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Availability-Based Importance Framework For Supplier Selection

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AVAILABILITY-BASED IMPORTANCE FRAMEWORK FOR SUPPLIER SELECTION

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THE BASIC IDEA

- We want a means to incorporate an ability to meet **system availability needs** into the supplier selection process
  - Addressing "**how do we build in system availability in the supplier selection process?**"
- We do this by determining
  - How **important** a component is to system availability
  - How well a **supplier** performs in providing that important component

FUNDING SOURCE, PUBLISHED RESULTS

- Naval Postgraduate School Assistance Grant/Agreement No. N00244-14-1-0027 awarded by the NAVSUP Fleet Logistics Center San Diego
  - The views expressed here do not necessarily reflect the official policies of the Naval Postgraduate School

- Two published/accepted journal articles
  - Gravette, M.A. and K. Barker. 2014. Achieved Availability Importance Measures for Enhancing Reliability Centered Maintenance Decisions. *Journal of Risk and Reliability*, **229**(1): 62-72.
  - Hague, R.K., K. Barker, and J.E. Ramirez-Marquez. 2015. Interval-valued Availability Framework for Supplier Selection Based on Component Importance. Accepted in *International Journal of Production Research*.

Methodological background

Integrated framework for supplier selection

Concluding remarks

METHODOLOGICAL BACKGROUND

- We integrate several ideas to the selection of sole-source suppliers for component parts
  - Availability-based importance measures
  - Multi-criteria decision analysis
  - Interval arithmetic

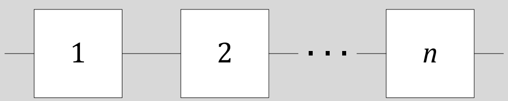
AVAILABILITY IMPORTANCE MEASURES

- **Availability** broadly combines **reliability** (mean time between failure, MTBF) and **maintainability** (mean time to repair, MTTR)

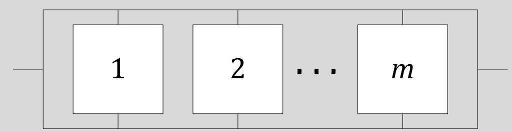
$$\text{Availability} = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

AVAILABILITY IMPORTANCE MEASURES

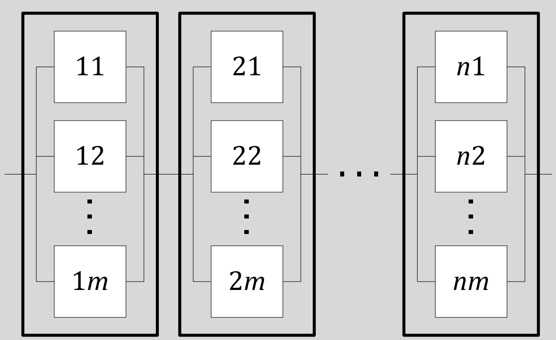
- For many traditional systems, **availability** can be calculated **analytically**



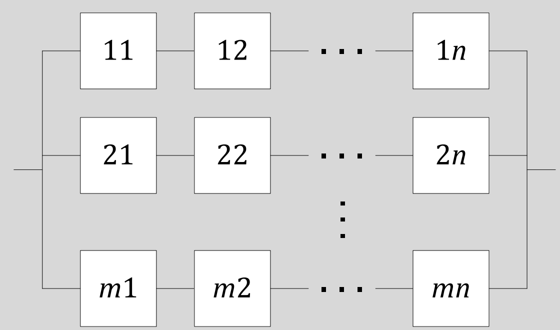
series



parallel



series-parallel



parallel-series

AVAILABILITY IMPORTANCE MEASURES

- **Importance measures** have often been used in reliability engineering to determine how **important** a component is to the overall **performance of the system**
  - e.g., Birnbaum importance for system reliability, $\mathrm{I}_i^B = \frac{\partial R_s}{\partial R_i}$

- Gravette and Barker [2014] considered **availability** as a system performance measure $I_i^A = \frac{\partial A_s}{\partial A_i}$

AVAILABILITY IMPORTANCE MEASURES

- For example, the availability of a **series-parallel** system

$$A^{\mathrm{SP}} = \prod_{i=1}^{n}\left[\coprod_{j=1}^{m} A_{\mathrm{a}_{ij}}\right] = \prod_{i=1}^{n}\left[1 - \prod_{j=1}^{m}\left(1 - \frac{\mathrm{MTBF}_{ij}}{\mathrm{MTBF}_{ij} + \mathrm{MTTR}_{ij}}\right)\right]$$

