SoSECIE Webinar

Welcome to the
2021 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

We will start at 11AM Eastern Time

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https://mitre.tahoe.appsembler.com/blog

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NDIA System of Systems SE Committee

- **Mission**
  - To provide a forum where government, industry, and academia can share lessons learned, promote best practices, address issues, and advocate systems engineering for Systems of Systems (SoS)
  - To identify successful strategies for applying systems engineering principles to systems engineering of SoS
- **Operating Practices**
  - Face to face and virtual SoS Committee meetings are held in conjunction with NDIA SE Division meetings that occur in February, April, June, and August

NDIA SE Division SoS Committee Industry Chairs:
Mr. Rick Poel, Boeing
Ms. Jennie Horne, Raytheon
OSD Liaison:
Dr. Judith Dahmann, MITRE

Simple Rules of Engagement

- I have muted all participant lines for this introduction and the briefing.
- If you need to contact me during the briefing, send me an e-mail at sosecie@mitre.org.
- Download the presentation so you can follow along on your own
- We will hold all questions until the end:
  - I will start with questions submitted online via the CHAT window in Teams.
  - I will then take questions via telephone; State your name, organization, and question clearly.
- If a question requires more discussion, the speaker(s) contact info is in the brief.

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2021-2022 System of Systems Engineering Collaborators Information Exchange Webinars

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September 21, 2021
Towards the Definition of a Strategic Complexity Management Framework for Complex Industrial Systems
Lucas Freund

October 19, 2021
Resilience in Systems of Systems: Electrified Transport Systems
Pontus Svenson, Kerstin Eriksson, and Sara Janhäll

November 2, 2021
Conceptual Models to Support Reasoning in Early Phase Concept Evaluation – a Subsea Case Study
Siv Engen

November 16, 2021
A Design Method for Collaborative Systems of Systems Applied to Metropolitan Multi-Mode Transport System
Pontus Svenson, Frida Reichenberg, and Jakob Axelsson

November 30, 2021
Should I Stay or Should I Go? How Constituent Systems Decide to Join or Leave Constellations in Collaborative SoS
Pontus Svenson and Jakob Axelsson

https://www.mitre.org/capabilities/systems-engineering/collaborations/system-of-systems-engineering-collaborators

2021-2022 System of Systems Engineering Collaborators Information Exchange Webinars

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December 14, 2021
A Heterogeneous Autonomous Collaborative System for Powerline Inspection Using Human-Robotic Teaming
Srikanth Vemula, Jovany Avila, and Michael Frye

January 11, 2022
Approach for Complex Deterministic and Nondeterministic Systems (ACDANS)
Dr. Paul C. Hershey

January 25, 2022
Applying SoSE in Healthcare: the case for a soft systems methodology approach to Digital-first Primary Care
Iqra Shahzad, Melanie King, and Michael Henshaw

May 3, 2022
Cross-Domain Stakeholder-Alignment in Collaborative SoS – Lego Serious Play as a Boundary Object
Johann Shuetz, Julia Koehlke, and Sebastian Hanna

https://www.mitre.org/capabilities/systems-engineering/collaborations/system-of-systems-engineering-collaborators

