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Workforce Allocation in Motorcycle Transmission Assembly Lines: A Case Study on Modeling, Analysis, and Improvement

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Outline

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2. System Description
3. System Modeling
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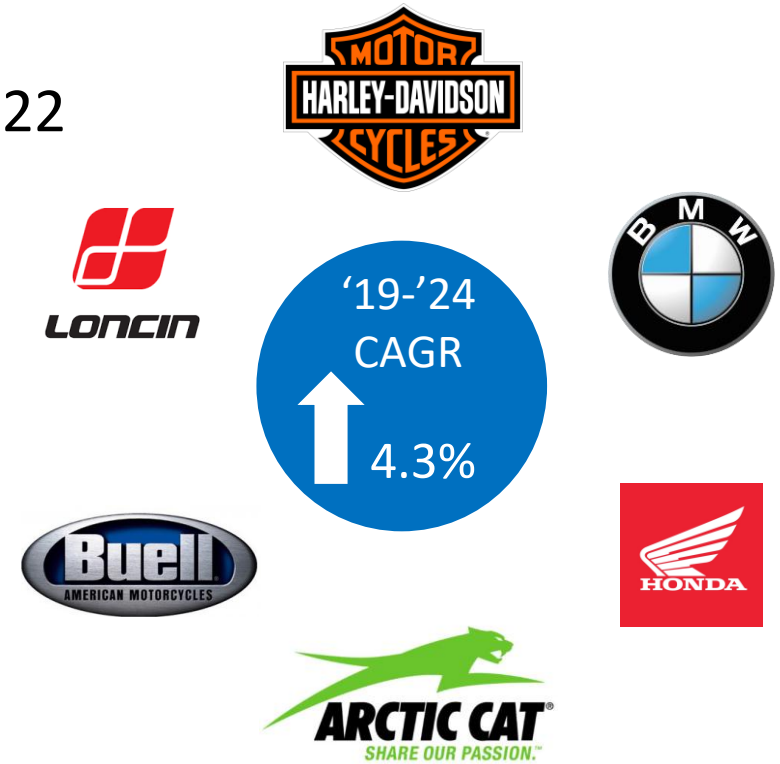
1. Introduction

- Global motorcycle manufacturing
  - Annual revenue growth rate: 4% per year through 2022
  - Units: 6% increase to 132 million in 2018
- U.S. motorcycle manufacturing
  - $5 billion combined annual revenue
  - More than 70 manufacturing facilities
- Critical issue: production efficiency
  - Strong competitions: brands, products