- Therefore, the importance of **parallel component** j in **subsystem** i would then be

$$\mathrm{I}_{ij}^{\mathrm{SP}} = \frac{\partial \mathrm{A}^{SP}}{\partial \mathrm{A}_{ij}}$$

$$= \prod_{k \neq i}^{n}\left[1 - \prod_{l=1}^{m}\left(1 - \frac{\mathrm{MTBF}_{kl}}{\mathrm{MTBF}_{kl} + \mathrm{MTTR}_{kl}}\right)\right] \times \prod_{l \neq j}^{m}\left(1 - \frac{\mathrm{MTBF}_{il}}{\mathrm{MTBF}_{il} + \mathrm{MTTR}_{il}}\right)$$

MULTI-CRITERIA DECISION ANALYSIS

- We want to choose a sole supplier based on how **effectively** it can supply **available components** in the system

- Therefore, we have **multiple criteria**: the **availability** of each component in the system
- And we can **weight** those components according to how **important** they are

- So we need a **multi-criteria decision analysis** technique to rank suppliers

MULTI-CRITERIA DECISION ANALYSIS

- We choose a technique called **TOPSIS**
  - Technique for Order Preferences by Similarity to an Ideal Solution
  - Common in supplier selection problems

- Based on the idea of a compromise solution
  - Closeness to the best solution, distance from the worst solution

MULTI-CRITERIA DECISION ANALYSIS

- What we do with TOPSIS: compare several **alternatives** across **multiple weighted criteria**

Availability provided by each supplier for each component

Sole suppliers	Criterion 1	Criterion 2	$\cdots$	Criterion C
Alternative 1	x_{11}	x_{12}	$\cdots$	x_{1C}
Alternative 2	x_{21}	x_{22}	$\cdots$	x_{2C}
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
Alternative B	x_{B1}	x_{B2}	$\cdots$	x_{BC}
Weights	w_1	w_2	$\cdots$	w_C

Weights determined by component importance

INTERVAL ARITHMETIC

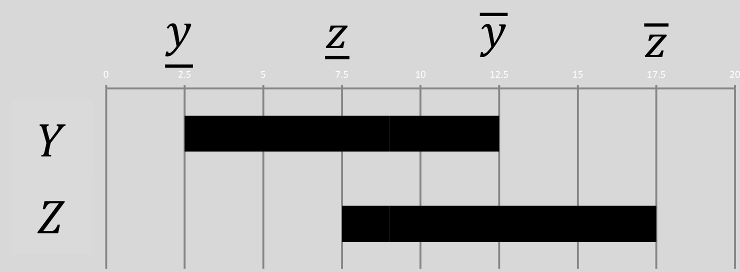
- There will likely be uncertainty associated with component availability provided by each supplier
  - Reliability is uncertain
  - Maintainability is uncertain

- And we may not have a probability distribution describing this uncertainty
  - "Forcing" a distribution when it is not known for sure could do more harm to the decision making process than good

INTERVAL ARITHMETIC

- We represent uncertainty with an **interval**
  - Assume we know a **lower bound** and an **upper bound** of metrics of interest (e.g., MTBF, MTTR)

- We can use a decision rule to compare Y and Z



$$Y \succ Z \Leftrightarrow \begin{cases} \underline{y} > \underline{z} & \text{Best case} \\ \overline{y} > \overline{z} & \text{Worst case} \\ \left(\underline{y} + \overline{y}\right) > \left(\underline{z} + \overline{z}\right) & \text{Laplace} \\ \theta\left(\underline{y} - \underline{z}\right) > (1-\theta)(\overline{y} - \overline{z}), \theta \in [0,1] & \text{Hurwicz} \\ \left(\overline{y} - \underline{z}\right) > \left(\overline{z} - \underline{y}\right) & \text{Min regret} \end{cases}$$

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FRAMEWORK FOR SUPPLIER SELECTION

- We integrate the existing methodologies into a **four-step framework**

Step 1. Calculate the interval-valued availability importance for each component
Based on historical performance or OEMs, importance is determined reflecting uncertainty using intervals

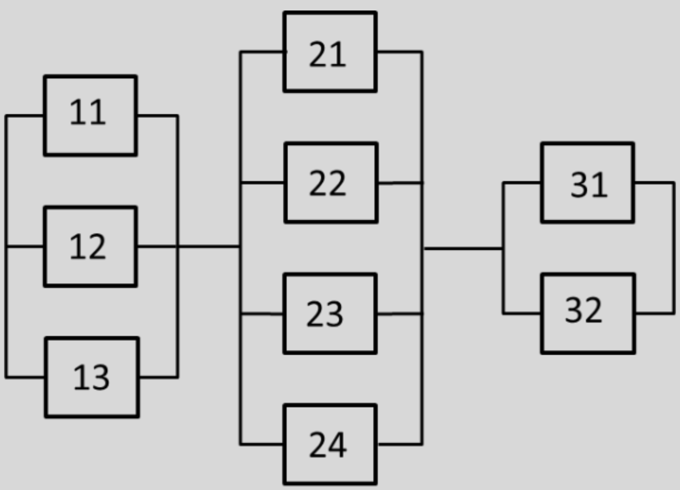
Step 2. Rank component according to availability importance
Interval arithmetic decision rules used to rank components according to their importance in contributing to availability of the system