SYSTEM OF SYSTEMS META-ARCHITECTURE APPROACH TO IMPROVE LEGACY METRORAILS FOR ENHANCED CUSTOMER EXPERIENCE

Paper Authored by: Maxwell Polley and Dr. Cihan Dagli

Presented by: Dr. Cihan Dagli

Agenda

- Introduction
- Methodology
- Results
- Conclusion

https://cities-today.com/contactless-payments-introduced-on-miamis-metrorail/

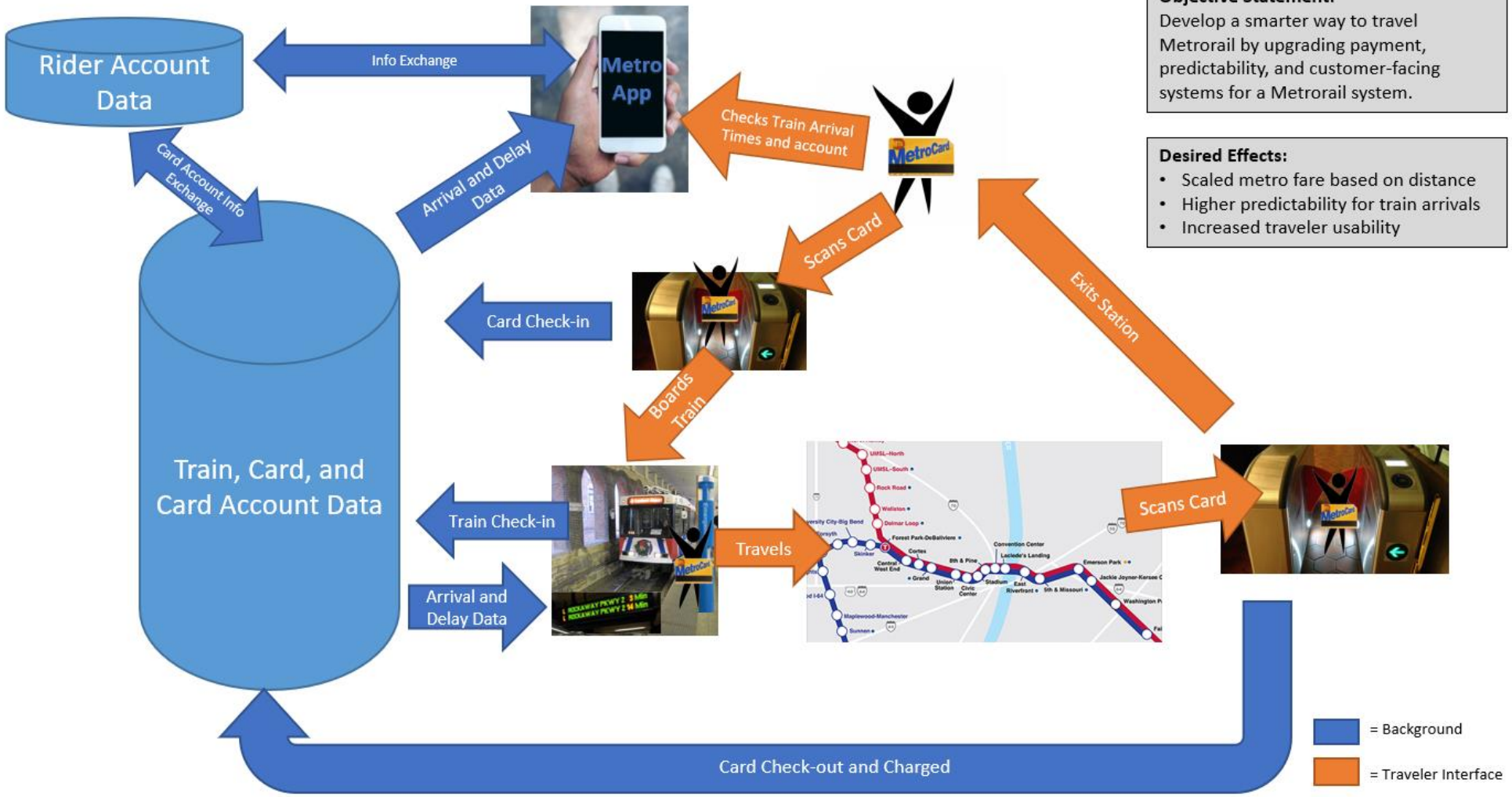
Introduction

Overview

- Issues
  - Out-of-date Metrorail systems
  - Not user friendly
- Goal
  - Improve an established Metrorail system to enhance traveler experience
  - Maintain SoS capability of transporting travelers via rail
- Process
  - Generated a 10-station fuzzy meta-architecture to determine best possible SoS configurations
  - Software used: MATLAB, FILA SoS Explorer

https://medium.com/@kganttwrites/miami-dade-again-breaks-promise-for-expanded-metrorail-e47e1e08cdf4

Operational View



Objective Statement:
Develop a smarter way to travel Metrorail by upgrading payment, predictability, and customer-facing systems for a Metrorail system.

Desired Effects:
- Scaled metro fare based on distance
- Higher predictability for train arrivals
- Increased traveler usability

Capabilities in the SoS

- SoS is comprised of multiple systems providing their own capabilities
- For this SoS analysis, 10 individual stations were assessed with 64 total capabilities
  - Per Station (60 capabilities)
    - Incoming Train Check for Station X
    - Outgoing Train Check for Station X
    - Present Train Times for Station X
    - Card Check-in for Station X
    - Card Check-out for Station X
    - Card Reload for Station X
  - Station Agnostic (4 capabilities)
    - Calculate Scaled Fare
    - Store Account Information
    - Card Tracking
    - Store Train/Card Information

https://archive.curbed.com/2019/9/20/20872680/subway-station-metro-best-beautiful-architecture-united-states

Competing Systems

- 84 total systems with directed interfaces
  - Per Station (80 total)
    - Enter Gate for station X (10 total)
    - Exit Gate for station X (10 total)
    - One-way Train Status Monitor for station X (20 total)
    - Bi-directional Train Status Monitor for station X (10 total)
    - Station Train Tracker Board for station X (10 total)
    - Card Refill Machine for station X (10 total)
    - Data Hub for station X (10 total)
  - Station Agnostic (4 total)
    - Metrocard
    - Train/Card Database
    - Account Database
    - Phone App

Key Performance Attributes (KPAs)

