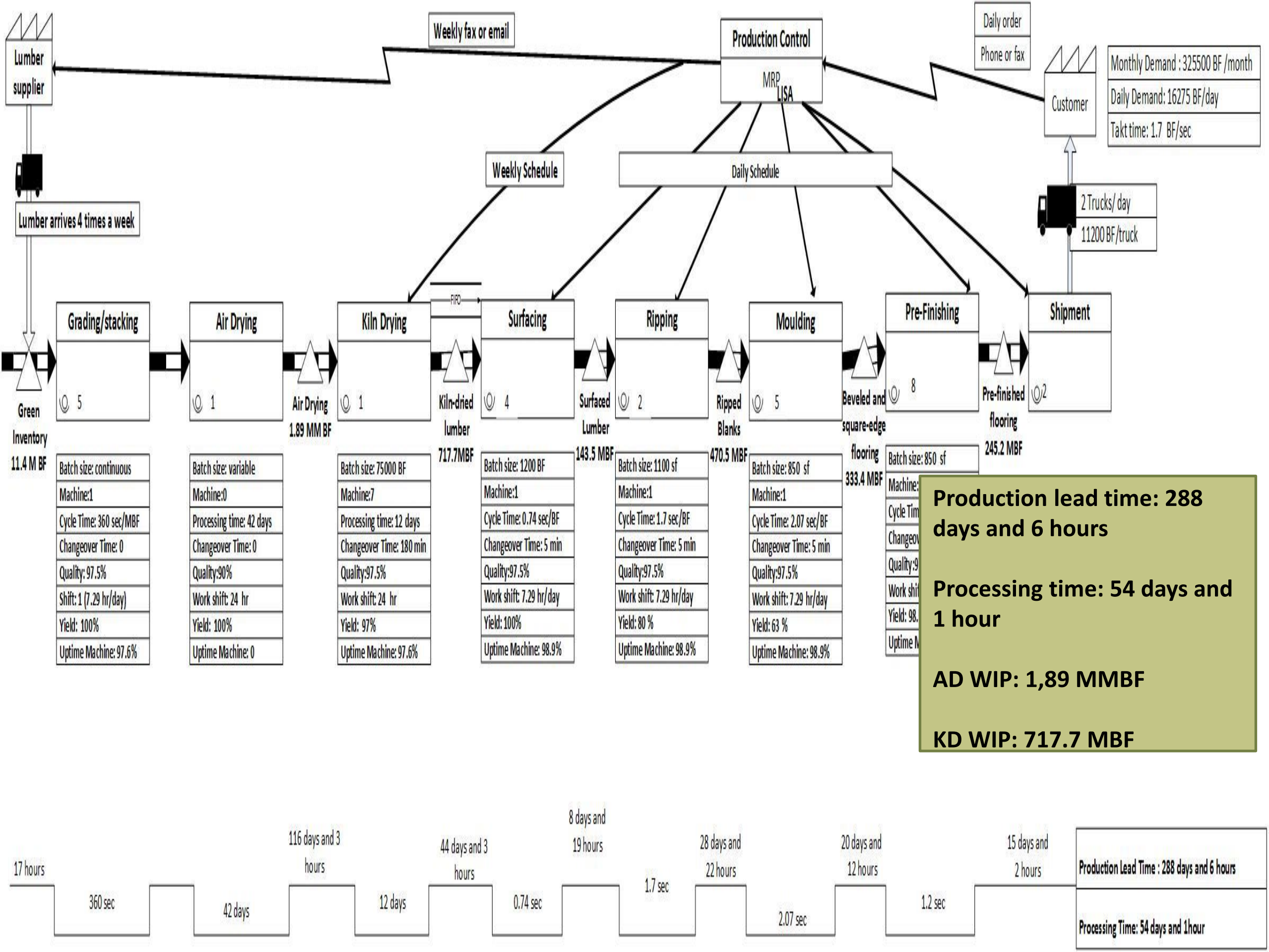
- Lean Manufacturing
  - Philosophy to eliminate all non-value added activities (waste)
- Waste
  - Over processing
  - Over production
  - Excessive inventories
  - Waste in motion
  - Waiting
  - Transportation
  - Defects

