

**MIT 2.852**  
**Manufacturing Systems Analysis**  
**Lecture 14-16**

*Line Optimization*

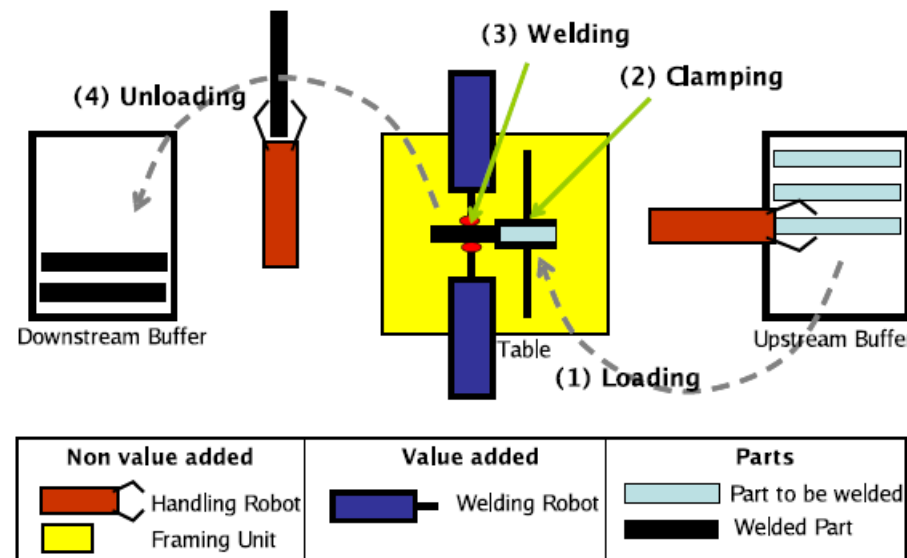
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Spring, 2007

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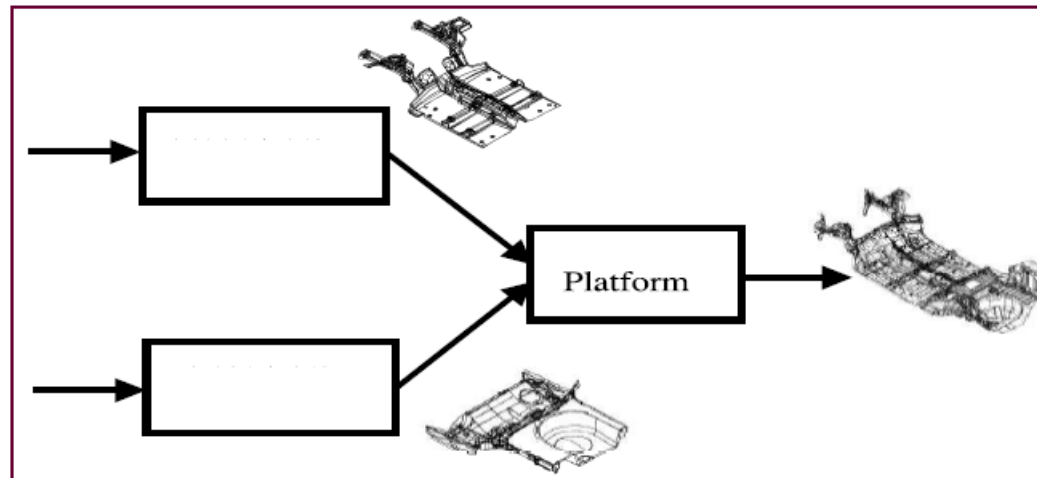
# Robot Cell Design

- This case study is a summary of “Optimal Buffer Sizes and Robot Cell Design in PSA Peugeot Citroën Car Body Production,” by Alain Patchong (unpublished paper — as of now).
- Most of the operations in a body shop are performed by robots that load and weld stamped steel parts. These robots are organized in cells, called *modules*, comprised of a set of robots with no intermediate buffer.