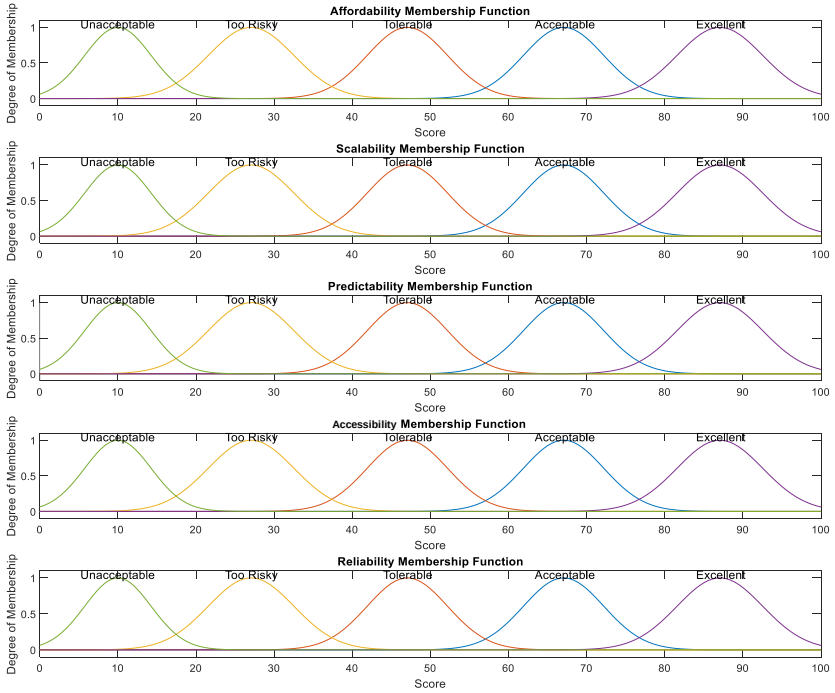
- The five key performance attributes:
  - **Affordability** – Measures how reasonably priced the SoS is to install and maintain
    - Each system in the SoS requires an install price, install time, and maintenance price (per year), and this constrains the system to find the lowest price.
    - Requires interfaces between the MetroCard and the gates to ensure travelers a charged a scaled fare.
  - **Accessibility** – Measures how usable the SoS is to travelers
    - Each system in the SoS has a usability ranking and the more systems that contribute to usability there are, the higher the accessibility fitness value.
  - **Scalability** – Measures how well the generated meta-architecture can be scaled up to incorporate more train stations
  - **Predictability** – Measures how well the SoS can predict when trains are inbound and outbound per station
    - By having a high predictability score, a traveler will likely have a better experience due to them knowing when their train is coming
  - **Reliability** – Measures the robustness of the overall SoS
    - Greater reliability could mean fewer breakdowns and a safer commute for customers.

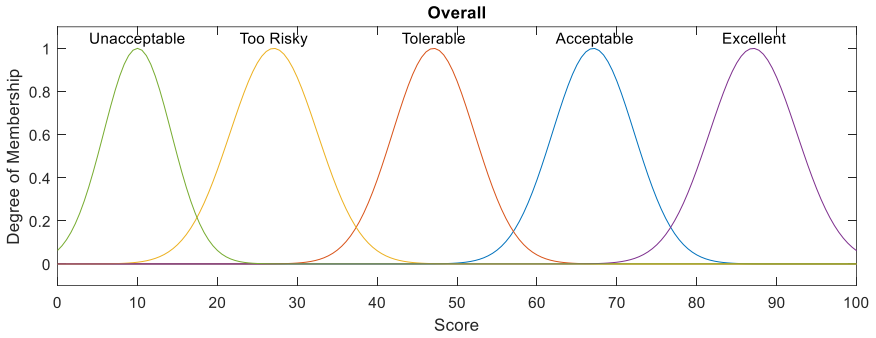
Methodology

Developing a Fuzzy Inference System

1. Established fuzzy terms with associated ranges on a scale (0 -100)
2. Associated the fuzzy scale with each KPA to create membership functions
   - All KPA were graded on the same scale
3. Combined membership functions into an overall membership function
   - Used to assess the SoS as a whole