Value Stream Map

- Value Stream Map (Shook and Rother 2003):



Symbols Used in Microsoft Visio	Meaning of the Symbol
	Process
	Timeline: waiting time and cycle time
	Inventory
	Production Flow
	Total Time


Lumber supplier
Weekly fax or email
Production Control
MRP LISA
Daily order
Phone or fax
Customer
Monthly Demand : 325500 BF /month
Daily Demand: 16275 BF/day
Takt time: 1.7 BF/sec
Weekly Schedule
Daily Schedule
2 Trucks/ day
11200 BF/truck
Lumber arrives 4 times a week
FIFO
Grading/stacking
Air Drying
Kiln Drying
Surfacing
Ripping
Moulding
Pre-Finishing
Shipment
5
1
1
4
2
5
8
2
Green Inventory 11.4 M BF
Air Drying 1.89 MM BF
Kiln-dried lumber 717.7MBF
Surfaced Lumber 143.5 MBF
Ripped Blanks 470.5 MBF
Beveled and square-edge flooring 333.4 MBF
Pre-finished flooring 245.2 MBF
Batch size: continuous
Machine:1
Cycle Time: 360 sec/MBF
Changeover Time: 0
Quality: 97.5%
Shift: 1 (7.29 hr/day)
Yield: 100%
Uptime Machine: 97.6%
Batch size: variable
Machine:0
Processing time: 42 days
Changeover Time: 0
Quality:90%
Work shift: 24 hr
Yield: 100%
Uptime Machine: 0
Batch size: 75000 BF
Machine:7
Processing time: 12 days
Changeover Time: 180 min
Quality:97.5%
Work shift: 24 hr
Yield: 97%
Uptime Machine: 97.6%
Batch size: 1200 BF
Machine:1
Cycle Time: 0.74 sec/BF
Changeover Time: 5 min
Quality:97.5%
Work shift: 7.29 hr/day
Yield: 100%
Uptime Machine: 98.9%
Batch size: 1100 sf
Machine:1
Cycle Time: 1.7 sec/BF
Changeover Time: 5 min
Quality:97.5%
Work shift: 7.29 hr/day
Yield: 80 %
Uptime Machine: 98.9%
Batch size: 850 sf
Machine:1
Cycle Time: 2.07 sec/BF
Changeover Time: 5 min
Quality:97.5%
Work shift: 7.29 hr/day
Yield: 63 %
Uptime Machine: 98.9%
Batch size: 850 sf
Production lead time: 288 days and 6 hours
Processing time: 54 days and 1 hour
AD WIP: 1,89 MMBF
KD WIP: 717.7 MBF
17 hours
360 sec
42 days
116 days and 3 hours
12 days
44 days and 3 hours
0.74 sec
8 days and 19 hours
1.7 sec
28 days and 22 hours
2.07 sec
20 days and 12 hours
1.2 sec
15 days and 2 hours
Production Lead Time : 288 days and 6 hours
Processing Time: 54 days and 1hour