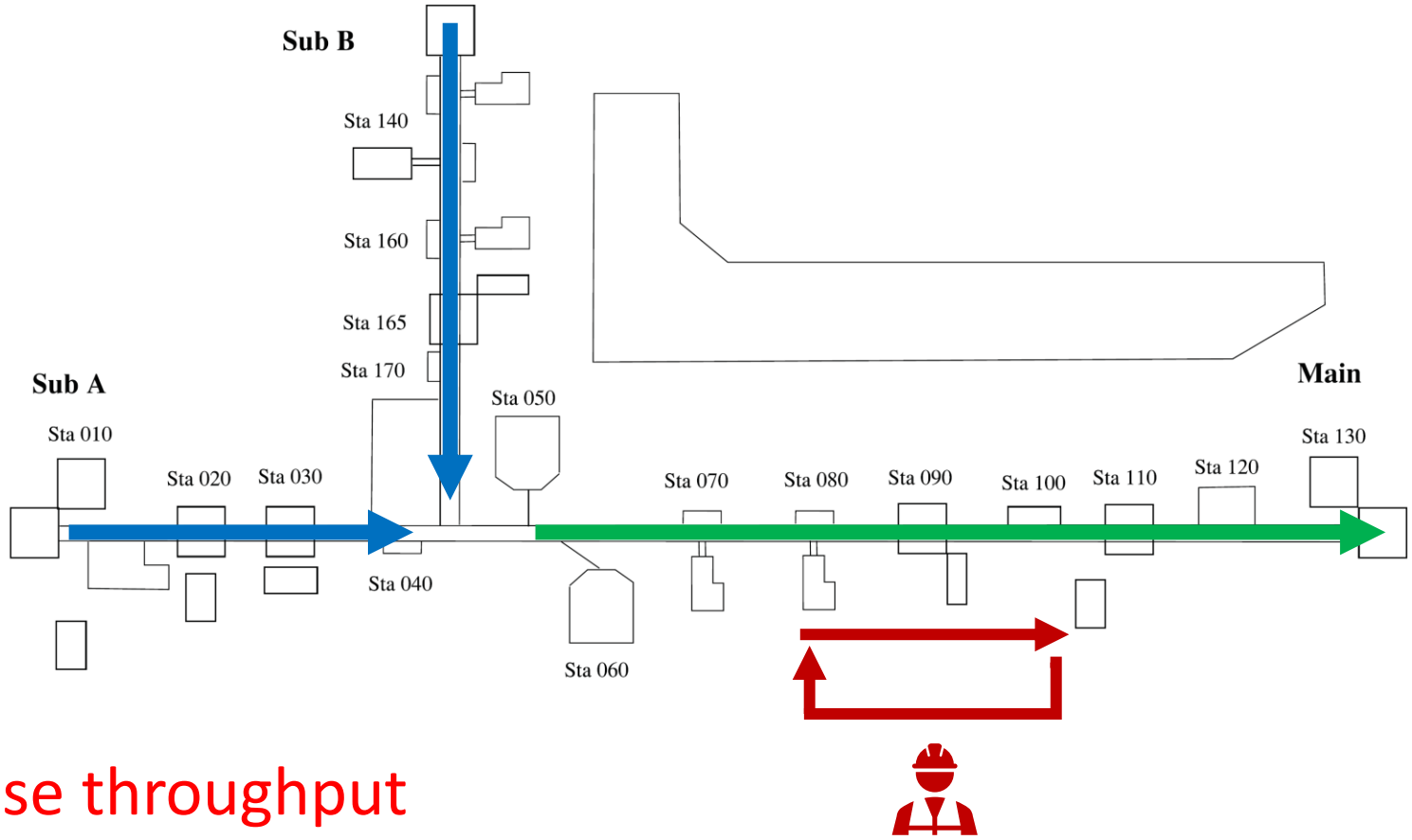


1. Introduction

- Related research
  - **Manufacturing systems:** throughput analysis, work-in-process and various performance in serial lines, assembly lines and other complex manufacturing systems (Papadopoulos et al., 1993; Li and Meerkov, 2009)
  - **Motorcycle manufacturing**: manufacturing strategy (Miltenburg, 2008) , layout planning (Zhou et al., 2010), workload balance (Zhang et al., 2011) and productivity improvement strategies (Park and Li, 2019)
  - **Workforce allocation**: dedicated operations(Cesani and Steudel, 2005; Langer et al., 2009; Saadat et al., 2013)
- Research Issue: limited workforce allocated to multiple machines, no analytical models available

2. System Description

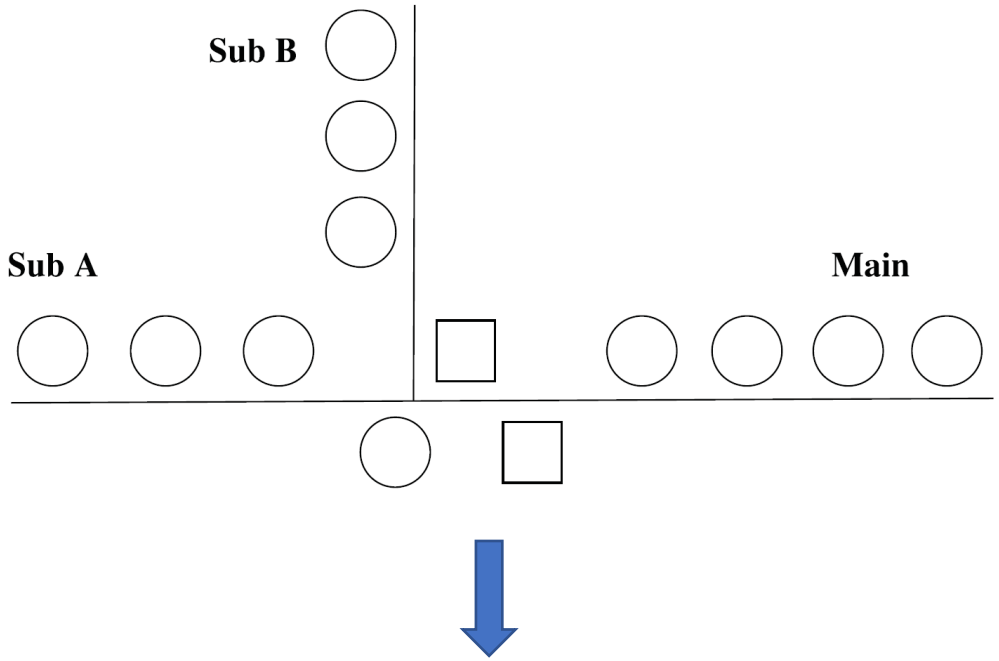
- Transmission assembly line
  - One main assembly line
  - Two sub-assembly lines
  - 15 manual stations
  - 2 fully automated robots
  - 6 to 8 operators
    - Sequentially operate multiple machines