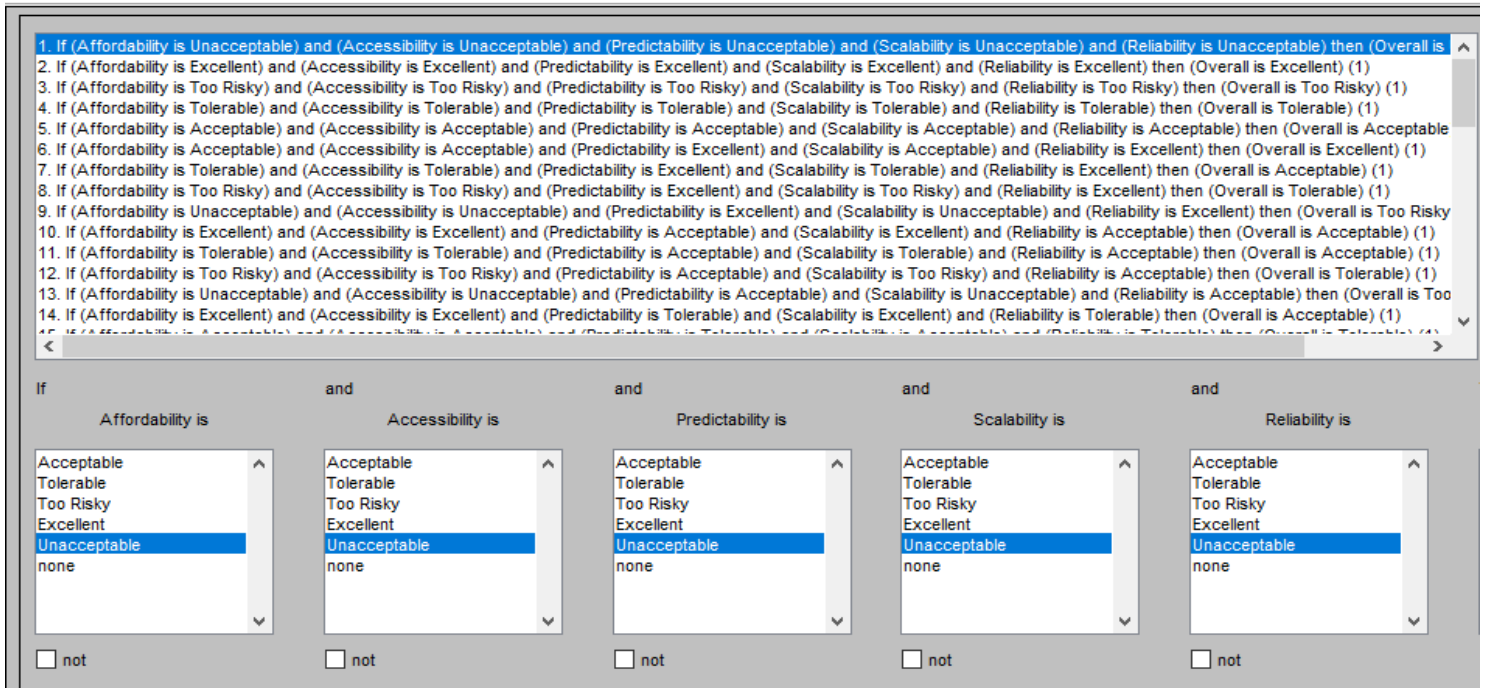
Fuzzy Term	Term Coverage
Excellent	[70, 100]
Acceptable	[50, 85]
Tolerable	[30, 65]
Too Risky	[10, 45]
Unacceptable	[0, 25]





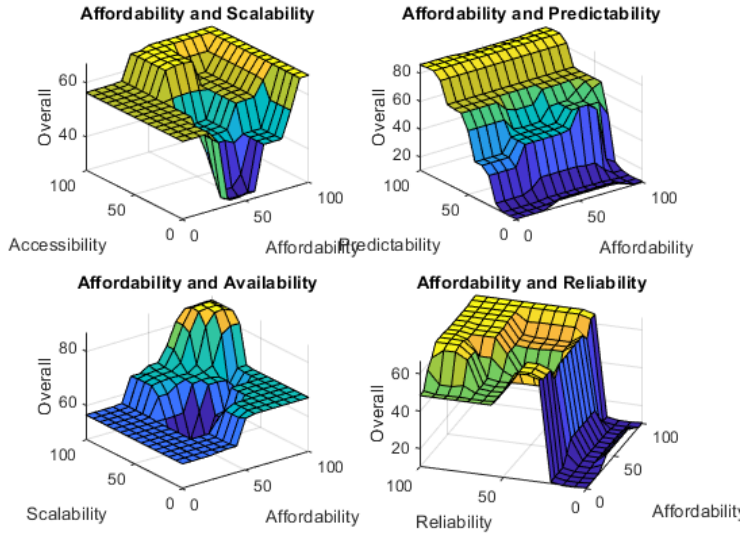
Establishing Membership Function Rules

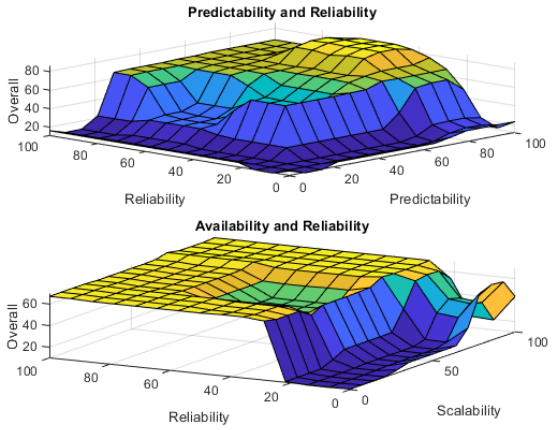
- Developed rules based on KPA to assess SoS meta-architecture viability
  - Emphasis placed on predictability and reliability KPAs
  - 53 total rules