Lumber Supplier

Orders by Fax or e-mail
Every two weeks

Production Control

Daily Demand: 50,000 BF
Takt Time: 588 sec/MBF

Orders by Fax or e-mail
Every two weeks

Customers

11 trucks/ day
7500BF / truck

Daily

12 trucks weekly (20 pallets/ trucks)
20% finished and 80% unfinished

Green Inventory
20.62 MBF

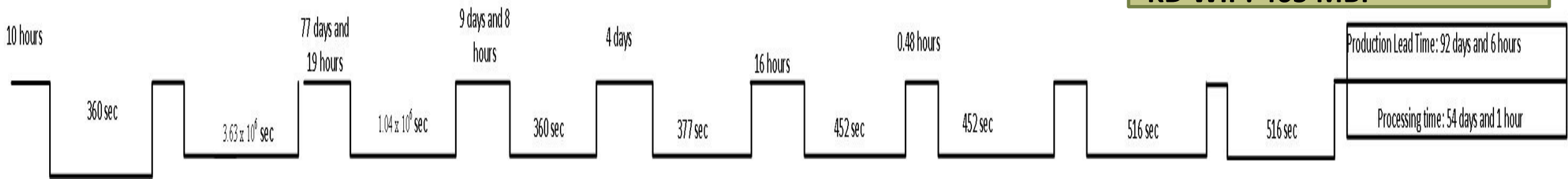
Grading &Stacking	Air Drying	Air Drying Inventory	Kiln Drying	Kiln Inventory	Rip Saw	Ripsaw Inventory	Chop Saw	Knot Inventory	Moulder	Floor Inventory	End Matchers	Grading	Nesting/Bundling	Shipment
6	1		1		4		12		4		12	10	16	
Number of machines: 1	Number of machines: 0	3.89 MMBF	Number of machines: 6	465 MBF	Number of machines: 1	200 MBF	Number of machines: 10	33.5 MBF	Number of machines: 3	1 MBF	Number of machines: 10		Number of machines: 5	
Batch size: continuous	Batch size: variable		Batch size: 77,500 BF		Batch size: 90,000BF		Batch size: 78,000BF		Batch size: 65,000BF		Batch size: 65,000BF			
Process Time: 360sec/MBF	Process Time: 42 days		Process Time: 12 days		Process Time: 360sec/MBF		Process Time: 377sec/MBF		Process Time: 452sec/MBF		Process Time: 452 sec/MBF			
Changeover time: 1 min	Changeover time: 0		Changeover time: 3 hours		Changeover time: 3 min		Changeover time: 5 min		Changeover time: 2 min		Changeover time: 2 min			
Quality: 95%	Quality: 97%		Quality: 95%		Quality: Not applicable		Quality: Not applicable		Quality: 85%		Quality: 95%			
Uptime: 90%	Uptime: 100%		Uptime: 100%		Uptime: 95%		Uptime: 90%		Uptime: 95%		Uptime: 95%			
Yield: Not applicable	Yield: 97%		Yield: 95%		Yield: 87%		Yield: 83%		Yield: 98%		Yield: 88%			
Shift: 1 (8.17 hrs/day)	Shift: 1 (24 hrs/day)		Shift: 1 (24 hrs/day)		Shift: 1 (9 hrs/day)		Shift: 1 (8.17 hrs/day)		Shift: 1 (8.17 hrs/day)		Work shift:1 (8.17 hrs/day)			

