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A Strategic Asset Planning Decision Analysis: An Integrated SD and MCDM Method

Introduction

- Asset planning is complex and dynamic.
- Decision makers must make decisions *now* that have long-term impacts across long life cycles.
- Here we investigate an integrated approach to the application of qualitative and quantitative methods.
- The approach is demonstrated in a real-life decision support project for fleet planning.

The Challenge of Asset Management

- Asset management is defined as an integrated activity to realize a value from a system of assets.
- This definition extends the scope of the asset management beyond traditional CM and maintenance to include a wide range of decision problems across the whole-life-cycle of the asset in order to deliver value to the asset owners and stakeholders.

The Challenge of Asset Management

- A *fleet* is a multi-asset system of assets of the same category (e.g. vehicle, vessels), in which individual assets are homogenous (e.g. identical vessels).
- A *portfolio* is a multi-asset system in which assets can belong to single or multiple categories that are mostly heterogonous (e.g. infrastructure portfolio of bridges and highways).

The Challenge of Asset Management

- There are three types of dependencies among assets:
  - *Performance* dependencies arise from the configuration among assets and/or among the components.
  - *Resource* dependencies arise from sharing resources for activities (e.g. maintenance) during the asset's lifecycle.
  - *Stochastic* dependencies arise from interactive failures caused by workload sharing, or similar external factors.

The Challenge of Asset Management

- We use the term *option* or *alternative* as a possible solution to achieve the decision maker's requirements.
- An option can cover one or more decision points, such as the number of assets to add, how maintenance is conducted, the number to retire, and when, and where.
- Criteria are the set of considerations used to evaluate options. For decision analysis, criteria are operationalized into a set of indicators that can be measured in a meaningful way.

The Challenge of Asset Management

- Decisions involve multiple criteria and multiple dimensions (e.g. technical, economic, political).
- The performance of these decisions changes over the lifetime of the asset. For example, the question about the number and timing of assets to acquire and retire (i.e. transition schedules) needs an understanding of how different combinations of those decisions will affect the organizational performance measures, such as availability and efficient resource utilization.

The Challenge of Asset Management

- Solving this problem is a non-trivial exercise—research has demonstrated that humans struggle with decision-making tasks that require the projection of outcomes over time, especially when considering multiple options and criteria.
- As a result, decision-support tools are essential for helping decision makers to navigate this task.

Decision Support for Asset Management

- Decision support for asset management requires:
  - Ability to examine long term effects of multiple options and strategies.
  - Ability to capture the interdependencies among assets, resources, decisions, and the overall performance.
  - Ability to explicitly incorporate decision maker's judgments and preferences.

Scope

- This paper applies a multi-method modelling approach for analyzing strategic asset planning using the fleet transition problem as a demonstration case study.
- The proposed approach integrates the use of two decision analysis techniques: the SD modelling approach and MCDM.
- Although both have proved very valuable for decision making, there are few investigations into the application of both in multi-method decision analysis.

System Dynamics (SD)

- SD captures the causal relationships between strategic factors, available resources, and performance outcomes when forming an asset management strategy.
- This allows for examining the dynamic performance of options, and shortlisting feasible candidate options.
- On the other hand, the simulation model evaluates options based on their performance of the quantitative criteria, and does not account for decision makers' judgments and preferences.