- Allocate workforce to increase throughput
- Evaluate the performance

3. System Modeling

- Structural modeling
  - Transfer the system layout into a part flow model
  - Combine and ignore some stations
  - Model robot as one unit buffer
  - Difficulty: operator workflow and part flow are different



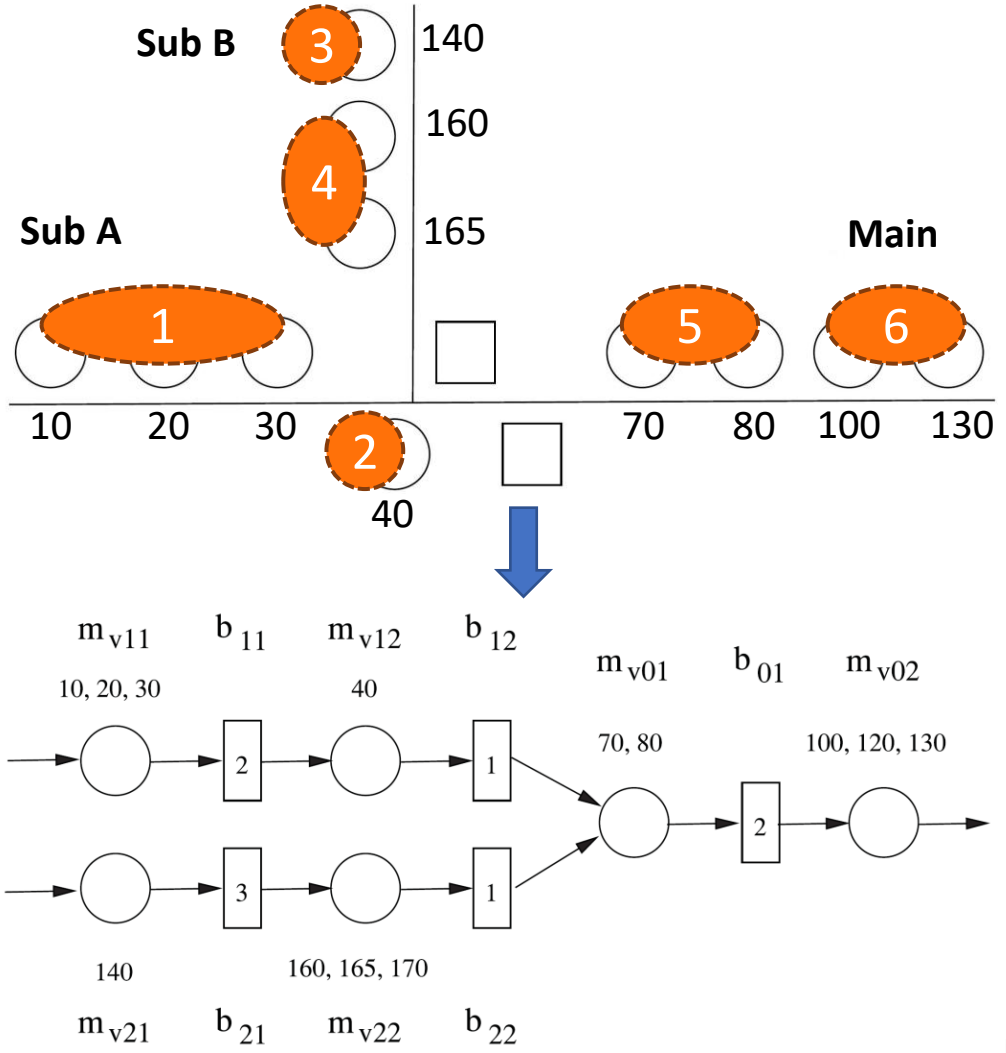
Depending on part flow and operator workflow