Production lead time: 92days and 6 hours

Processing time: 54 days and 1 hour

AD WIP: 3.89 MMBF

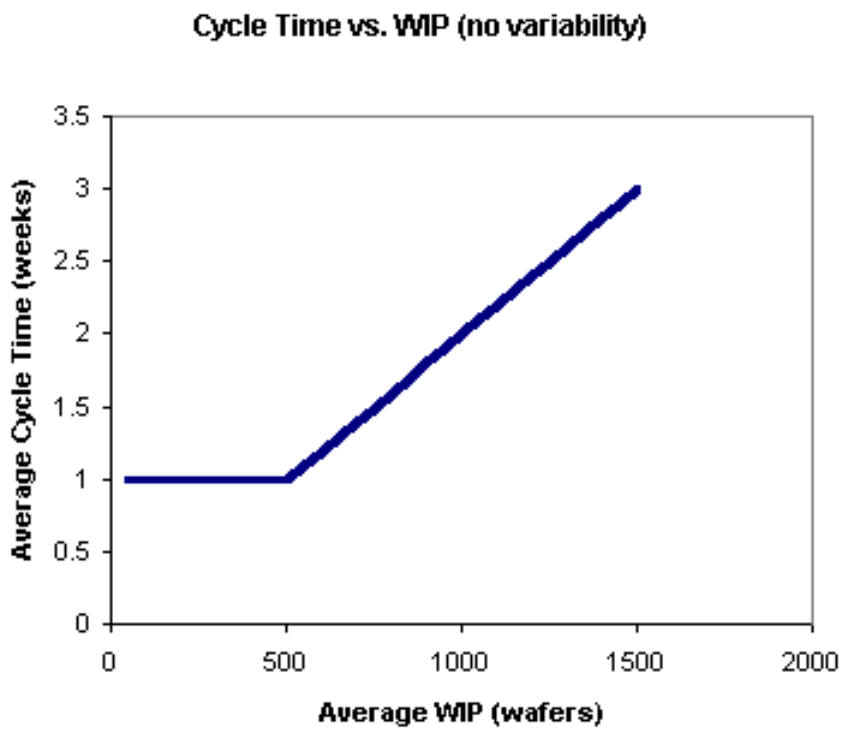