# Robot Cell Design

- The smallest possible system has three modules:



# Robot Cell Design

## Problem

## Assumptions

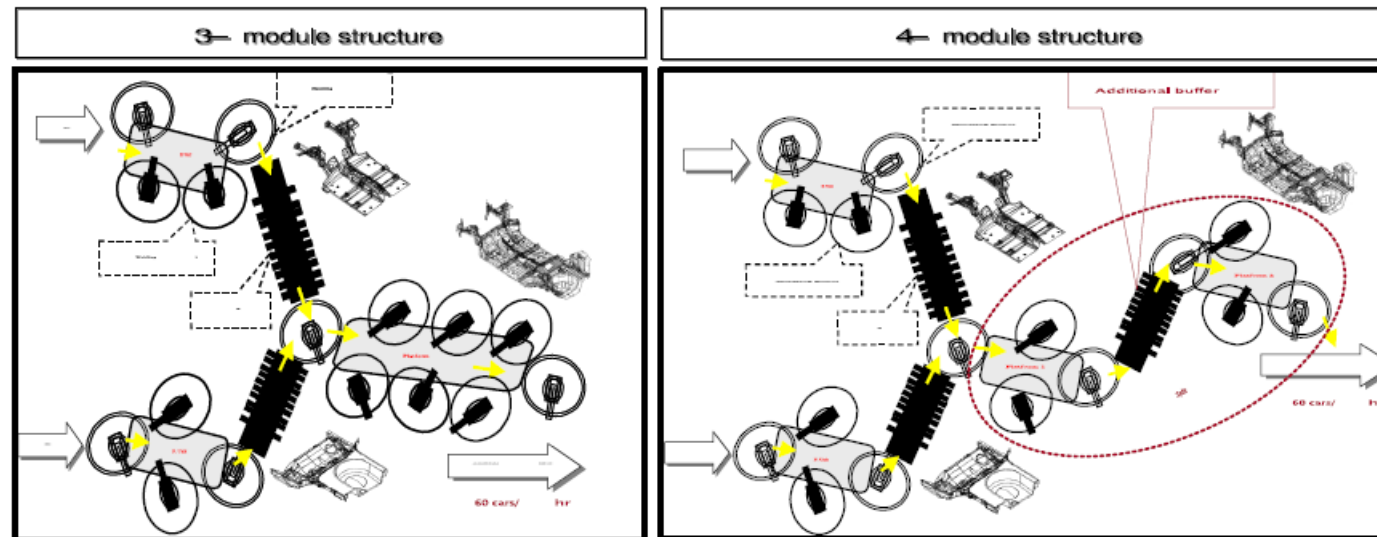
- There is a specified total number of spot welds that must be performed.
- All welders are identical and their reliability is constant whatever the number of spots they perform.
- All welders of the same module perform the same number of spots (ie, the work is divided equally).
- The cycle time of a module is determined by the number of welds performed in that module and the number of welding robots in it.
- The cost of a module is determined by the number of welding robots and material handling robots.
- The cost of the cell is determined by the cost of the modules and the cost of the buffers.

# Robot Cell Design

## Problem

*What set of robots (in each module) and buffers (between modules) will meet the production target at the least cost?*

Two possible solutions:



# Robot Cell Design

## Analysis

### Operational parameters

- Approximate a module as a single machine. Determine its parameters (cycle time, MTTF, MTTR) from its constituent parts.
- Each module is a production line with no buffers. It consists of welding and material handling robots.
- MTTF and MTTR and cycle time of each robot is known.
- The production rate of a module is determined from Buzacott's zero-buffer formula.
- The MTTF, MTTR, and cycle time of the module is derived from those of individual robots and the number of robots.