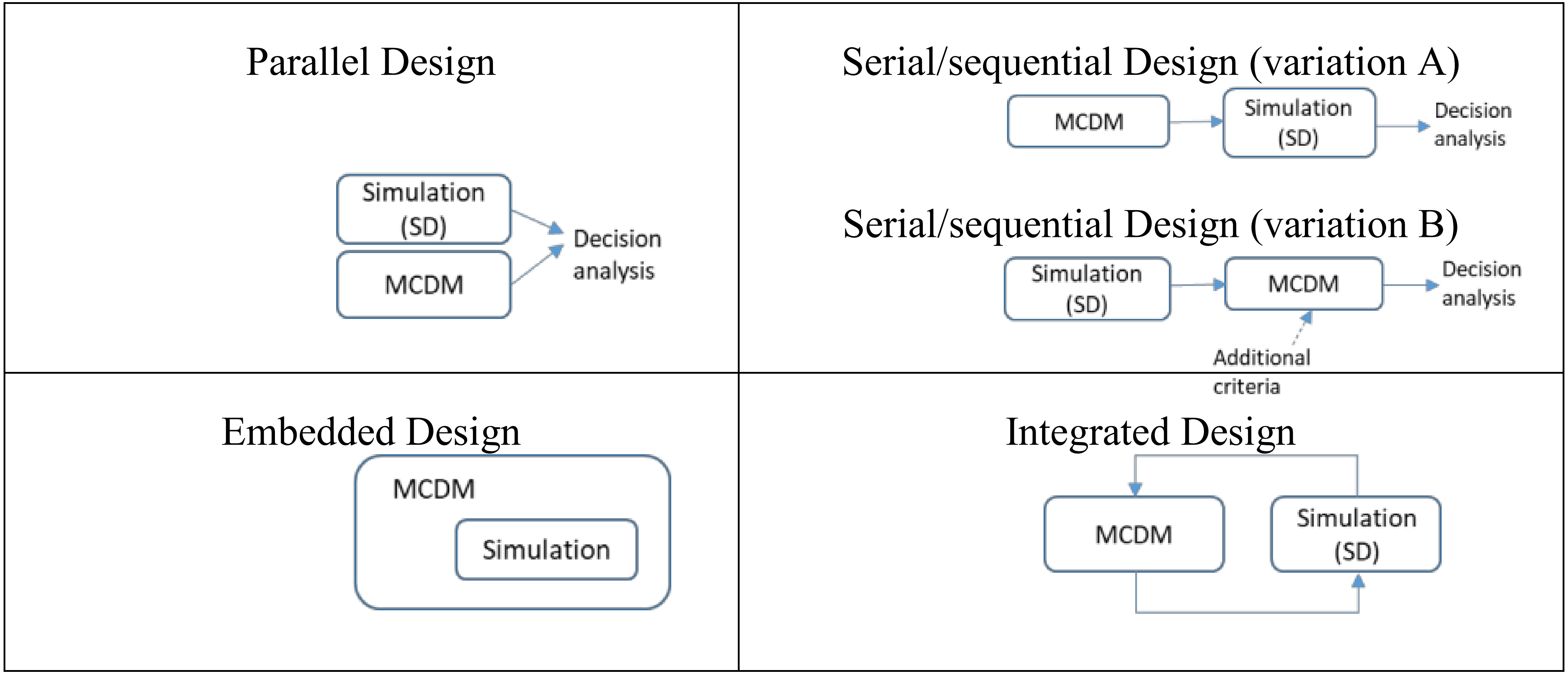
Multi-criteria Decision Making (MCDM)

- MCDM encompasses a group of decision-analysis methods used to handle complex problems with high dimensionality of criteria (e.g. economic, technical, environmental, security).
- The explicit focus on criteria helps decision makers understand their own preferences, and how they play out as an element of the problem complexity.
- On the other hand, MCDM lacks the ability to show the performance of the selected options and validate the veracity of view underpinning the users' judgments.

Multi-method Approach for Decision Support

- Multi-method approach integrating quantitative and qualitative data.
- Leveraging the power of simulation and systems thinking techniques.
- Leveraging the power of different techniques to tackle different aspects of the problem complexity (e.g. social, dynamic, detail).