KD WIP: 465 MBF

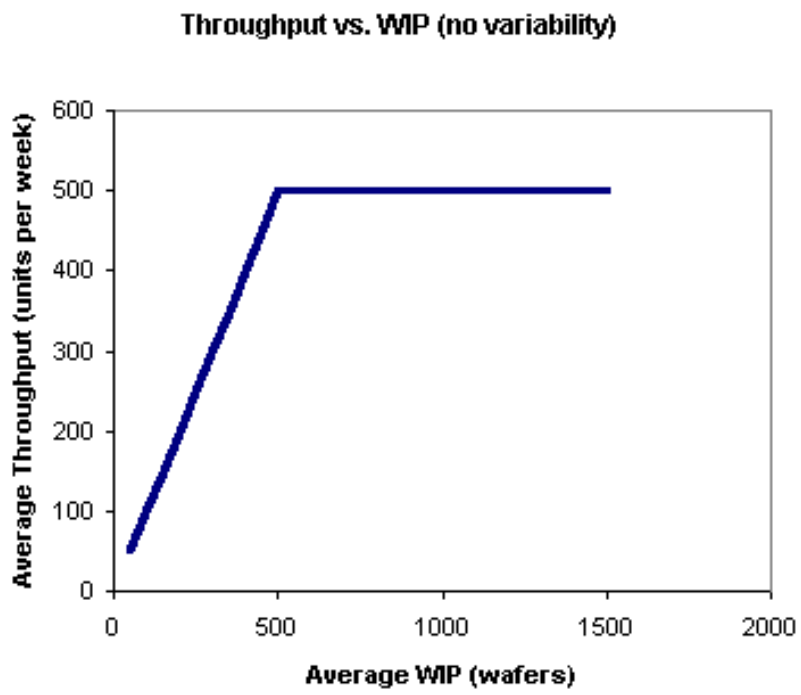


Little's Law

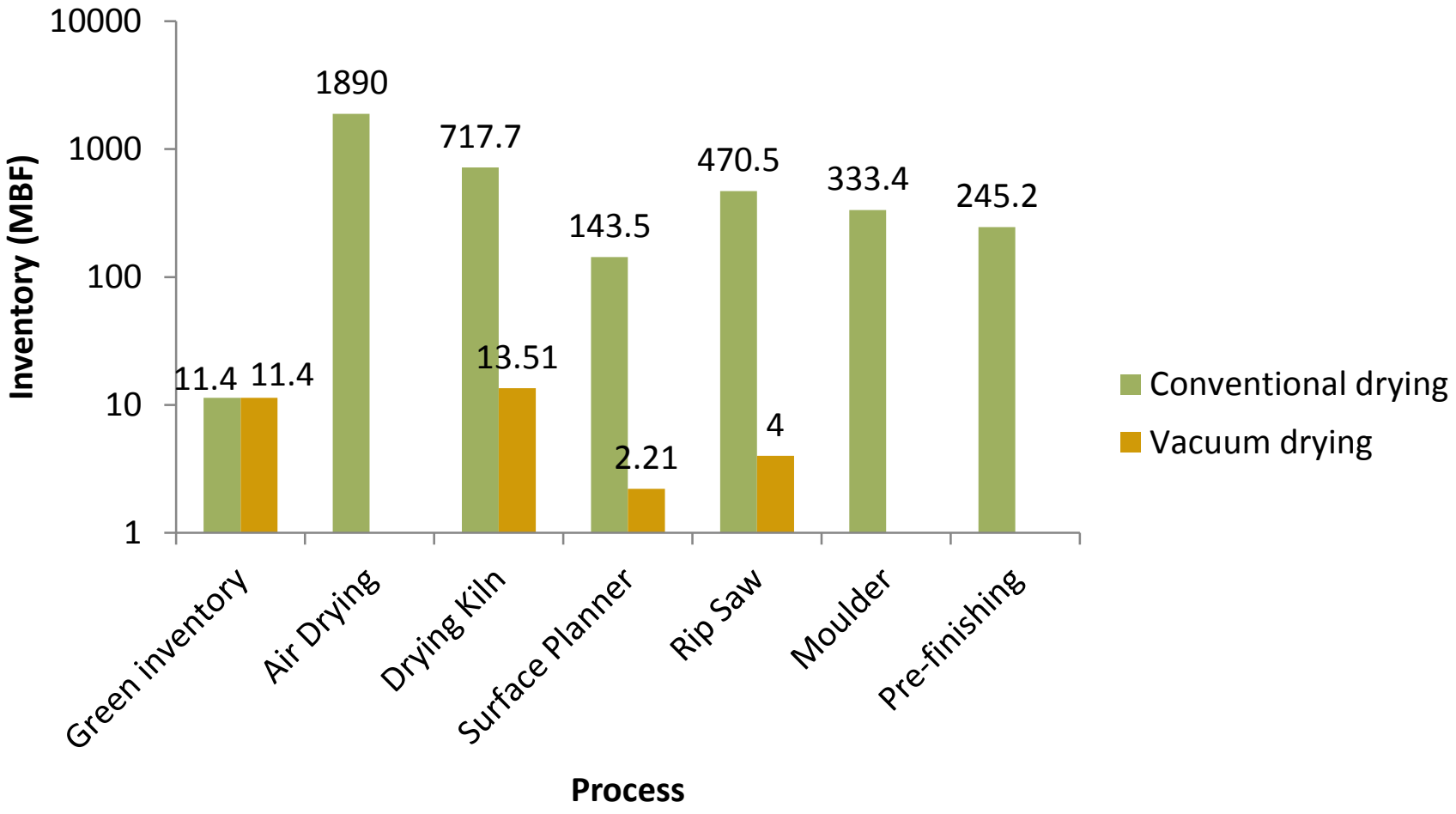
- Little's Law:

WIP= TH *CT

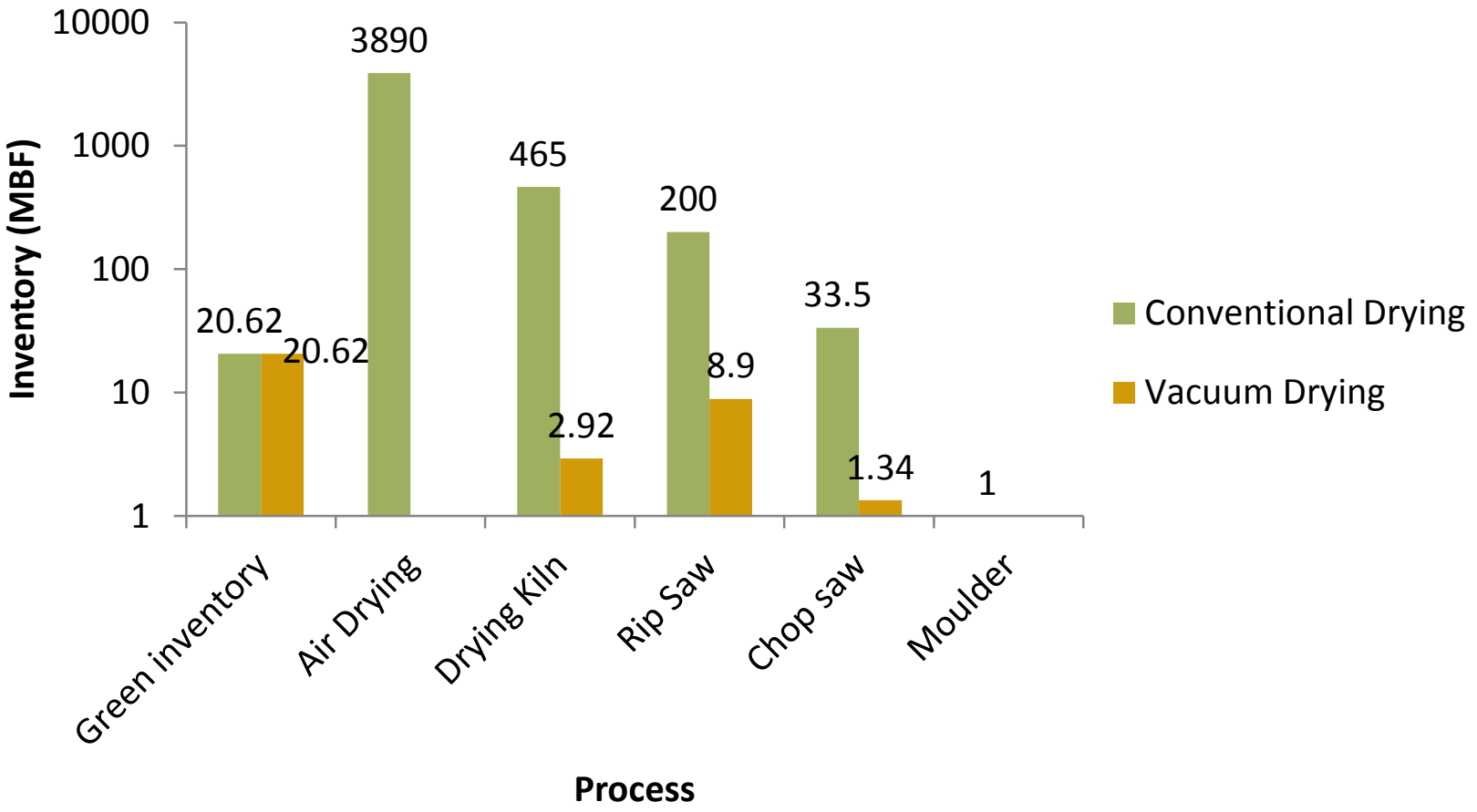




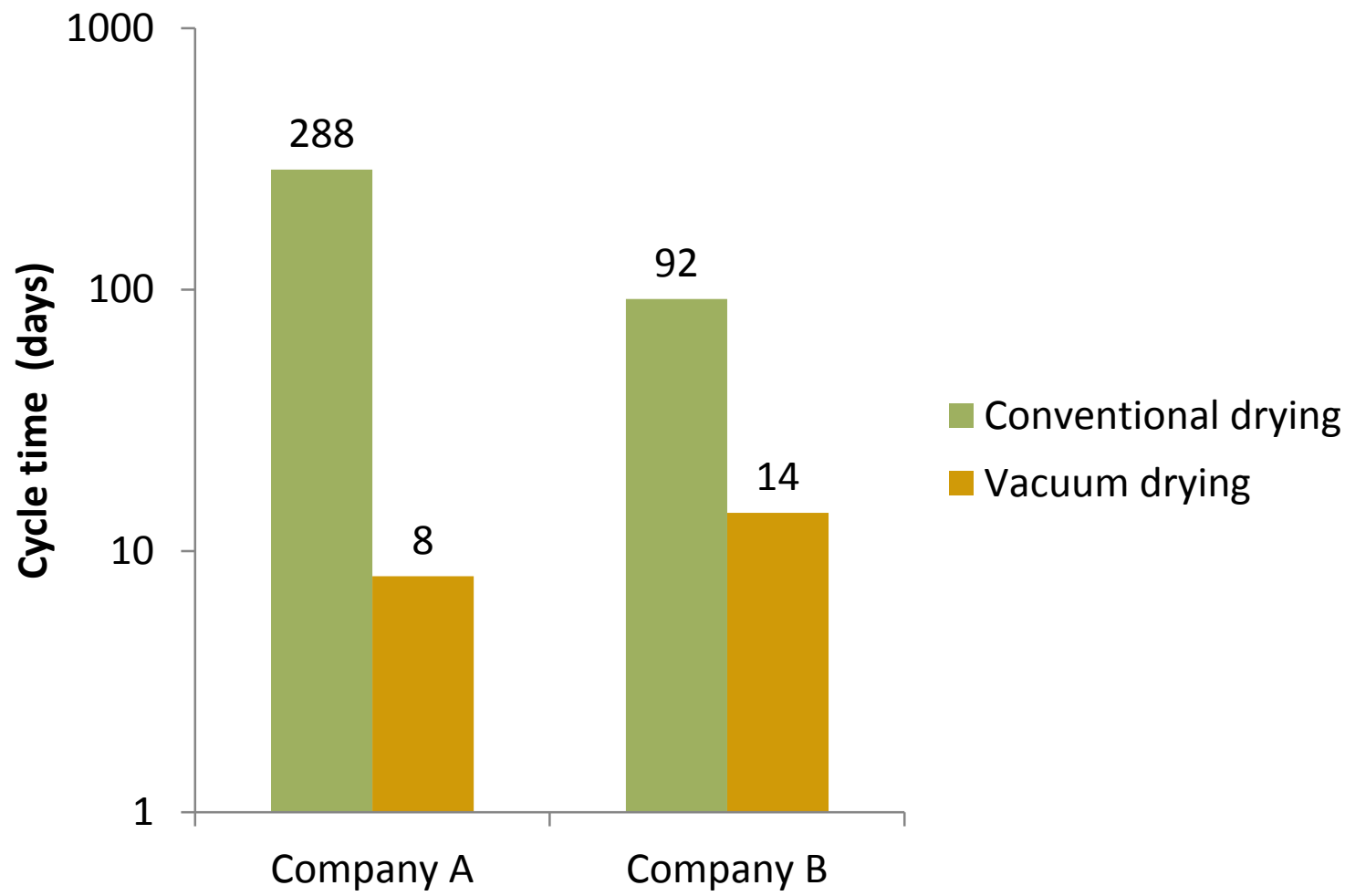
Simulation WIP Results for Company A



Simulation WIP Results for Company B



Simulation Results for Cycle Time



Cost Comparison

Parameter	Company A		Company B	
	Conventional Drying	Vacuum Drying	Conventional Drying	Vacuum Drying
Lumber inventory cost	$16,061,500	$12,698,231	$14,673,750	$11,174,443
Inventory cost	$2,388,750	$626,990	$2,838,290	$657,083
Kiln equipment	$2,575,000	$6,659,700	$2,225,000	$7,566,750

- Regarding lumber inventory cost, vacuum drying was 21% and 24% less than conventional drying for Company A and B, respectively.
- Regarding inventory cost, vacuum drying was 74% and 77% les than conventional drying for Company A and B, respectively.

Future Work

- Compare vacuum to conventional drying with no air-drying
- Other species
- Other vacuum kilns
- More complex production lines

Study Limitations

- The study specifically assessed one single line production of a flooring manufacture, and the results gathered may not reflect the rest of the hardwood industry.

- The results are limited to the conventional and vacuum technology and associated costs used.

- Future state map was based on average customer demand and results from the simulation, seasonal demand variation may not be reflected in the inventory levels.

Acknowledgements

- This project was founded by the Wood Education and Resource Center (WERC).

Questions