- Production system modeling
  - Integrate part flow and operators' workflow
  - Virtual machine: complete working cycle of an operator

4. Analysis and Improvement

- Six operators: Model development
  - Operator 1: 10, 20, 30
  - Operator 2: 40
  - Operator 3: 140
  - Operator 4: 160, 165
  - Operator 5: 70, 80
  - Operator 6: 100, 130

- Parameters
  - Cycle time of virtual machine
  - Buffer capacity



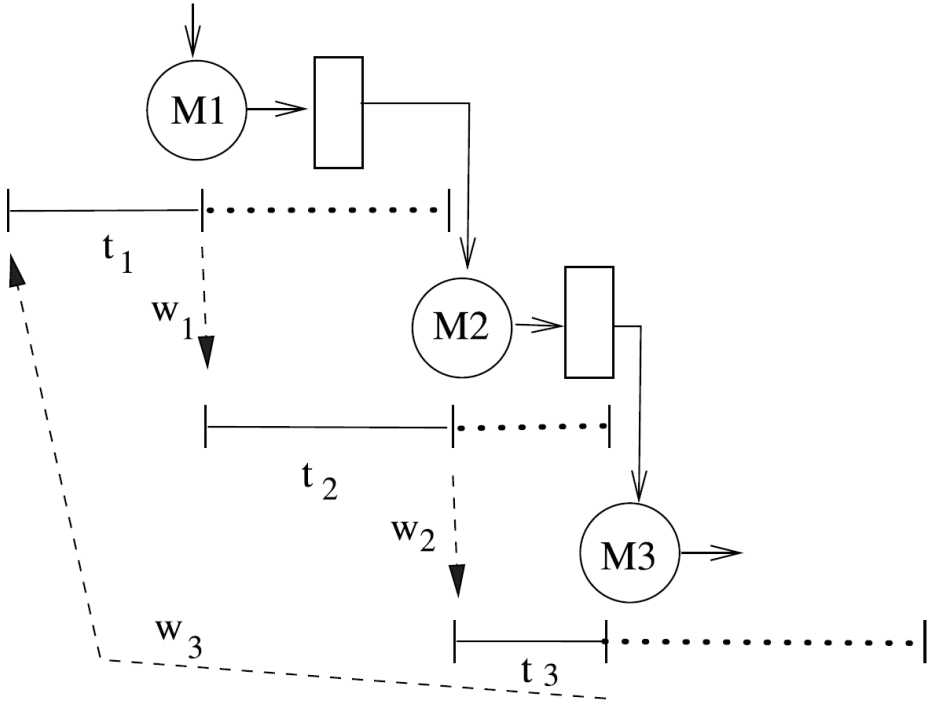
4.1 Six Operators

- Cycle time

$$\tau_v = \sum_k t_k + \sum_k w_k$$

- Bernoulli machine reliability model

$$p_{vij} = \min\left\{\frac{\tau}{\tau_{vij}}, 1\right\}, \quad i = 0, 1, 2, \quad j = 1, 2$$



Station	10	20	30	40	140	160	165/170
Self-processing time (sec)	36	12	32	37	69	25	32
Operator	1			2	3	4	
Virtual machine cycle time (sec)	80			37	69	57	

(a) Sub lines

Station	70	80	100	120/130
Self-processing time (sec)	65	15	62	32
Operator	5		6	
Virtual machine cycle time (sec)	80		94	

(b) Main line

m_i	m_{v11}	m_{v12}	m_{v21}	m_{v22}	m_{v01}	m_{v02}
p_i	0.71	1	0.83	1	0.71	0.61
b_i	b_{11}	b_{12}	b_{21}	b_{22}	b_{01}	-
N_i	2	1	3	1	2	-