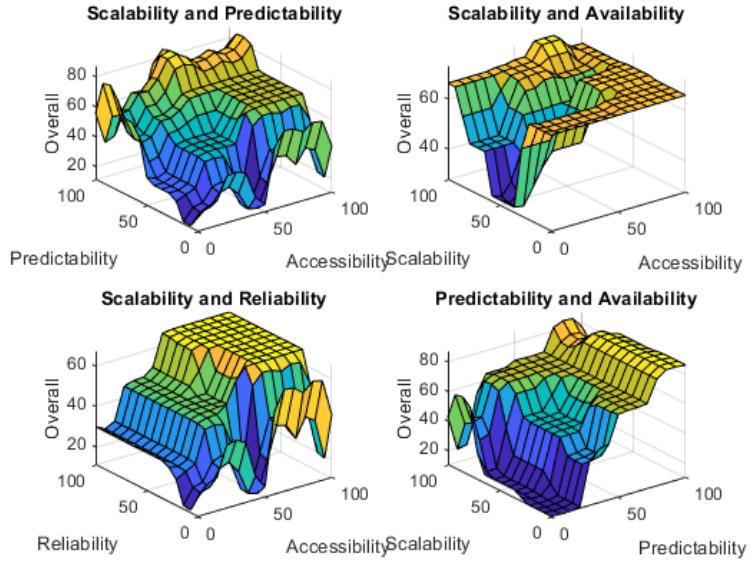


Membership Function Surfaces

- Generated membership function surfaces to assess rule variation between two KPAs
  - Sharp drops and plateaus indicate where more rules could be added to help smooth surfaces







Forming a Chromosome

- Developed a directed chromosome to later feed a genetic algorithm
  - "1" indicates a directed interface
  - "0" indicates no interface
- Figure shows a 20x20 chromosome excerpt from the larger 84x84 chromosome
- Also established feasible interfaces at this time

	Out Gate 1	Out Gate 2	Out Gate 3	Out Gate 4	Out Gate 5	Out Gate 6	Out Gate 7	Out Gate 8	Out Gate 9	Out Gate 10	In Gate 1	In Gate 2	In Gate 3	In Gate 4	In Gate 5	In Gate 6	In Gate 7	In Gate 8	In Gate 9	In Gate 10
Out Gate 1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0
Out Gate 2	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	0
Out Gate 3	0	0	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	1
Out Gate 4	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0
Out Gate 5	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
Out Gate 6	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	1	1	1	0
Out Gate 7	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	0	0	1	0	0
Out Gate 8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Out Gate 9	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	1	1
Out Gate 10	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	0	0
In Gate 1	0	0	1	1	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0
In Gate 2	0	1	0	1	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0
In Gate 3	0	0	0	1	0	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0
In Gate 4	1	1	1	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0
In Gate 5	0	0	1	1	1	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0
In Gate 6	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0
In Gate 7	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
In Gate 8	1	1	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0
In Gate 9	0	1	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	1	0
In Gate 10	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1

Assessing the KPAs (1 of 2)

- Affordability

$$Affordability(\boldsymbol{X}, \boldsymbol{C}) = -\sum_{i=1}^{n} S(\boldsymbol{X}, i)\left(\left(\boldsymbol{C}_{Cost,Maintain,i} + \boldsymbol{C}_{Cost,Install,i}\left(\boldsymbol{C}_{Cost,installTime,i}\right)\right) + \sum_{j=1}^{n} S(\boldsymbol{X}, j)\left(\boldsymbol{C}_{Cost,Maintain,j} + \boldsymbol{C}_{Cost,Install,j}\left(\boldsymbol{C}_{Cost,installTime,j}\right)\right)\right)$$

- Accessibility

$$Accessibility(\boldsymbol{X}, \boldsymbol{C}) = \sum_{i=1}^{n} S(\boldsymbol{X}, i)\boldsymbol{C}_{Usability,i} \prod_{j=1}^{n}(1 + \delta S(\boldsymbol{X}, j) I(\boldsymbol{X}, i, j))$$

Assessing the KPAs (2 of 2)

- Scalability

$$Scalability(\boldsymbol{X}, \boldsymbol{C}) = \frac{\sum_{i=1}^{n} S(\boldsymbol{X}, i)\boldsymbol{C}_{scalability,i}}{\sum_{i=1}^{n} S(\boldsymbol{X}, i)}$$