# Robot Cell Design

## Analysis

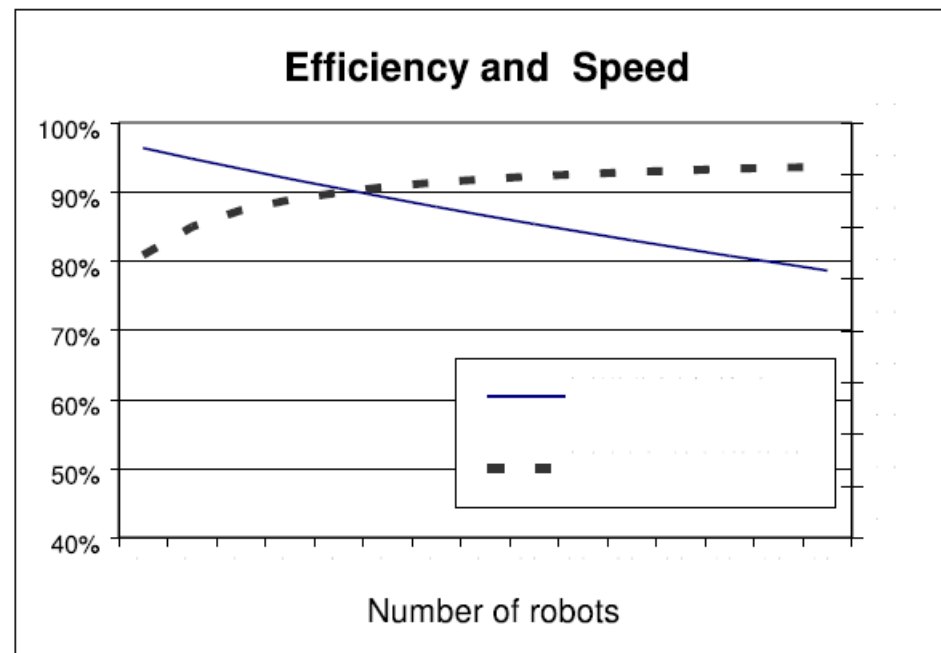
### Operational parameters

- Assume that the welding robots have the same parameters and the material handling robots have the same parameters.
- MTTF of a module decreases ( $p$  increases) as the number of robots increases because there are more opportunities for failure.
- MTTR is a weighted average of MTTR of welders and MTTR of material handlers. It approaches a constant as the number of welding robots increases.
- Therefore, isolated efficiency decreases as the number of welding robots increases.
- The operation time of a module decreases (the speed  $\mu$  increases) as the number of welding robots increases because each robot has fewer welds to do.

# Robot Cell Design

## Analysis

### Operational parameters



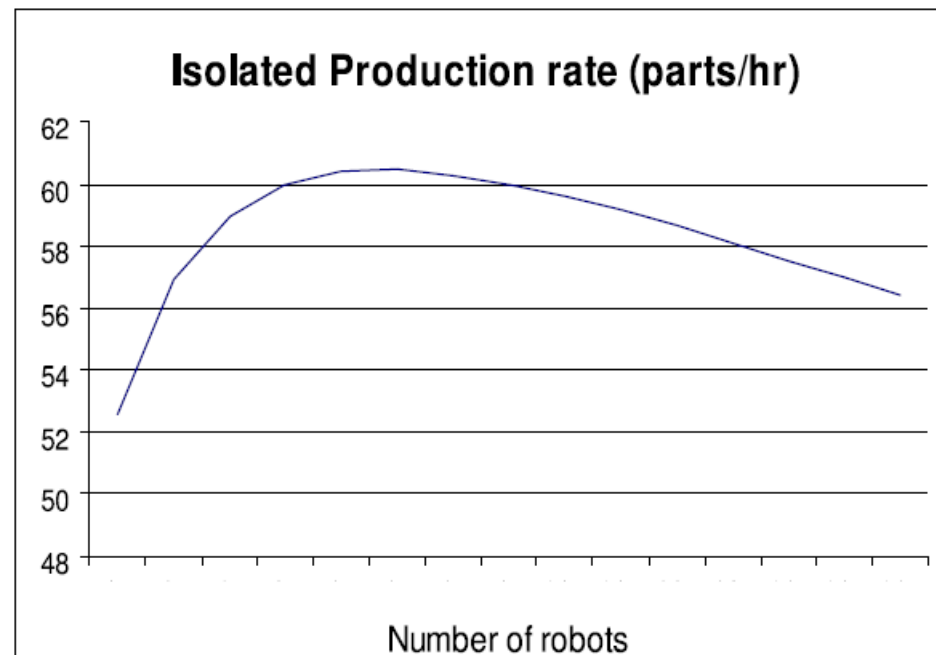
Efficiency and speed of a module as a function of the number of welders



