Flexibility and Capacity Planning

• What is flexibility?
• GM examples
• Lessons from Flex Cap software
• Flex Cap model
• Flexibility principles
What is flexibility?

• Ability to **respond to change**
• What type of changes?

• Demand volume
• Demand mix
• Product features
• Process or technology changes
• Job priorities
• Process yield

• How responsive?
How to achieve flexibility?

• Flexible processes
• Short setups or changeovers
• Flexible work force
• Excess capacity
• Overtime
• Out sourcing or subcontracting
• Product design, e. g., modularity, common components, postponement
• Contracts, e.g., options
BACKGROUND

• Forward planning in automotive industry for allocating products to assembly plants

• Flexibility:
  – Ability to build different product types in the same plant at the same time

• Motivation:
  – Product demand is VERY uncertain. average forecast error > 50%!
  – Cost of unfilled demand or poorly utilized capacity is very high.
  – Flexible capacity is very expensive.
<table>
<thead>
<tr>
<th>CARLINES</th>
<th>ASSEMBLY PLANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEV J</td>
<td>LORDSTOWN</td>
</tr>
<tr>
<td>PONT J</td>
<td></td>
</tr>
<tr>
<td>L CAR</td>
<td>LINDEN</td>
</tr>
<tr>
<td>PONT N</td>
<td>WILMINGTON</td>
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<tr>
<td>OLDS N</td>
<td>LANSING A</td>
</tr>
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<td>BUICK N</td>
<td>LANSING B</td>
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<td>PONT H</td>
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</tr>
<tr>
<td>OLDS H</td>
<td>BUICK CITY</td>
</tr>
<tr>
<td>BUICK H</td>
<td>WENTZVILLE</td>
</tr>
<tr>
<td>BUICK C</td>
<td></td>
</tr>
<tr>
<td>OLDS C</td>
<td>ORION</td>
</tr>
<tr>
<td>CAD C</td>
<td>HAMTRAMACK</td>
</tr>
<tr>
<td>BUICK E</td>
<td></td>
</tr>
<tr>
<td>OLDS E</td>
<td></td>
</tr>
<tr>
<td>CAD E/K</td>
<td></td>
</tr>
</tbody>
</table>

Is this enough flexibility?
PLANNING VOLUME UNCERTAINTY

PLANNING VOLUMES FOR MY 85-89 NAMEPLATE-CARLINES COMPARED TO ACTUAL PRODUCTION:

[Graph showing the percentage difference between planning volumes and actual production over quarters before the start of production.]
# AVERAGE UNCERTAINTY

## MY 85-89 NAMEPLATE-CARLINE PLANNING VOLUMES COMPARED TO ACTUAL PRODUCTION

<table>
<thead>
<tr>
<th>QUARTERS BEFORE SOP</th>
<th>AVERAGE ABSOLUTE DIFFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>54%</td>
</tr>
<tr>
<td>8</td>
<td>44%</td>
</tr>
<tr>
<td>4</td>
<td>37%</td>
</tr>
</tbody>
</table>
Dedicated System

Sales: 528.26
Shortfall: 76.26
Utilization: 88.11%
$X_{ij}$: amount produced at plant $i$ for product $j$

