# A Screening Model to Explore Planning Decisions in Automotive Manufacturing Systems under Demand Uncertainty

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## Outline

- *What am I doing?* (Research Question)
  - How to design large scale and complex manufacturing systems so that they perform well under demand uncertainty
- *How am I doing it?* (Research method)

***A screening model + an evaluation model***

  - *Screening model* ⟶ *to identify good decision candidates*
  - *Evaluation model* ⟶ *to extensively examine decision candidates*
- *How does it work?* (Method application)
  - Case study in Automotive body assembly system planning



## Motivation

- Large complex engineering systems, such as automotive manufacturing systems, are:
  - Capital intensive
  - Require long lead time to develop
  - Difficult to change
- Demand uncertainty

# Motivation(2): Demand Uncertainty




# Motivation

- Large complex engineering systems, such as automotive manufacturing
  - Capital intensive
  - Require long lead time to develop
  - Difficult to change
- Demand uncertainty
  - Macroeconomic change
  - Shifting consumer preference
  - Incorrect prediction, etc.

**How to design the systems so that they can perform well under demand uncertainty?**



# Motivation(3): Multiple sources of flexibility

- System architecture
  - Product to plant allocation (Process flexibility)
  - Capacity
- Technology
  - Tooling Technology
  - Equipment automation

**Strategic Planning Decisions**

**(Strategic Flexibility)**

- Operation
  - Shifts selection
  - Overtime operation
  - Inventory

**Operational Decisions**

**(Operational Flexibility)**

## Research Questions

- For large complex manufacturing systems, given
  - Demand uncertainty
  - Multiple sources of flexibility
- How to design these systems so that they can perform well under uncertainty?
  - What is the impact of considering demand uncertainty on strategic decision making?
  - What is the impact of considering operational flexibility?
  - How to identify good design candidate in a large design space?



## Research Scope

- System architecture
  - ***Product to plant allocation***
  - ***Capacity***
- Technology
  - Tooling Technology
  - Equipment automation

**Strategic Planning Decisions**

**(Strategic Flexibility)**

- Operation
  - Shifts selection
  - ***Overtime operation***
  - Inventory

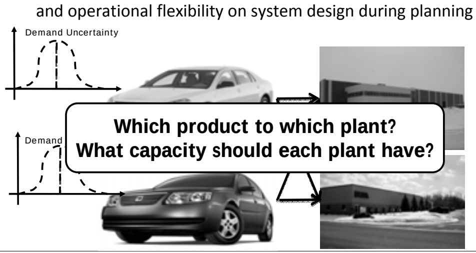
**Operational Decisions**

**(Operational Flexibility)**



## Case study 1: Simple Hypothetical Case

- Objective:
  - To demonstrate the impact of considering demand uncertainty and operational flexibility on system design during planning stage.



## Case study 1: Simple Hypothetical Case

- System under consideration
  - 2 products, 2 plants, 5 years
- Demand
  - Normal distribution
  - Expected values 200k, standard deviation 50k each year for both
  - No correlation
- Investment cost, as a function of
  - Equipment, tool, building, capacity, process flexibility upcharge
- Operating cost:
  - Operating cost during overtime > Operating cost during normal time



## Decision Approaches

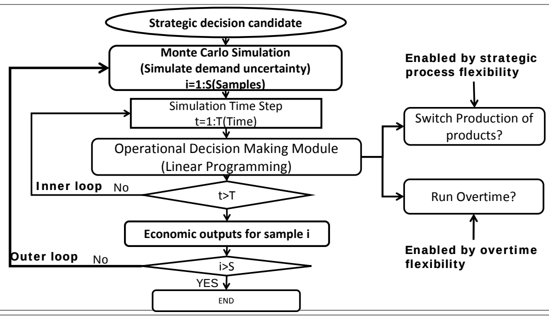
| Operational Flexibility | Demand Uncertainty: No | Demand Uncertainty: Yes |
|---|---|---|
| No | DA1 | DA3 |
| Yes | DA2 | DA4 |



