SoSECIE Webinar

Welcome to the
2020 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

We will start at 11AM Eastern Time

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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

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Mr. Rick Poel, Boeing

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- 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 Skype.
  - 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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2020-2021 System of Systems Engineering Collaborators Information Exchange Webinars

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September 22, 2020
SoS Meta-Architecture Selection for Infrastructure Inspection System Using Aerial Drones
Dr. Cihan Dagli and Muhammad Monjurul Karim

October 6, 2020
A System-of-Systems Approach to Optimize a Real-time Risk Situational Awareness System
Dr. Flavio Oquendo

October 20, 2020
Situation Awareness and Decision Making for Constituent Systems
Dr. Pontus Svenson and Dr. Jakob Axelsson

November 3, 2020
Challenges for System of Systems in the Agriculture Application Domain
Dr. Benjamin Weinert and Dr. Mathias Uslar

December 1, 2020
Achieving System Integration through Interoperability in a large System of Systems (SoS)
Mr. Oliver Hoehne

A System of Systems Approach to Optimize a Real-time Risk Situational Awareness System

Dr. Cihan Dagli, Yu Li
Department of Engineering Management and Systems Engineering
Missouri University of Science and Technology

Outline

> Introduction
> Proposed Model
> Results
> Conclusions

> Introduction
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Developing Meta Systems Architectures

Cyber Physical Systems for Next Decades

There will be *multi-faceted systems* in different levels of implementation that entail complex logic with many levels of reasoning in intricate arrangement, organized by web of connections and demonstrating self-driven adaptability which are designed for autonomy and exhibiting emergent behavior that can be visualized.

They will impact manufacturing industry, defense, healthcare, energy, transportation, emergency response, agriculture and society overall.

Developing Meta Systems Architectures for

Cyber Physical Systems for Next Decade

The success will depend on how the current challenges related to;

Cybersecurity,

Interoperability,

Privacy,

Human System Integration

are handled.

Industry 4.0. Society 5.0 are the term used

Developing Meta Systems Architectures

Developing Meta Systems Architectures

Can we determine these architecture based on context, dynamic stability and pluralism using a structured interactive approach?

Human System Integration, Cybersecurity, Interoperability, Privacy, Safety,

Industry 4.0/ Society 5.0

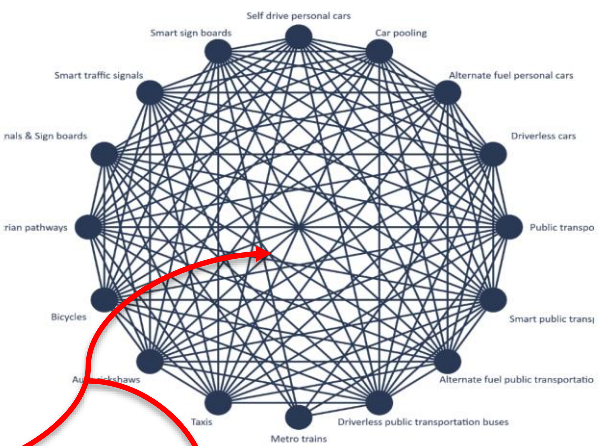


Fig. 6. Type 2 SM platform with 3D printing.

From Mind to Products: Towards Social Manufacturing and Service Gang Xiong, et.al.
IEEE/CAA JOURNAL OF AUTOMATICA SINICA, VOL. 5, NO. 1, JANUARY 2018

Developing Meta Systems Architectures

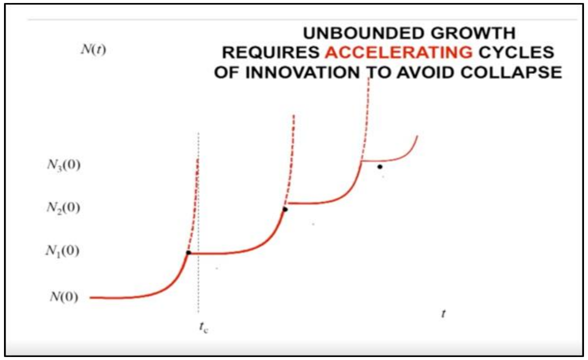
Developing Meta Systems Architectures

- Structuring the modeling effort (context)

- Optimization methods yielding targeted solution sets (pluralism)

- Visualization of architectures (context)

- Interactive architectures allowing
- “what-if” experimentation
- (dynamic stability)