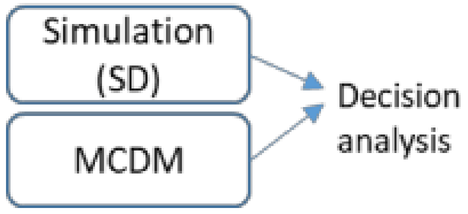
Multi-method Approach for Decision Support



Multi-method Approach for Decision Support

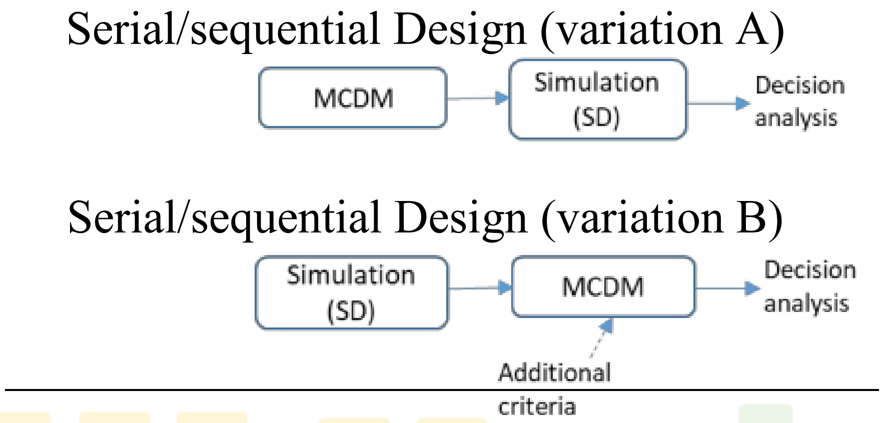
- Both methods are employed in isolation with no information exchange.
- Results are interpreted within the worldview of each method, and then are combined (usually in the form of qualitative narratives).
- May be viewed as simplest approach to implement multi-methods designs.

Parallel Design



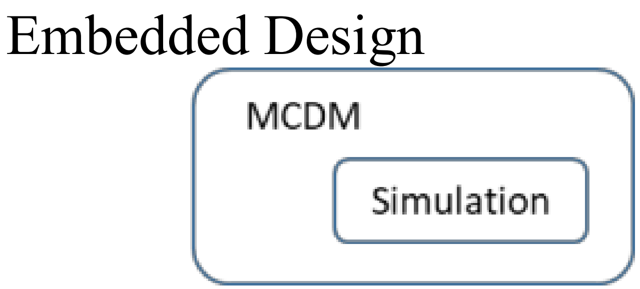
Multi-method Approach for Decision Support

- A. MCDM (often AHP) is employed first to shortlist candidate options to be run through the simulation model.
- B. Simulation is used to evaluate and rank options that are fed to the MCDM, where stakeholders add their own preferences to weighting scores.



Multi-method Approach for Decision Support

- Elements from one method are used to enrich the other, where the method is fully embedded in the methodological and theoretical framework of the dominant method.
- For example, Monte Carlo simulation is often used to examine the sensitivity of changes in users' preferences with a MCDM process.

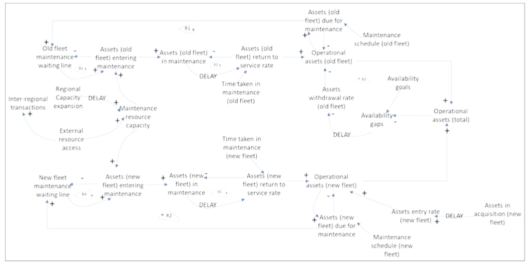


Multi-method Approach for Decision Support

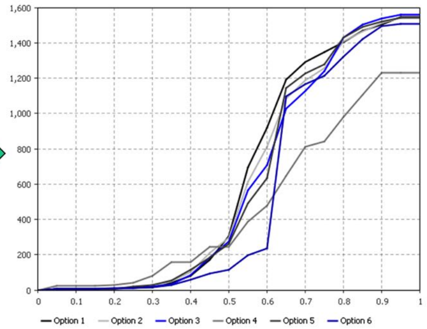
- The output from one technique feeds to the other. MCDM is used to construct scenarios and criteria, which are evaluated through the simulation.
- In the second iteration, options are evaluated in the context of each scenario using MCDM. Results from this process can lead to identifying new scenarios within which the solutions can be tested.