4.1 Six Operators

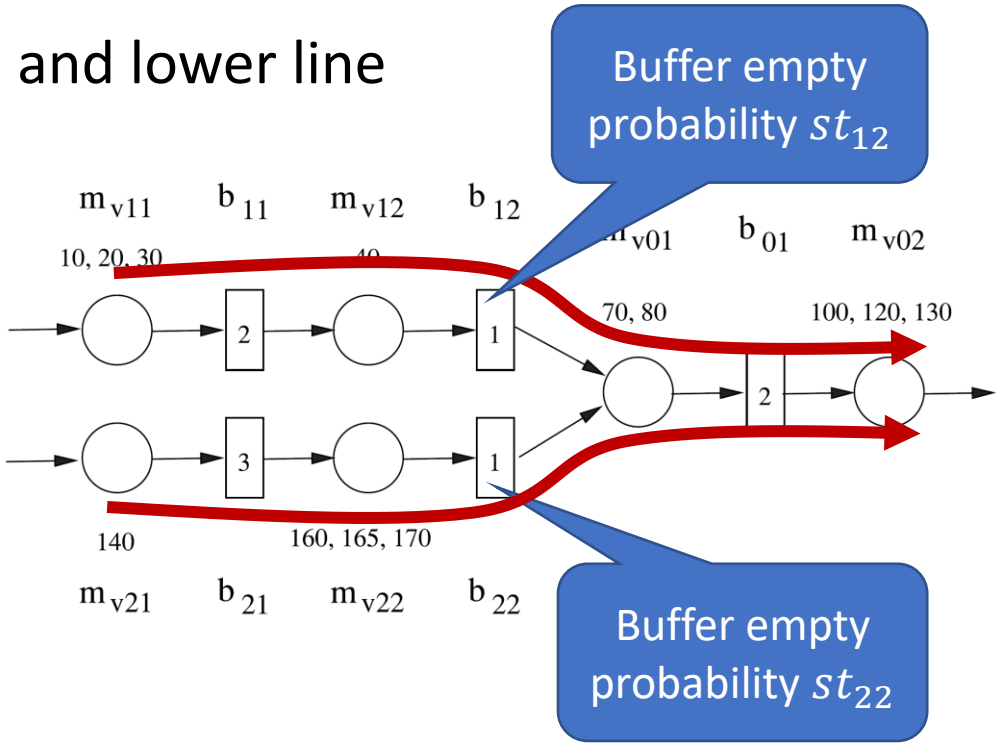
- Performance Evaluation
  - Procedure 1: decomposition into upper line and lower line
  - Procedure 2: serial line aggregation
- Procedure 1

$$p'_{v01}(s) = p_{v01}(1 - st_{22}(s-1)),$$

$$st_{12}(s) = \Psi(p_{v11}, p_{v12}, p'_{v01}(s), p_{v02}, N_{11}, N_{12}, N_{01}),$$

$$p''_{v01}(s) = p_{v01}(1 - st_{12}(s)),$$

$$st_{22}(s) = \Psi(p_{v21}, p_{v22}, p''_{v01}(s), p_{v02}, N_{21}, N_{22}, N_{01}),$$



4.1 Six Operators

- Procedure 2

$$p_k^b(n+1) = p_k[1 - Q(p_{k+1}^b(n+1), p_k^f(n), N_k)], \qquad k = v11, v12, v01',$$

$$p_k^f(n+1) = p_k[1 - Q(p_{k-1}^f(n+1), p_k^b(n+1), N_{k-1})], \quad k = v12, v01', v02,$$

when procedure 2 is convergent (Li and Meerkov, 2009) ,

$$p_{v01'}^f = \lim_{n\to\infty} p_{v01'}^f(n), \qquad st_{12}(s) = \Psi(\cdot) = 1 - \frac{p_{v01'}^f}{p_{v01'}(s)}.$$

- When procedure 1 is convergent (Li and Meerkov, 2009)

$$st_{i2} = \lim_{s\to\infty} st_{i2}(s), \quad i = 1, 2. \qquad PR = p_{v02}(1 - Q(p_{v_{01}}(1 - st_{12})(1 - st_{22}), p_{v02}, N_{01})).$$