## Optimal Decisions under DAs

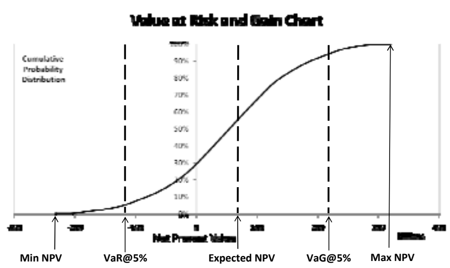
| Decision Approach | Considers Demand Uncertainty? | Considers Operational Flexibility? | Allocation Decision | Capacity Decision | Decision Characteristics |
|---|---|---|---|---|---|
| DA1 | *No* | *No* | Product A → Plant 1<br>Product B → Plant 2 | 200k<br>200k | *S1:(2 Dedicated-200k)* |

## Results Evaluation-Simulation Model



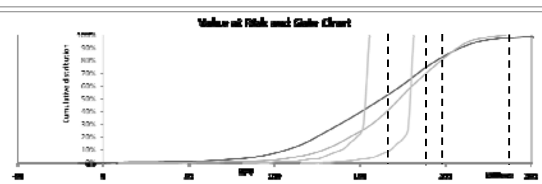



## Results Evaluation-VaRG Chart






## Results for Case Study 1



| Decision Approach | Considers Demand Uncertainty | Considers Operational Flexibility? |
|---|---|---|
| DA1 | *No* | *No* |
| DA2 | *No* | *Yes* |
| DA3 | *Yes* | *No* |
| DA4 | *Yes* | *Yes* |

## Conclusions for Case Study 1

- The impact of considering demand uncertainty:
  - Leads to flexible process design as compared to dedicated process design under deterministic approach
  - As a result, reduces system's risk under demand uncertainty
- The impact of considering overtime flexibility:
  - Enhances the value of strategic process flexibility
  - Reduced investment cost, improved ENPV, min NPV, and max NPV.



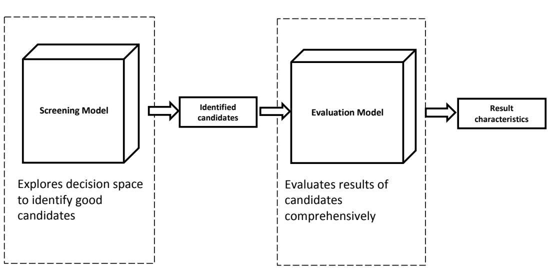
## Computational Challenge

- Exhaustive search
  - Total number of design alternatives grows exponentially with the number of products and the number of plants
  - i.e. 3 products and 3 plants ≈ 2400 hours
- Stochastic optimization

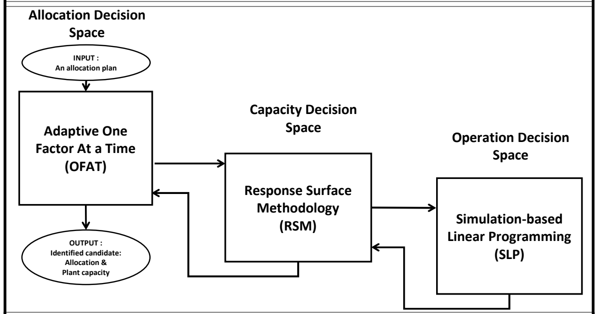
| # of product | # of plant | # of variables | # of constraints | Computational Time |
|---|---|---|---|---|
| 2 | 2 | 500 | 2,000 | 2 min 44s |
| 2 | 3 | 750 | 2,875 | 1hour 14min |
| 2 | 4 | 1,000 | 3,750 | >20hours |
| 3 | 2 | 3,750 | 13,125 | 13min12s |
| 3 | 3 | 5,625 | 18,750 | >20hours |
| 3 | 4 | 7,500 | 24,375 | >20hours |