Integrated Design

Best of Both Worlds: Integrating SD and MCDM

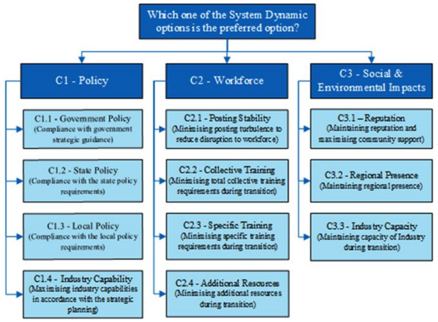


Strategy Mapping



Strategy dynamics simulation

LEARNING

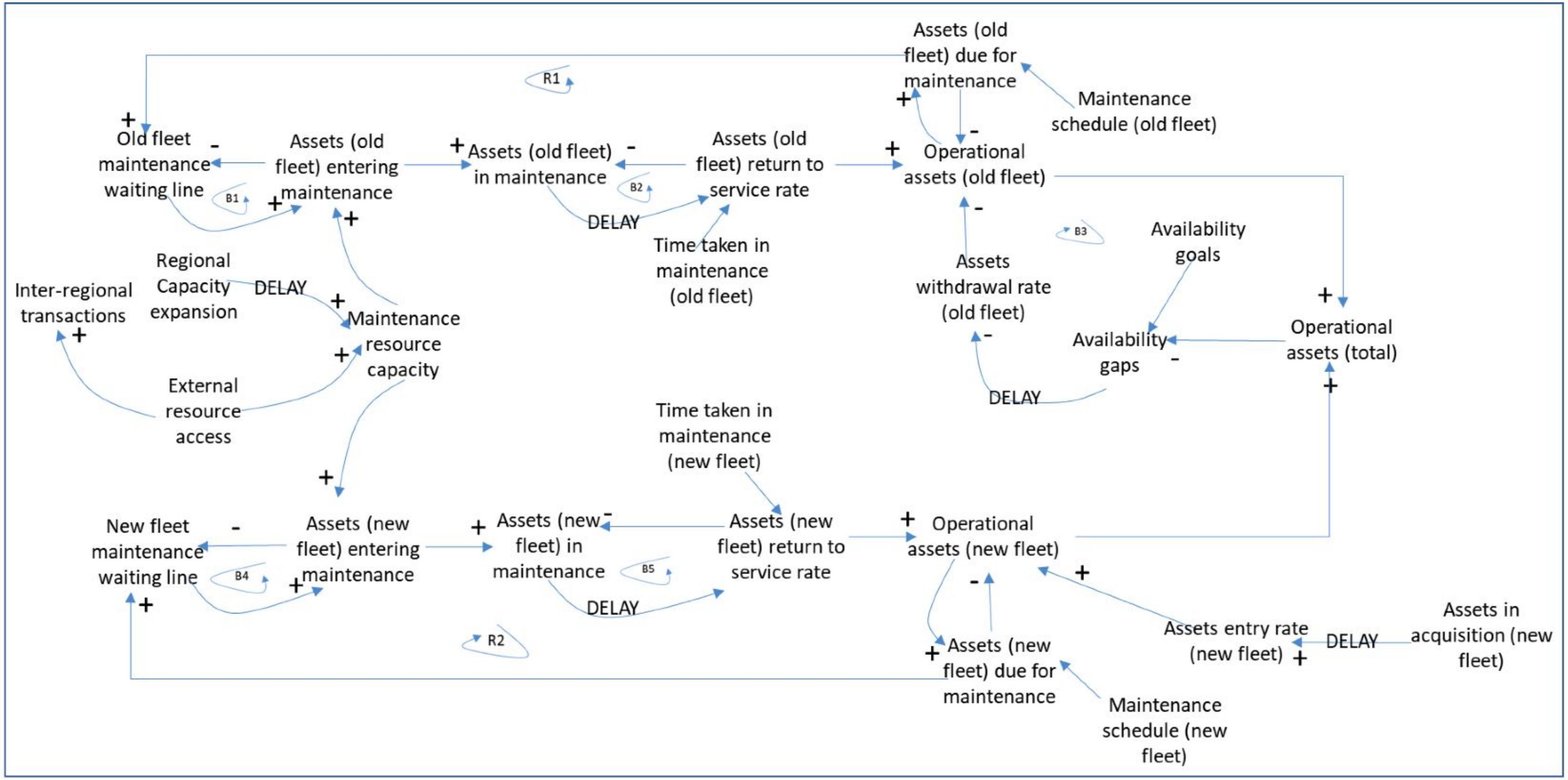


Multi-criteria strategy analysis

	Final Weight		Ranking
	W*Total*	%	
Option 1	0.130099	13.01%	6
Option 2	0.140246	14.02%	5
Option 3	0.156271	15.63%	4
Option 4	0.180781	18.08%	2
Option 5	0.177785	17.78%	3
Option 6	0.214819	21.48%	1

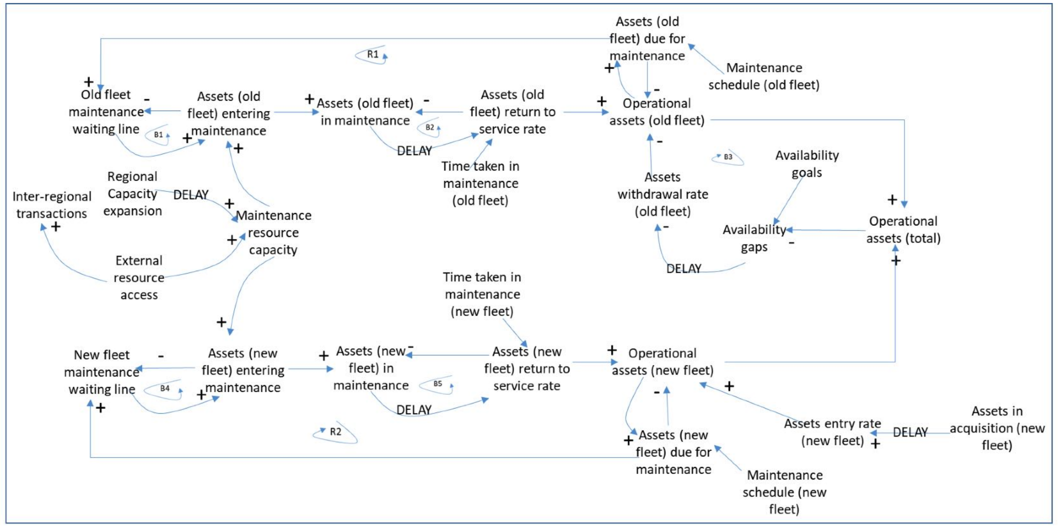
Strategy ranking and selection

Conceptual SD Models



Conceptual SD Models

- CLD shows key problem elements and relationships and captures the interactions among the three types of dependencies in asset management: performance, resource, and stochastic.



SD Simulation Model

- Based on the CLD, a SD simulation model was implemented using Anylogic Software.
- A number of options are formulated to be analyzed through the SD model. The experiment is designed to show the trade-off between availability of the fleet and the number of inter-regional transactions.

SD Simulation Model

- The following assumptions were used to formulate options.
  - The planning horizon of the problem is 30 years (2018-2048).
  - At the beginning of the simulation, all old fleet assets are in service. By the end of the planning period, the new fleet should have totally replaced the old fleet.
  - The new and old fleet have different maintenance cycles (i.e. maintenance durations and resource requirements).
  - …

SD Simulation Model

- The following assumptions are used to formulate options.
  - ...
  - The new and old fleet share the same resource capacity.
  - Both fleets live in the same homeport region.
  - Assets can access maintenance capacity inside their homeport region as a first preference. If the maintenance resources are not available, assets can access resources outside their homeport region. There is no restriction on access to external maintenance capacity (outside the homeport region).