- $$TP = PR \times \frac{7.5 \times 3600}{57}.$$

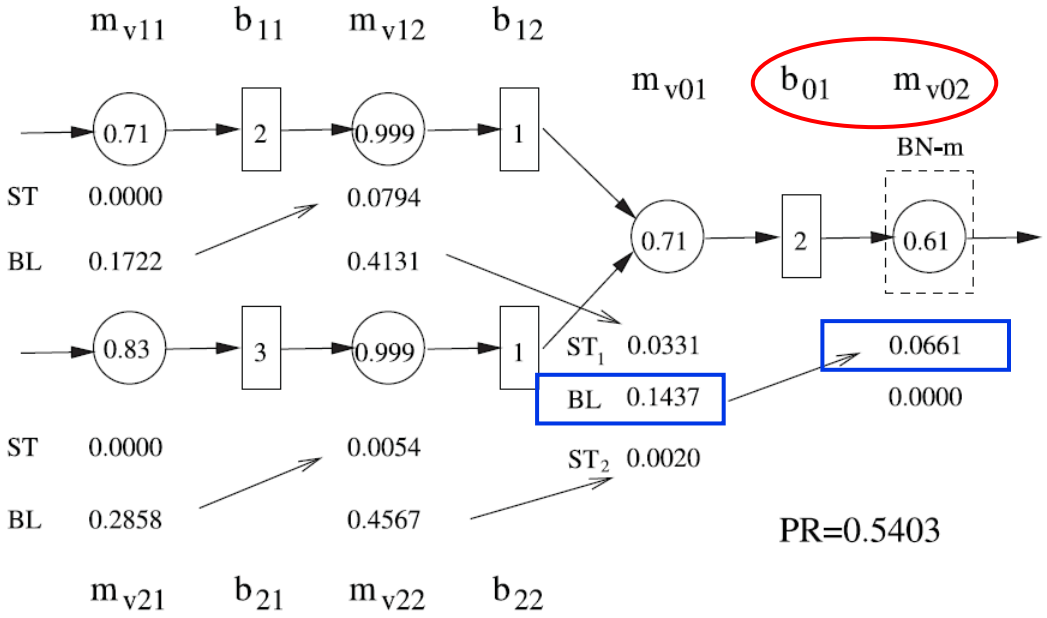
4.1 Six Operators

- Model validation

(parts/shift)	History	Model	Difference	Error
TP	250	255.93	5.93	2.38%

- Arrow assignment rule
  - Blockage probability: BL_i
  - Starvation probability: ST_{i+1}

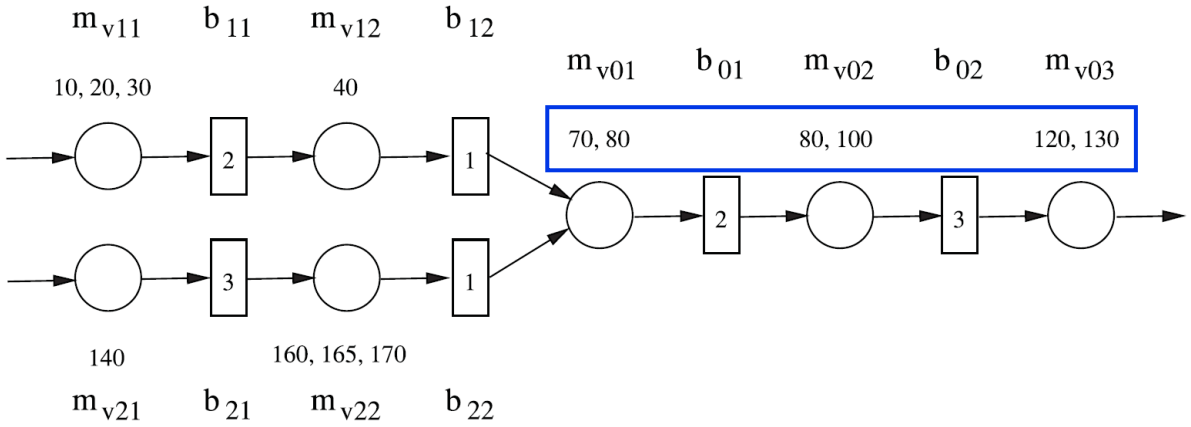
- Improvement analysis
  - Bottleneck machine: m_{v02}
  - Buffer adjustment
    - Increasing b_{01} from 2 to 3



(parts/shift)	Original	New	Improvement	Improvement %
TP	255.93	267.49	11.56	4.52%

4.2 Seven Operators

- Model development
  - Main assembly line: 3 operators



Station	70	80	80	100	120/130
Time (sec)	65	7.5	7.5	62	32
Operator	5		6		7
Time (sec)	72.5		69.5		32

m_i	m_{v11}	m_{v12}	m_{v21}	m_{v22}	m_{v01}	m_{v02}	m_{v03}
p_i	0.71	1	0.83	1	0.79	0.82	1
b_i	b_{11}	b_{12}	b_{21}	b_{22}	b_{01}	b_{02}	-
N_i	2	1	3	1	2	3	-