$S_j$: shortfall for product $j$

Min $\sum_j S_j$

$\sum_j X_{ij} \leq C_i$ for all plants $i$

$\sum_i X_{ij} + S_j \geq \tilde{D}_j$ for all products $j$
• What is the best way to add flexibility to the system?
• What are the benefits?
• How much flexibility do you need to add?
<table>
<thead>
<tr>
<th></th>
<th>sales</th>
<th>shortages</th>
<th>Util.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated</td>
<td>531</td>
<td>71</td>
<td>88.5 %</td>
</tr>
<tr>
<td>1 link</td>
<td>534</td>
<td>68</td>
<td>89.0 %</td>
</tr>
<tr>
<td>2 links</td>
<td>540</td>
<td>62.5</td>
<td>90.0 %</td>
</tr>
<tr>
<td>3 links</td>
<td>545</td>
<td>57</td>
<td>90.9 %</td>
</tr>
<tr>
<td>4 links</td>
<td>552</td>
<td>50.5</td>
<td>91.9 %</td>
</tr>
<tr>
<td>5 links</td>
<td>559</td>
<td>43.4</td>
<td>93.1 %</td>
</tr>
<tr>
<td>6 links</td>
<td>572</td>
<td>29.7</td>
<td>95.3 %</td>
</tr>
<tr>
<td>Total flex</td>
<td>572</td>
<td>29.6</td>
<td>95.4 %</td>
</tr>
</tbody>
</table>
Limited Flexibility
Sales: 569.39
Shortfall: 35.13
Utilization: 94.96%

Total Flexibility
Sales: 569.40
Shortfall: 35.12
Utilization: 94.96%
FLEXIBILITY PRINCIPLES

• **A LITTLE FLEXIBILITY GOES A LONG WAY!:**
  – SMALL AMOUNT OF FLEXIBILITY APPROPRIATELY USED YIELDS MOST OF THE BENEFITS OF TOTAL FLEXIBILITY

• **“CHAINING”:**
  – ADDING FLEXIBILITY TO “CHAIN” PLANTS AND PRODUCTS TOGETHER IS MOST EFFECTIVE
PRODUCTS ASSIGNED TO PLANTS ARE CONNECTED TO LINKS AS SHOWN.

A CHAIN IS DEFINED SUCH THAT A PATH CAN BE TRACED VIA LINKS FROM ANY PRODUCT OR PLANT TO ANY OTHER PRODUCT OR PLANT WITHIN THE CHAIN.

- NO PRODUCT IS BUILT BY A PLANT OUTSIDE THE CHAIN
- NO PLANT BUILDS A PRODUCT FROM OUTSIDE THE CHAIN
• DEMAND FOR EACH PRODUCT:
  – EXPECTED = 100 UNITS
  – STANDARD DEVIATION = 40 UNITS
  – PRODUCT DEMANDS UNCORRELATED

• CAPACITY OF EACH PLANT = 100 UNITS
ADD FLEXIBILITY

PRODUCTS

A
B
C
D
E
F
G
H
I
J

PLANTS

1
2
3
4
5
6
7
8
9
10

ADD FIRST LINK

ADD SECOND LINK

ADD THIRD LINK
NO FLEXIBILITY VS. TOTAL FLEXIBILITY

![Graph showing expected sales units versus expected capacity utilization percentage.]

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IMPACT OF ADDING FLEXIBILITY

![Graph showing the impact of adding flexibility on expected sales and expected capacity utilization. The graph includes four scenarios: NO FLEX, ADD 1 LINK, ADD 2 LINKS, and ADD 10 LINKS. The expected sales increase as the expected capacity utilization increases in each scenario, with the TOTAL FLEX scenario showing the highest expected sales at the highest expected capacity utilization.]
LIMITED FLEX. CAN HAVE THE BENEFITS OF TOTAL FLEX.
CHAINING YIELDS THE GREATEST BENEFITS

ONE CHAIN

PRODUCTS | PLANTS
---|---
A | 1
B | 2
C | 3
D | 4
E | 5
F | 6
G | 7
H | 8
I | 9
J | 10

FIVE CHAINS

PRODUCTS | PLANTS
---|---
A | 1
B | 2
C | 3
D | 4
E | 5
F | 6
G | 7
H | 8
I | 9
J | 10

≠
IMPACT OF CHAINING
Figure 4  Impact of Capacity Changes on Benefits of Flexibility

- One-Chain Flex
- Add Capacity
- Add Flex.
- No Flex
- Subtract Capacity

*C = Total Capacity (Total Expected Demand = 1000 units)
NEGATIVE DEMAND CORRELATION

• CHAINING MORE IMPORTANT THAN COMBINING NEGATIVELY CORRELATED PRODUCTS

• EXAMPLE:
  – ASSUME PRODUCTS A AND C NEGATIVELY CORRELATED. THEN THESE CONFIGURATIONS ARE EQUIVALENT IN TERMS OF FLEXIBILITY BENEFITS.