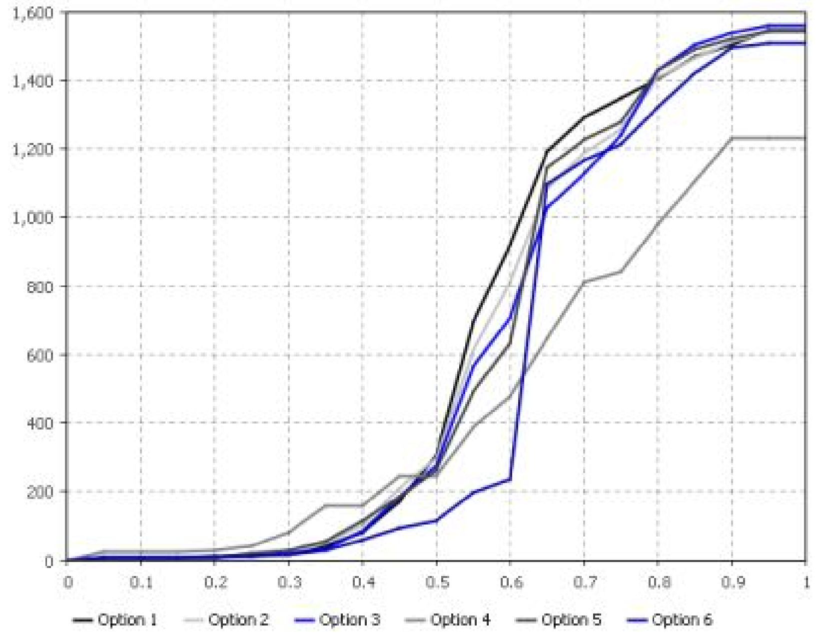
Quantitative SD Models

- While the paper is based on a real case study, all the following data are hypothetical and do not represent actual decision maker’s views.
- Six options were developed—each option represented a single combination of service entry schedule (for the new fleet) and withdrawal schedule (for the old fleet).

Options	Withdrawal window (old fleet)	Acquisition window (new fleet)
1	2025 - 2047	2019 - 2030
2	2025 - 2045	2019 - 2030
3	2025 - 2045	2020 - 2030
4	2020 - 2030	2025- 2045
5	2030 - 2045	2025- 2035
6	2032 - 2042	2032- 2036

Quantitative SD Models

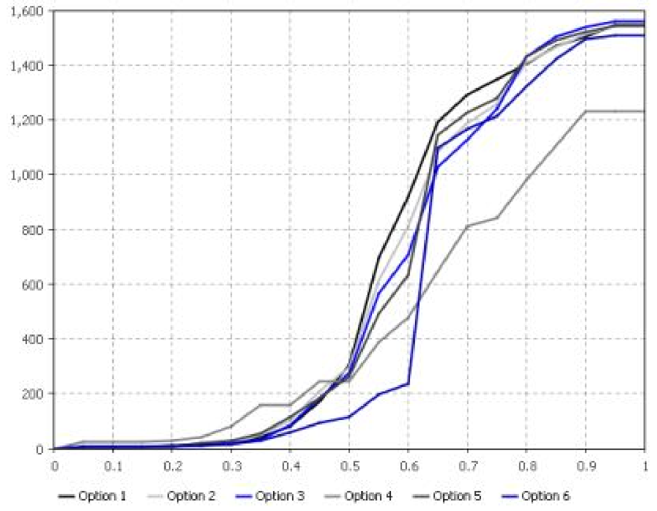
- Fig 3a shows a CFD of the fleet availability (calculated as the ratio between the total number of operational assets and the total number of assets in the old and new fleets). Points on the CFD shows the number of weeks where availability was less than a particular target level.



3.a. CFD of the fleet availability.

Quantitative SD Models

- Figure 3b shows the number of inter-region transactions for each option.