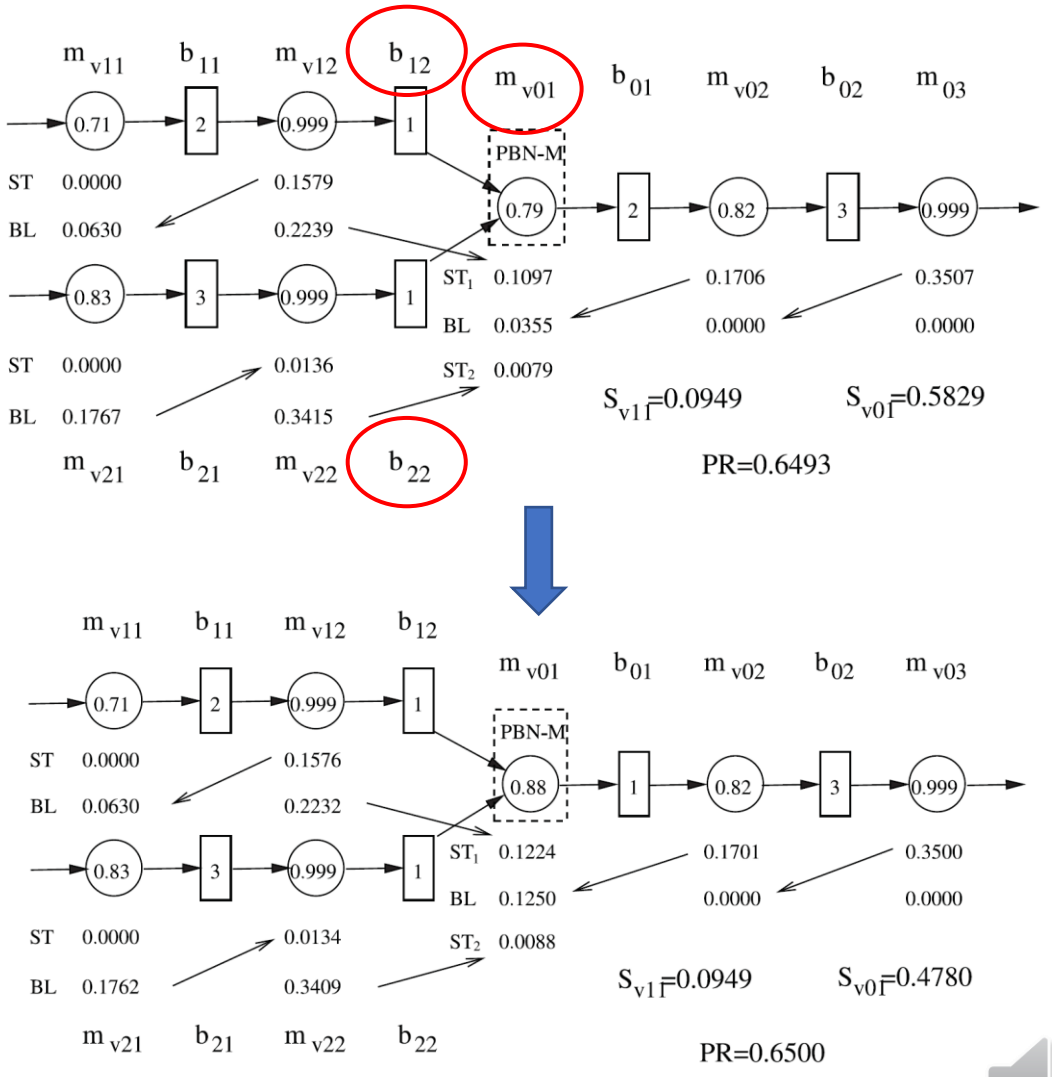
- Model validation

(parts/shift)	History	Model	Difference	Error
TP	300	307.56	7.56	2.52%

4.2 Seven Operators

- Improvement analysis
  - Primary bottleneck machine: m_{v01}
  - Workforce reallocation
    - Remove Station 80 from m_{v01} to m_{v02}
  - Buffer adjustments
    - Increase b_{12} from 1 to 2
    - Increase b_{22} from 1 to 2
    - Or both