Step 3. Calculate weights for components
Interval availability importance of each component is used to calculate a scalar importance weight, with all weights summing to 1

Step 4. Apply TOPSIS to select supplier
Suppliers compared with multi-criteria decision analysis technique, where interval availability for component i acts as the ith decision criterion, weighted by the importance of that component in the availability of the system

ILLUSTRATIVE EXAMPLE

- We applied the approach to a **series-parallel system**, inspired by an aircraft servo-actuation system



Component	$\underline{MTBF}$	$\overline{MTBF}$	$\underline{\mathrm{MTTR}}$	$\overline{MTTR}$
C_{11}	25	35	1	5
C_{12}	365	395	2	7
C_{13}	150	165	1	8
C_{21}	150	200	2	5
C_{22}	75	110	1	6
C_{23}	185	200	3	5
C_{24}	120	125	1	3
C_{31}	365	465	1	1.5
C_{32}	365	485	1	2

ILLUSTRATIVE EXAMPLE

- Based on the intervals for MTBF and MTTR, we **rank the importance** of the nine components
  - Risk neutral **Laplace rule**

Component	Laplace criterion $\left(\underline{\mathrm{I}_{ij}^{SP}} + \overline{\mathrm{I}_{ij}^{SP}}\right)$	Rank
C_{11}	0.0123	5
C_{12}	0.0501	3
C_{13}	0.0347	4
C_{21}	0.0022	8
C_{22}	0.0016	9
C_{23}	0.0059	6
C_{24}	0.0093	7
C_{31}	0.2532	1
C_{32}	0.2203	2

ILLUSTRATIVE EXAMPLE

- We have **interval-valued availability** capabilities for each component from each of **four suppliers**

Component	Supplier S_1 $\underline{A_{S_1,c}}$	Supplier S_1 $\overline{A_{S_1c}}$	Supplier S_2 $\underline{A_{S_2c}}$	Supplier S_2 $\overline{A_{S_2c}}$	Supplier S_3 $\underline{A_{S_3,c}}$	Supplier S_3 $\overline{A_{S_3,c}}$	Supplier S_4 $\underline{A_{S_4,c}}$	Supplier S_4 $\overline{A_{S_4,c}}$
C_{11}	0.85	0.99	0.82	0.98	0.81	0.99	0.86	0.97
C_{12}	0.90	0.99	0.85	0.99	0.89	0.97	0.91	0.99
C_{13}	0.85	0.94	0.91	0.99	0.86	0.92	0.88	0.97
C_{21}	0.84	0.94	0.87	0.96	0.88	0.99	0.91	0.99
C_{22}	0.84	0.94	0.87	0.96	0.88	0.99	0.91	0.99
C_{23}	0.91	0.98	0.90	0.97	0.92	0.97	0.87	0.99
C_{24}	0.91	0.98	0.90	0.97	0.92	0.98	0.87	0.99
C_{31}	0.81	0.95	0.86	0.97	0.92	0.95	0.89	0.93
C_{32}	0.88	0.95	0.93	0.98	0.88	0.96	0.90	0.97

ILLUSTRATIVE EXAMPLE

- Finally, we integrate the following into a **ranking of suppliers**
  - **Interval-valued** supplier **availability** capabilities
  - **Weights** associated with **component importance**
  - **Laplace rule** for comparing interval values

Supplier	Laplace criterion $\left(\underline{D_b^\star} + \overline{D_b^\star}\right)$	Rank
S_1	0.631	4
S_2	1.596	3
S_3	1.857	1
S_4	1.607	2

ILLUSTRATIVE EXAMPLE

- For this particular illustration, the ranking of suppliers differs slightly when considering a **point estimate** for availability
  - Relative to **interval values** and the **Laplace rule**

Supplier	Interval uncertainty		Point estimate	
	$\left(\underline{D_b^\star} + \overline{D_b^\star}\right)$	Rank	$D_b^\star$	Rank
S_1	0.631	4	0.5741	3
S_2	1.596	3	0.2129	4
S_3	1.857	1	0.6391	1
S_4	1.607	2	0.5952	2

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CONCLUDING REMARKS

- This work provided two important perspectives
- **First**, determining **component importance** based on **system availability**
- **Second**, using availability-based importance to **rank sole suppliers** of components
- Ultimately addressing "**how do we build in system availability through appropriate supplier selection?**"

CONCLUDING REMARKS

- We'd like to extend our formulation for more **complex systems**
  - i.e., those systems that don't fall into the **traditional four system designs** for which analytical solutions exist
  - Could then describe selection of suppliers of, say, **infrastructure network services**

- This work resulted in two published/accepted papers

END OF PRESENTATION

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