# Robot Cell Design

## Analysis

### Operational parameters



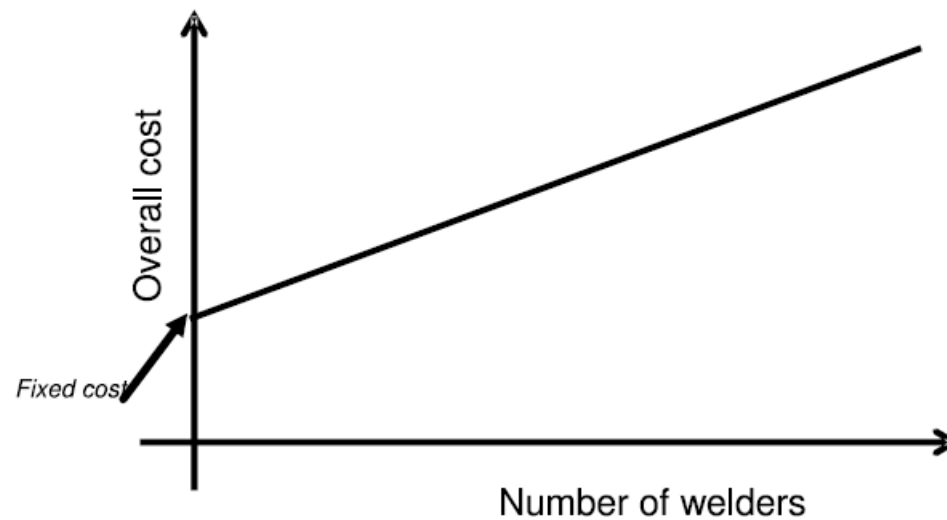
Isolated production rate of a module as a function of the number of welders

# Robot Cell Design

## Analysis

### Costs

The cost of a module is the cost of the welding robots + fixed costs.

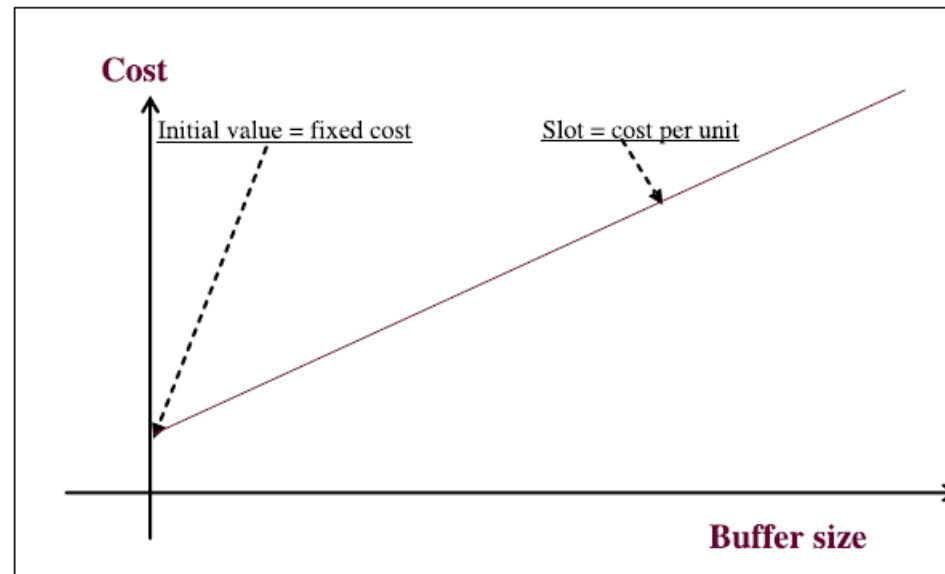


# Robot Cell Design

## Analysis

### Costs

The capital cost of a buffer is similar: linear in buffer size + fixed cost.



## Robot Cell Design

### Analysis

#### Costs

The operating cost of a buffer is proportional to its average buffer level.

*Assumption:* In an optimized line, buffers are half-full on the average.

Therefore the total cost of a buffer is linear in buffer size + fixed cost.

# Robot Cell Design

## Analysis

### Constraints

*Assumption:* Leveled flow gives optimal performance.

To achieve a leveled flow, the line must be balanced. Therefore the modules must have:

- their efficiencies as close as possible;
- their cycle times as close as possible.

To keep cycle times close, the number of welds performed by each robot should be close.

To keep efficiencies close, the numbers of robots in each cell satisfy a set of linear equations.

# Robot Cell Design

## Analysis

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# Robot Cell Design

## Analysis

### Issues

- The primal problem has nonlinear constraints.
- If there are  $k$  robots, there are  $k - 1$  possible positions for buffers, so there are  $2^{k-1}$  optimization problems.
- The number of robots  $k$  is a design choice.