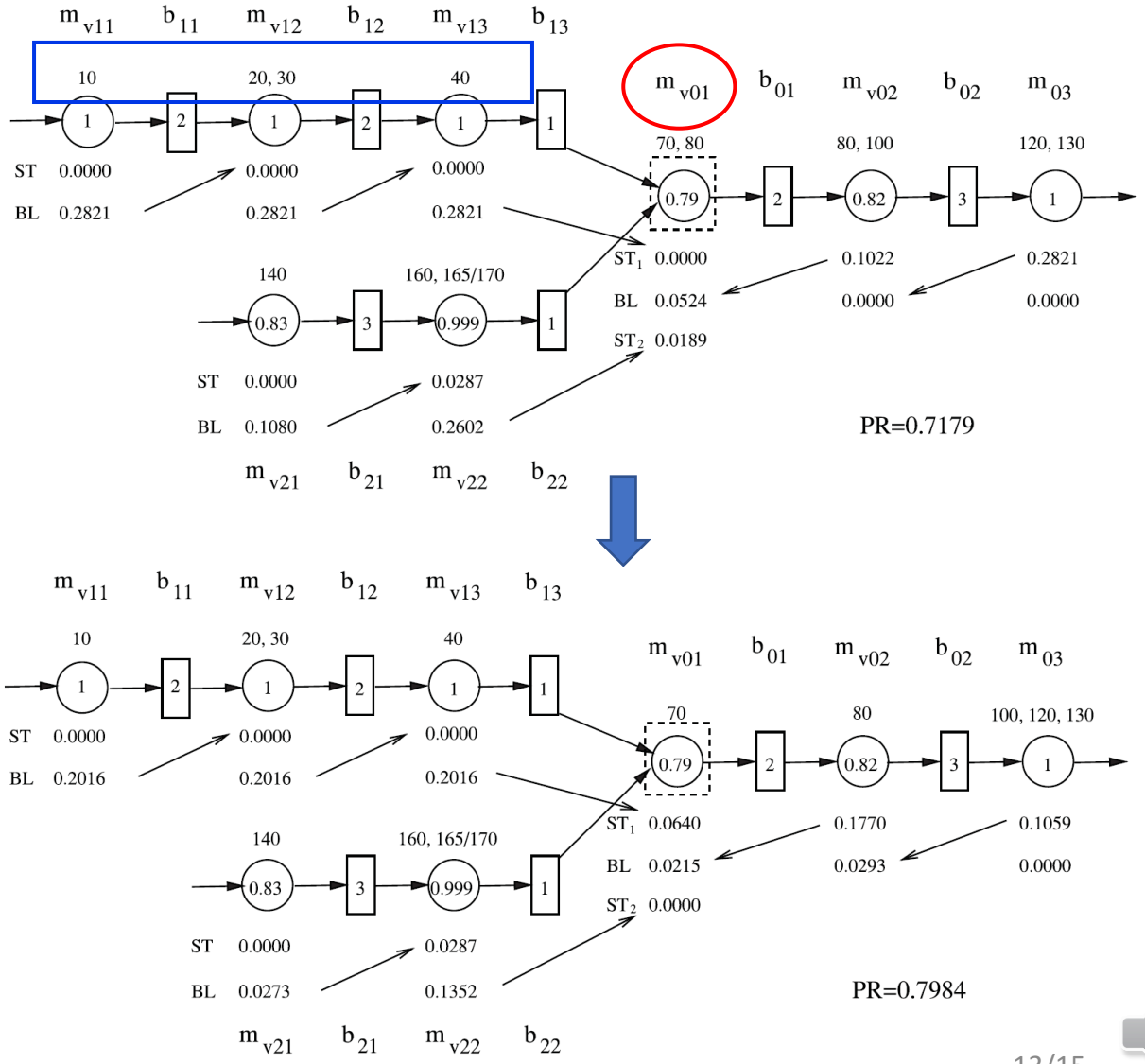
(parts/shift)	Original	Reallocation	$b_{12}\uparrow$	$b_{22}\uparrow$	Both $\uparrow$
TP	307.56	307.89	308.65	316.49	317.65
Improve	-	0.23	1.09	8.93	10.09
(%)	-	0.07%	0.35%	2.90%	3.28%



4.3 Eight Operators

- Model development
  - Sub line A: 3 operators
- Improvement analysis
  - Bottleneck machine: m_{v01}
  - Workforce reallocation

(parts/shift)	Original	Reallocation
TP	340.44	378.57
Improve	-	38.13
(%)	-	11.2%



5. Conclusion

- An application study of modeling, analysis and improvement of a gear assembly system in a motorcycle powertrain plant
- Integration of the part flow and operator workflow with different workforce allocation scenarios
- Bottleneck identification and mitigation to achieve continuous improvement

Thank you!