- Predictability

$$Predictability(\boldsymbol{X}, \boldsymbol{C}) = \frac{\sum_{j=1}^{n}\left(S(\boldsymbol{X}, i, j) + \boldsymbol{C}_{Accuracy,i}\right)}{\sum_{i=1}^{n}\left(S(\boldsymbol{X}, i) + \boldsymbol{C}_{Accuracy,i}\right)}$$

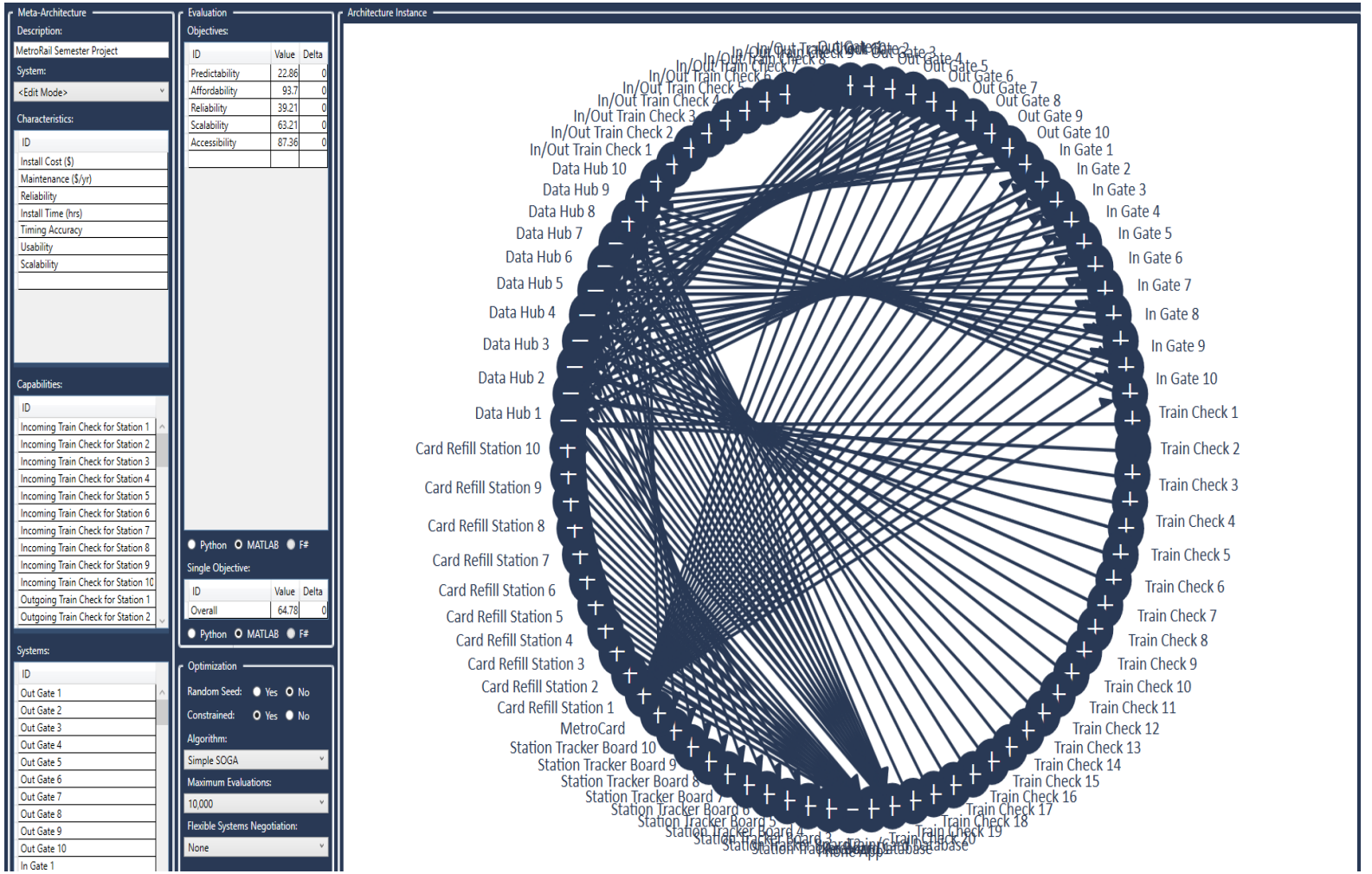
- Reliability

$$Reliability(\boldsymbol{X}, \boldsymbol{C}) = \sum_{i=1}^{n} S(\boldsymbol{X}, i)\boldsymbol{C}_{Reliabilty,i} \prod_{j=1}^{n}(1 + S(\boldsymbol{X}, j)I(\boldsymbol{X}, i, j))$$