# Robot Cell Design

## Analysis

### Dual problem

Maximize  $P$

*Subject to:*

- total cost specified
- upper bounds on number of robots in each cell and buffer size
- linear equations on numbers of robots in each cell



# Robot Cell Design

## Analysis

### Solution strategy

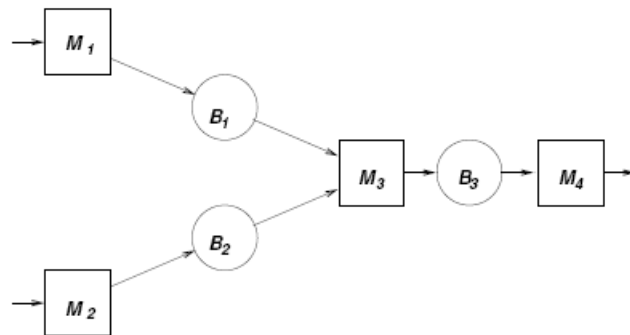
- Dual is easier than primal, so solve dual as a means of solving primal.
- Use heuristics to reduce the number of cases (ie, the number of robots and the locations of buffers) to be considered.

# Robot Cell Design

## Analysis

### Step 1

Cost for buffer proportional to space; no buffer fixed cost.  
Modules already determined.



Module	mttf (min)	mttr (min)	$t$ (min)	Isolated Production (parts/hour)
$M_1$	1800	6.00	0.8	74.75
$M_2$	220	6.00	0.8	73.00
$M_3$	300	6.00	0.9	65.35
$M_4$	800	6.00	0.8	74.44

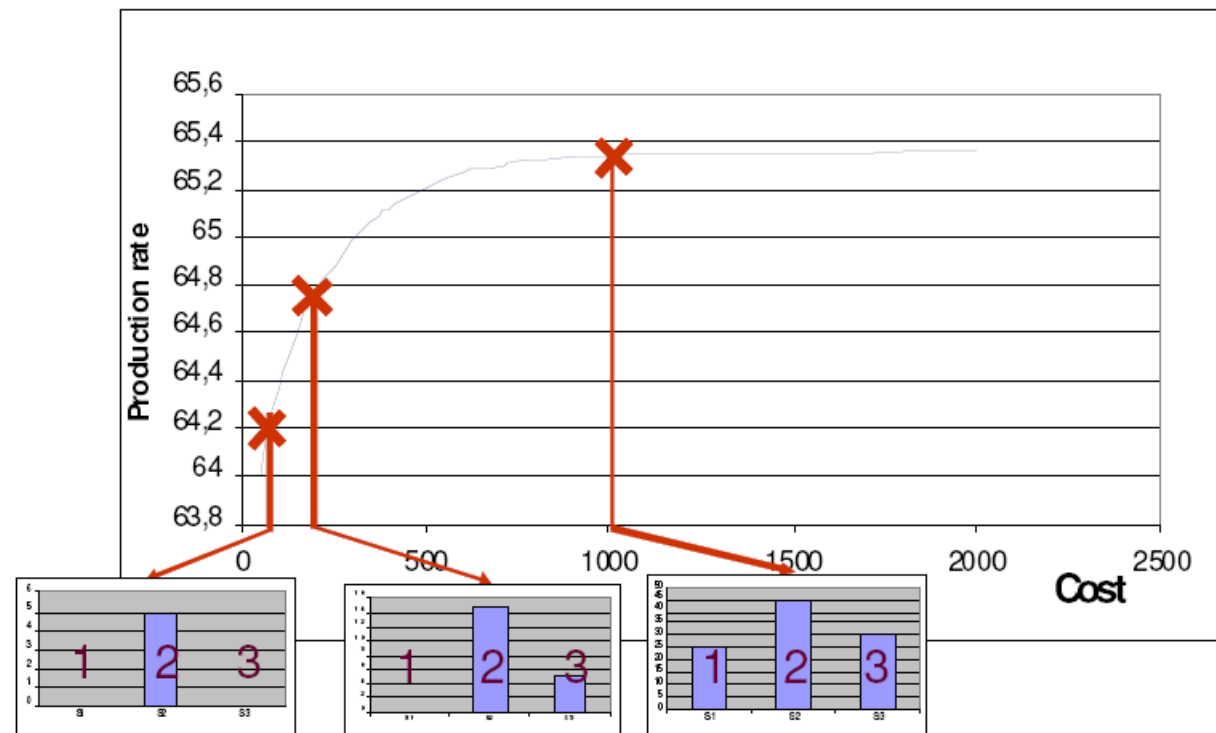
Buffer	Cost per unit (Euro)
$B_1$	9
$B_2$	10
$B_3$	11

# Robot Cell Design

## Analysis

### Step 1

*Solution:*



# Robot Cell Design

## Analysis

### Step 2

Same as Step 1 but buffers have fixed as well as variable costs.