## Proposed Method: A Screening Model

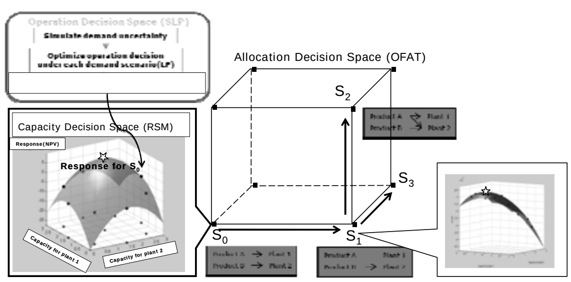


# Screening Model



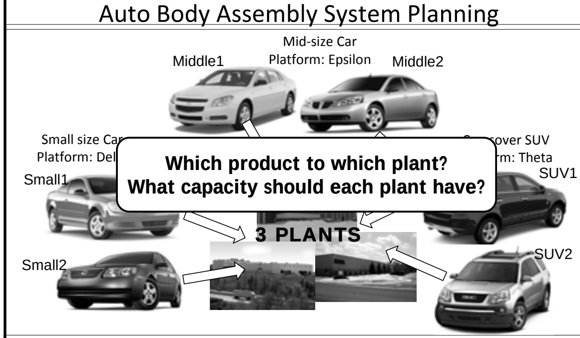



# Schematic Chart of the Screening Model






# Case Study2:
# Auto Body Assembly System Planning



# Case Study 2

- System under consideration
  - 6 products, 3 plants, and 5 years
- Demand
  - Normal distribution
  - Expected values of demands decrease at 4%/year
  - Standard deviation increases 5%/year
  - Demands are correlated
- Investment, as a function of
  - Equipment, tool, building, capacity, flexibility upcharge
  - Flexibility upcharge, as a function of
    - # of styles, # of platforms, difference between platforms
- Operating cost
  - Includes purchased part cost, assembly material and energy, maintenance, labor cost and overhead cost



# Case Study 2: Decisions From Different Approaches

**DA1**

| | |
|---|---|
| Demand Uncertainty | No |
| Operational flexibility | No |

**DA2**

| | |
|---|---|
| Demand Uncertainty | No |
| Operational flexibility | Yes |

**DA3**

| | |
|---|---|
| Demand Uncertainty | Yes |
| Operational flexibility | No |

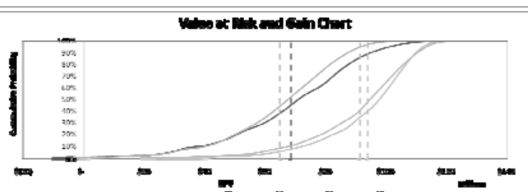
**DA4**

| | |
|---|---|
| Demand Uncertainty | Yes |
| Operational flexibility | Yes |


Small size car   Mid-size car   SUV



# Case Study 2: Results




| Decision Approach | Considers Demand Uncertainty? | Considers Operational Flexibility? | Investment | NPV | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | ENPV | MIN | MAX | Standard Deviation | VaR@5% | VaG@5% |
| DA1 | *No* | *No* | $340M | $68M | ($10.3M) | $117M | 32% | $28M | $98M |
| DA2 | *No* | *Yes* | **$324M** | $65M | ($4M) | $102M | 29% | $27M | $92M |
| DA3 | *Yes* | *No* | $359M | $91M | $20M | **$120M** | 19% | $60M | **$115M** |
| DA4 | *Yes* | *Yes* | $346M | **$93M** | **$26M** | $118M | **16%** | **$64M** | $114M |

## Conclusions For Case Study 2

- The screening model identified different auto body assembly system designs as compared to traditional practice
  - More flexible processes
  - Fewer plants
- The identified design results in big improvement of performance
  - 47% improved ENPV
  - Reduced downside risks
  - Increased upside gain



## Contributions

- A framework to design manufacturing system, which considers
  - Demand uncertainty
  - Multiple sources of flexibility
- An integrated screening model that
  - Considers demand uncertainty and multiple sources of flexibility
  - Adaptively explores design space by integrating OFAT, RSM, and SLP methods
  - Is computationally practical to identify good design candidates
- Application in automotive body assembly systems planning
  - The case study shows screening model leads to system design with a 47% of improvement of ENPV and reduced downside risks as compared to traditional practice.



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## Questions and Comments?