Unoptimized SoS

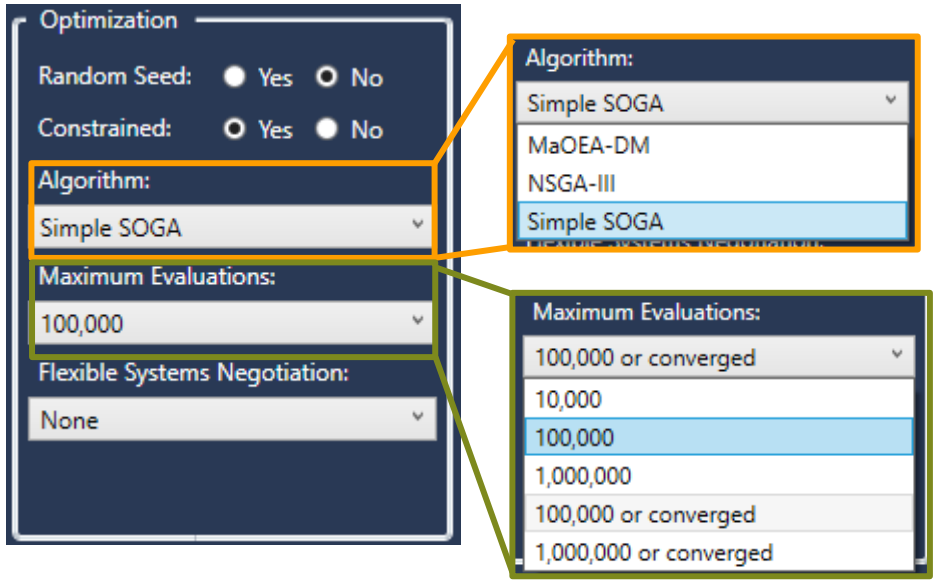
- Software: FILA SoS Explorer
- Generated a Tolerable/Acceptable meta-architecture according to the overall membership function

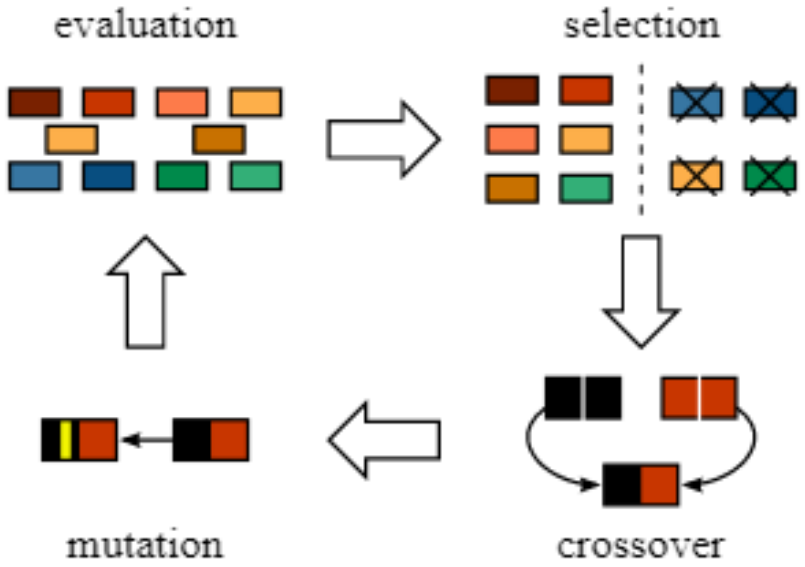
KPA	Unoptimized Score
Predictability	22.86
Affordability	93.70
Reliability	39.21
Scalability	63.21
Accessibility	87.36
OVERALL	**64.78**

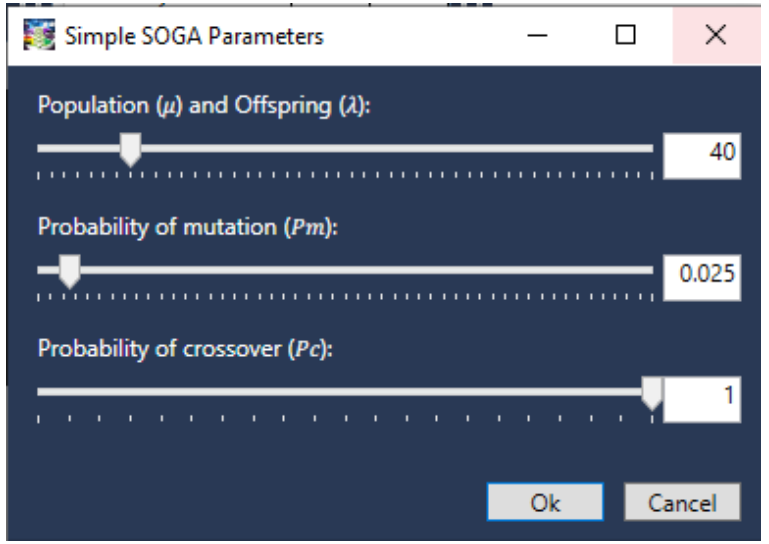


Genetic Algorithm

- SoS Explorer Built-in Genetic Algorithms
  - Self-Organizing Genetic Algorithm (SOGA)
    - Outputs an optimized overall fitness value
    - References previously established feasible interfaces
- Ran at two maximum evaluation values
  - 10,000 and 100,000