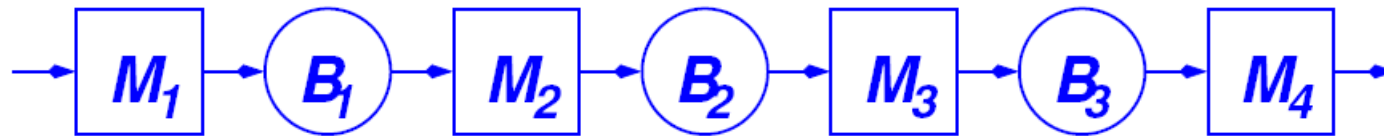
- There is now a large cost for a small buffer.
- *Minimal buffer set:*
  - ★ Calculate the isolated production rate of two contiguous modules using the zero-buffer formula.
  - ★ If it is less than  $P^*$ , then a solution exists only if a buffer exists between those two modules
- *Assumption:* If a buffer belongs to the optimal solution for  $q$  buffers, then it also belongs to the optimal solution for  $q + 1$  buffers.

# Robot Cell Design

## Analysis

### Step 2

Example:



Module	mttf (min)	mtrr (min)	$t$ (min)	Isolated Production (parts/hour)	Buffer	Fixed cost (Euro)	Cost per unit (Euro)
$M_1$	800	2.00	0.55	108.82			
$M_2$	850	2.80	0.55	108.73	$B_1$	3400	400
$M_3$	500	6.40	0.6	98.74	$B_2$	4700	600
$M_4$	600	6.50	0.55	107.92	$B_3$	4900	300

# Robot Cell Design

## Analysis

### Step 2

*Solution:*

<b>What is the best position for one buffer?</b>		\$15000 Line	Setting Cost	Remaining Money invested in the size	Hourly production
			3400	11600	98.91
			4700	10300	99.20
			4900	10100	99.03
<b>Holding the first buffer position constant, what is the best position for second buffer?</b>		\$15000 Line	Setting Cost	Remaining Money invested in the size	Hourly production
			8100	6900	99.17
			9800	5400	
<b>What is the best position for the third buffer?</b>		\$15000 Line	Setting Cost	Remaining Money invested in the size	Hourly production
			13000	2000	

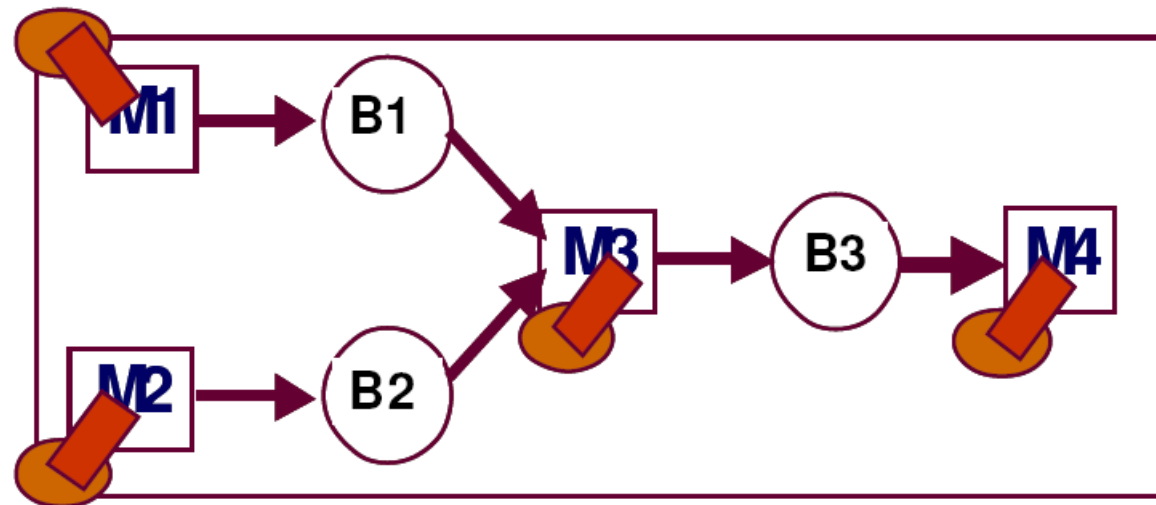
# Robot Cell Design

## Analysis

### Step 3

Same as Step 2 but the number of robots has to be chosen and the robots have to be allocated — the full problem.