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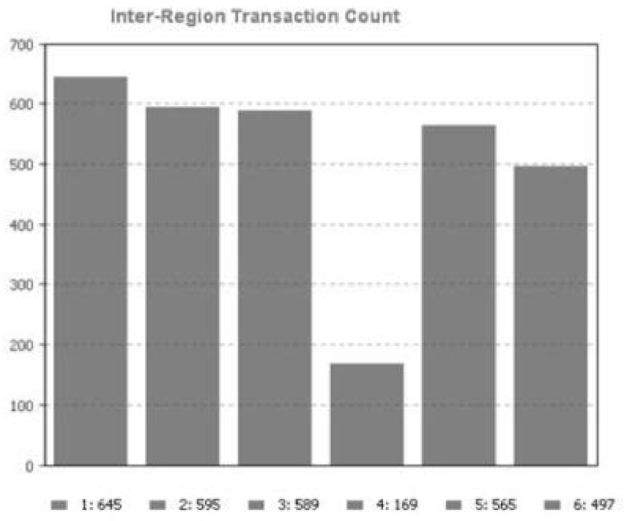
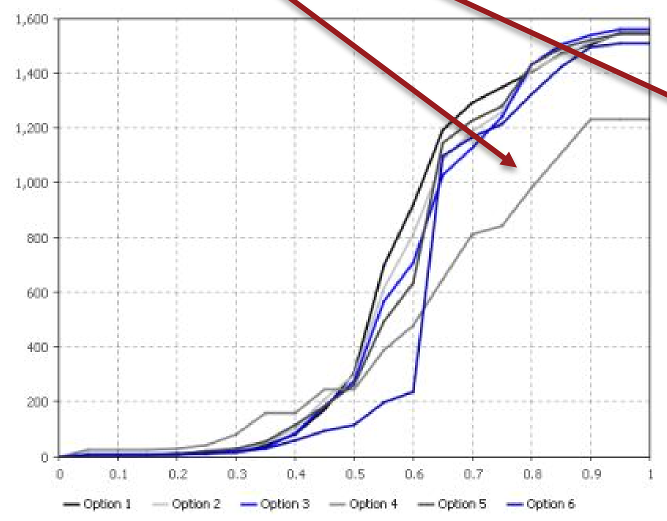


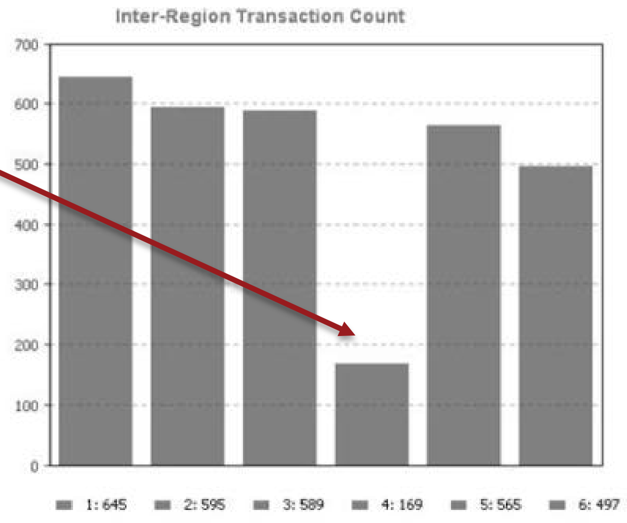
3.b Number of inter-region transactions for the six options.

Quantitative SD Models

- Option 4 achieves the best availability and lowest inter-region transactions.



3.a. CFD of the fleet availability.



3.b Number of inter-region transactions for the six options.