Results

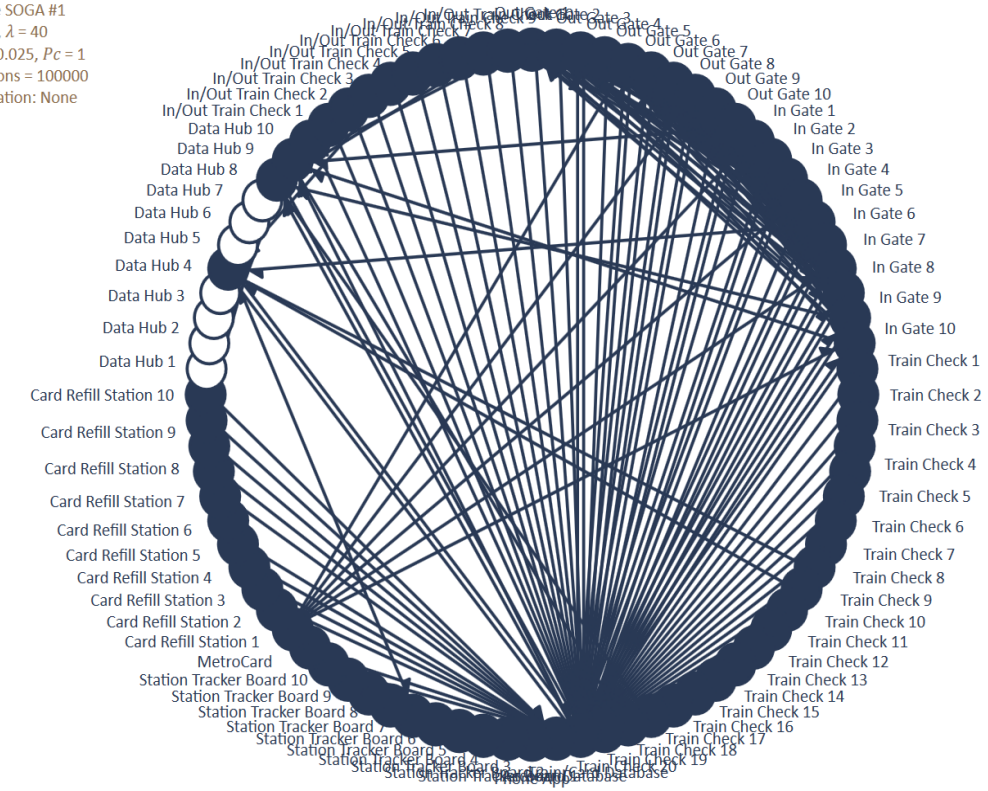
Optimized Results

10,000 Evaluations

Simple SOGA #1
$\mu = 40, \lambda = 40$
$Pm = 0.025, Pc = 1$
Iterations = 10000
Negotation: None

100,000 Evaluations

Simple SOGA #1
$\mu = 40, \lambda = 40$
$Pm = 0.025, Pc = 1$
Iterations = 100000
Negotation: None



KPA	Unoptimized Score	Optimized Score (10,000 Evaluations)	Optimized Score (100,000 Evaluations)
Predictability	22.86	38.74	47.75
Affordability	93.70	90.78	86.57
Reliability	39.21	56.11	47.83
Scalability	63.21	63.38	66.23
Accessibility	87.36	92.56	90.8
Overall	**64.78**	**67.06**	**71.28**

Conclusions

Conclusions

- Methodology
  - Generated a rule-based Fuzzy Inference System
  - Created an initial chromosome
  - Established KPA equations to assess meta-architecture for crisp fitness values
  - Ran a SOGA to determine optimized meta-architecture outputs
- Results
  - Metrorail configurations were algorithmically improved to find the best overall meta-architecture fitness value
    - Results increased based on number of evaluations
- Impact
  - Useful decision-making to help identify Metrorail configurations
    - Possible to update project configuration to account for already established metrorail infrastructure
  - Find SoS configuations that may not necessarily be intuitive

https://medium.com/@kganttwrites/miami-dade-again-breaks-promise-for-expanded-metrorail-e47e1e08cdf4

Questions?