### Example

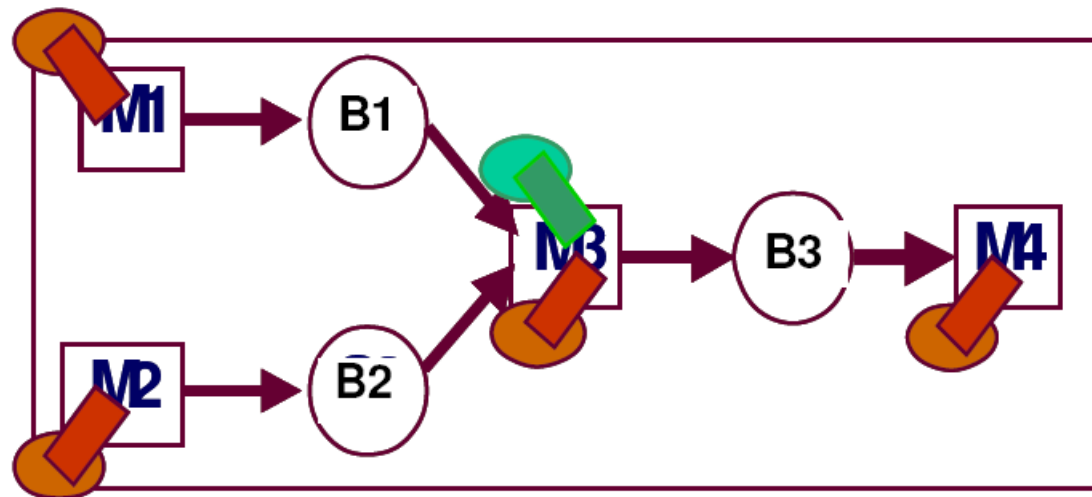


# Robot Cell Design

## Analysis

### Step 3

Add a robot to  $M_3$ .