Quantitative SD Models

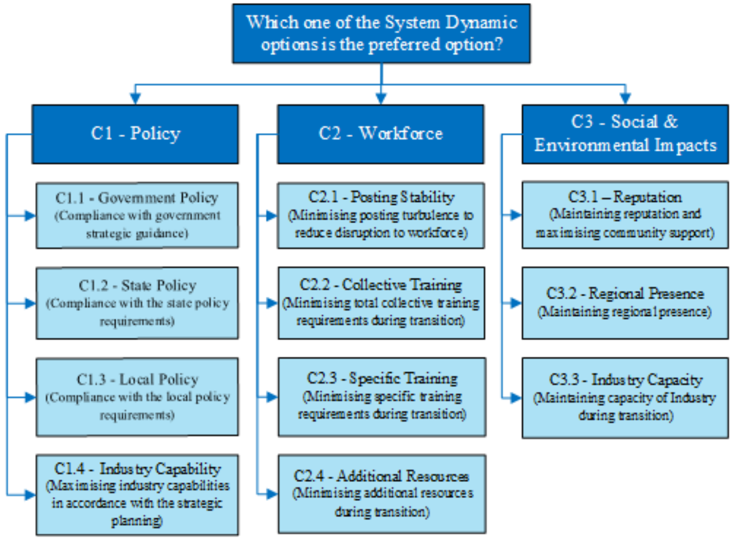
- Under Option 4, the old fleet is replaced earlier and faster, which causes less competition for maintenance resources, shorter waiting time in the maintenance lines, and therefore higher return-to-service rate.

MCDM Analysis

Step 1: Identification of the Criteria.

Step 2: Comparison of the Criteria.

Step 3: Comparison of the Options.



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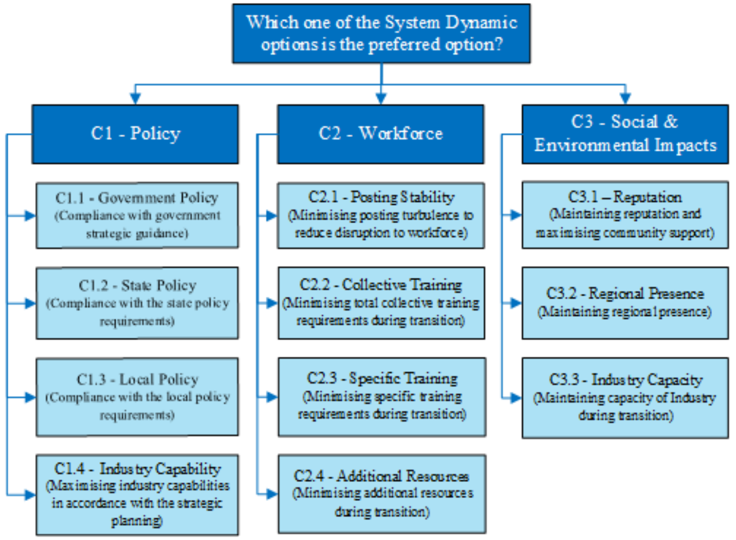
MCDM Analysis

- The ranks after applying MCDM are similar in order to those based on the purely quantitative aspects as derived from the SD model.
- Although Option 4 is the preferred SD option followed by Option 6, it is ranked second by the MCDM process.
- Combining techniques, therefore, illustrates that the qualitative preferences can change the preferences of decision makers.



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Findings (1/2)

- The use of simulation models has the power to evaluate and compare the performance of options over time, identifying (technically) unacceptable solutions and possible trade-offs.
- The use of MCDM has the strengths to bring in decision maker's judgments and preferences. It also can incorporate qualitative criteria, which is not easily included in the simulation model.

Findings (2/2)

- From a modelling viewpoint, the model's complexity is also reduced by focusing on those technical factors that influence the fleet's performance.
- The iteration between cycles of experimentation using SD and MCDM allows decision makers to refine their mental model about the problem and solution, and focus their attention on those factors that can influence their preferred options.

Future Research Directions

- Future research is still needed to help build detailed understanding of the practical and technical challenges and opportunities of combining SD and MCDM.
- The claims about the value of combining methods is not supported by empirical evidence.
- Evaluating the decision analysis approach not only in terms of the decision outcomes, but in terms of utility for decision makers. This should help understand when and how users find each method useful.

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