PRODUCTS  PLANTS

A  1
B  2
C  3
D  4

PRODUCTS  PLANTS

A  1
B  2
C  3
D  4

• PRODUCT CORRELATIONS ARE NOT A KEY FACTOR IN DECIDING WHICH PRODUCTS TO BUILD TOGETHER IN A PLANT, AS LONG AS THE PRODUCTS ARE CHAINED TOGETHER
“REAL” EXAMPLE

EX. DEMAND (000’S)

<table>
<thead>
<tr>
<th>Demand</th>
<th>Capacity (000’S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>240</td>
</tr>
<tr>
<td>80</td>
<td>230</td>
</tr>
<tr>
<td>140</td>
<td>230</td>
</tr>
<tr>
<td>160</td>
<td>230</td>
</tr>
<tr>
<td>60</td>
<td>230</td>
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<tr>
<td>35</td>
<td>230</td>
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<td>40</td>
<td>230</td>
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<tr>
<td>35</td>
<td>240</td>
</tr>
<tr>
<td>30</td>
<td>240</td>
</tr>
<tr>
<td>80</td>
<td>2,030</td>
</tr>
</tbody>
</table>

CAPACITY (000’S)

CHAINS

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8

- 380

2,060

2,030
BOC PRODUCT ASSIGNMENT MY 93 PLAN

- **CHEV J**
  - **PONT J**
  - **LORDSTOWN**

- **L CAR**
  - **PONT N**
  - **OLDS N**
  - **BUICK N**
  - **LANSING A**
  - **LANSING B**
  - **“L” PLANT**

- **PONT H**
  - **OLDS H**
  - **BUICK H**
  - **BUICK C**
  - **WENTZVILLE**
  - **BUICK CITY**

- **OLDS C**
  - **OLDS G**
  - **BUICK G**
  - **ORION**

- **CAD E**
  - **CAD K**
  - **CAD Ksp**
  - **HAMTRAMCK**

- **CHAIN**

25
ADD FLEXIBILITY

EX. DEMAND (000’S)

CAPACITY (000’S)

- CHAINS
BASE VS. TOTAL FLEXIBILITY

Expected sales, 000's of units

Expected capacity utilization, %
THERE IS NOT ONE “OPTIMAL” FLEX. PLAN
SUMMARY

• A SMALL AMOUNT OF FLEXIBILITY CAN HAVE MOST OF THE BENEFITS OF TOTAL FLEXIBILITY.

• FLEXIBILITY HAS THE GREATEST BENEFITS WHEN ADDED TO YIELD FEWER, LONGER CHAINS.

• THERE IS NO SINGLE “OPTIMAL” FLEXIBILITY PLAN; SEVERAL PLANS WILL YIELD THE BENEFITS OF TOTAL FLEXIBILITY
SUMMARY

• VALUE FROM FRAMEWORK FOR QUANTIFYING BENEFITS OF FLEXIBILITY

• FLEX CAP TOOL ALLOWS EXPLORATION OF ALTERNATIVES, AND THEIR EVALUATION UNDER UNCERTAINTY

• SUBSEQUENT RESEARCH HAS SHOWN HOW IDEAS EXTEND TO SUPPLY CHAIN, I.E, MULTIPLE STAGES
EXAMPLE FLEXIBILITY ADDITIONS B-O-C MY 93 PLAN

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ADD FLEXIBILITY
Principles

• Limited flexibility can give you the benefit of total flexibility
• Limited flexibility has greatest benefits when create chains