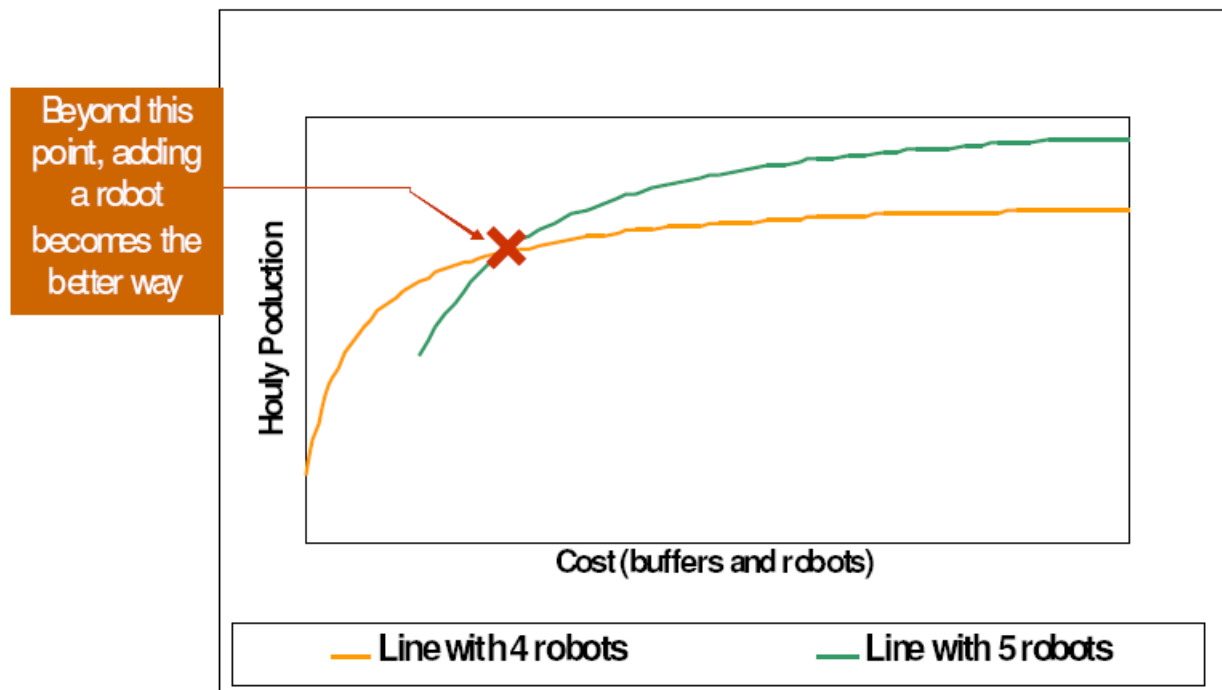


# Robot Cell Design

## Analysis

### Step 3

Cost comparison between 4 robots and 5 robots:

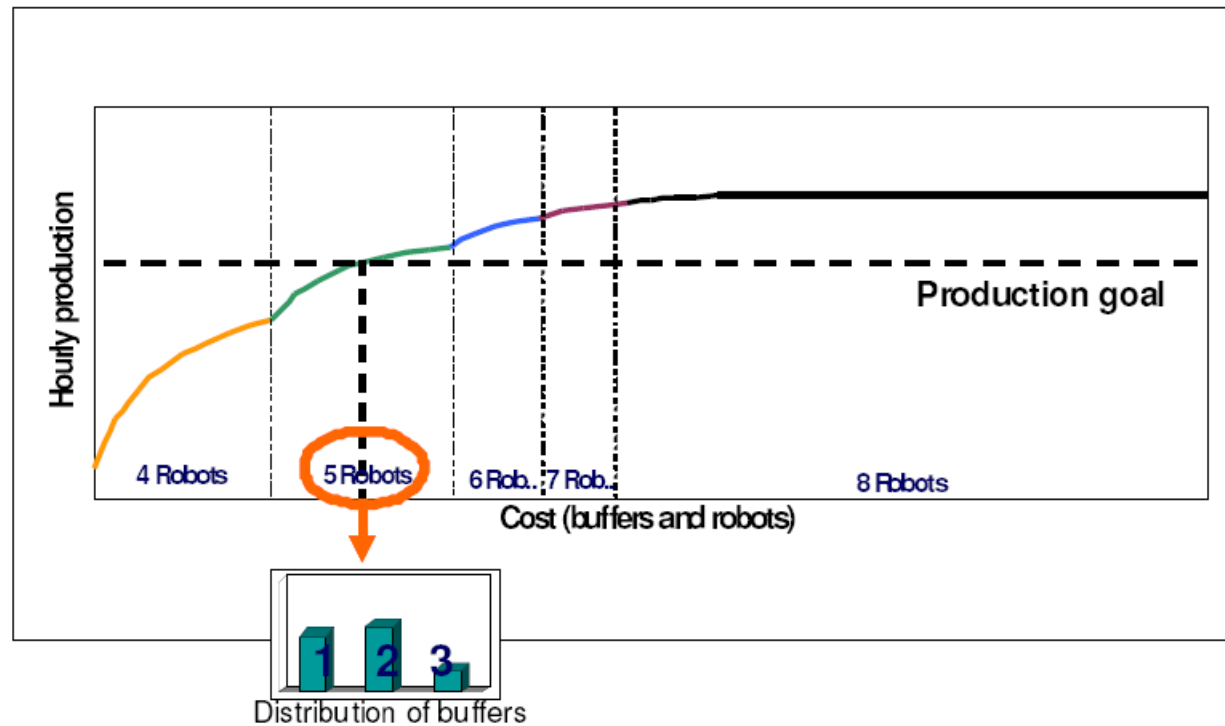


# Robot Cell Design

## Analysis

### Step 3

Solution:



## Robot Cell Design

### Analysis

#### Step 3

- Patchong's paper shows another example whose solution has 7 buffers and 19 robots. This is realistic.
- He says this could be applied to more than 90% of lines in existing body shops.
- Real cases can be solved in under 10 minutes of computer time.