Developing Meta Systems Architectures

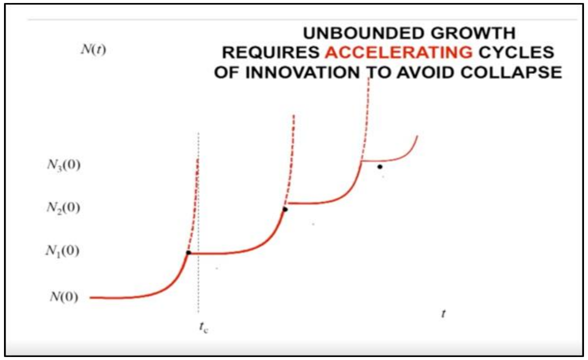
SoS Explorer is Missouri S&T's solution
http://emse.mst.edu/sos-explorer/

A novel optimization method called "MOEA-DM" tailored to the needs of cyber physical systems

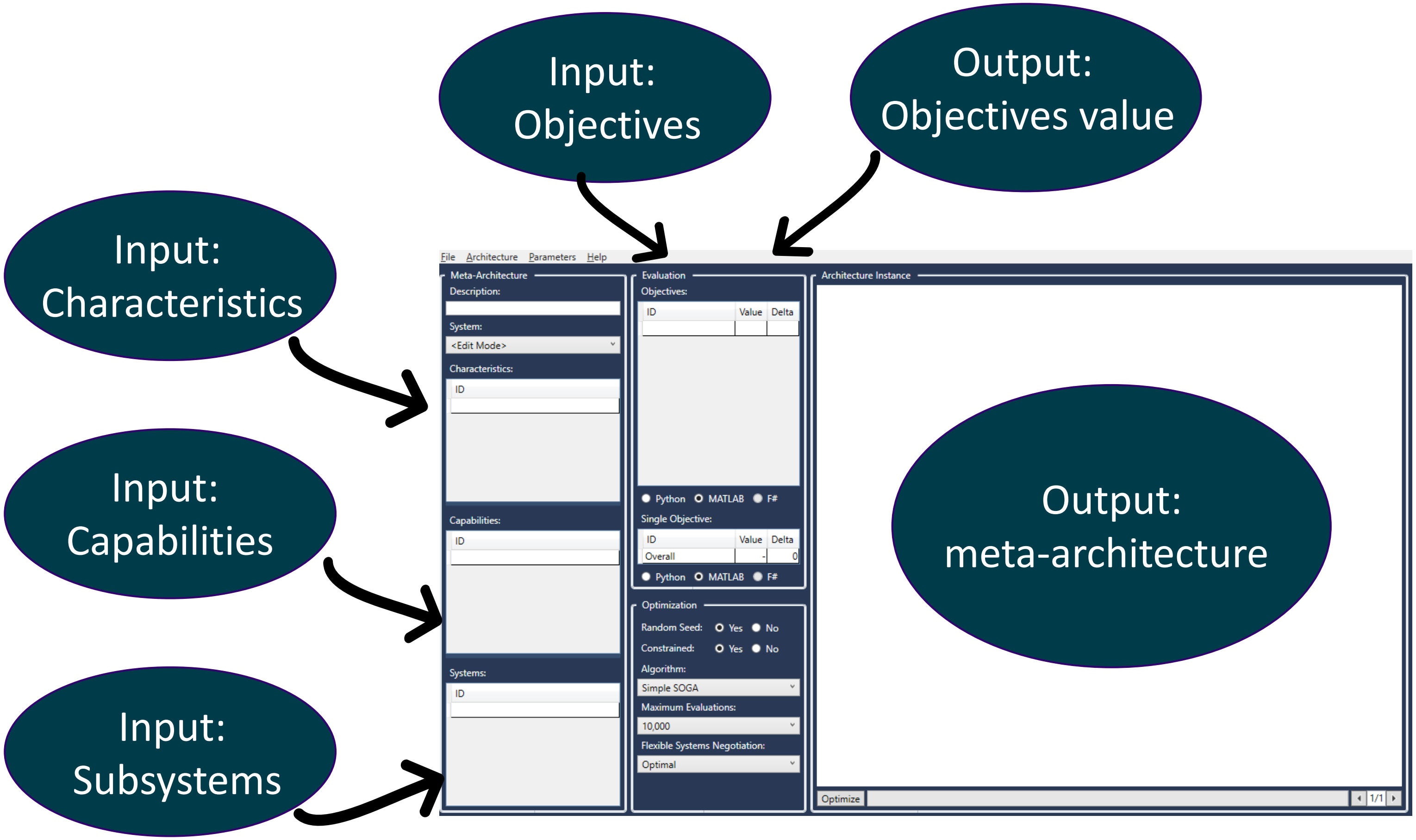
Many-objective optimization

Use of clustering to cultivate a limited set of solutions of interest

Visualization of architectures
Interactive "what-if" experimentation



SoS Explorer Architecting Tool



Violent Events & Lifelong Implications [1-5]

> Traffic crashes are violent events that can have lifelong implications

Direct involved

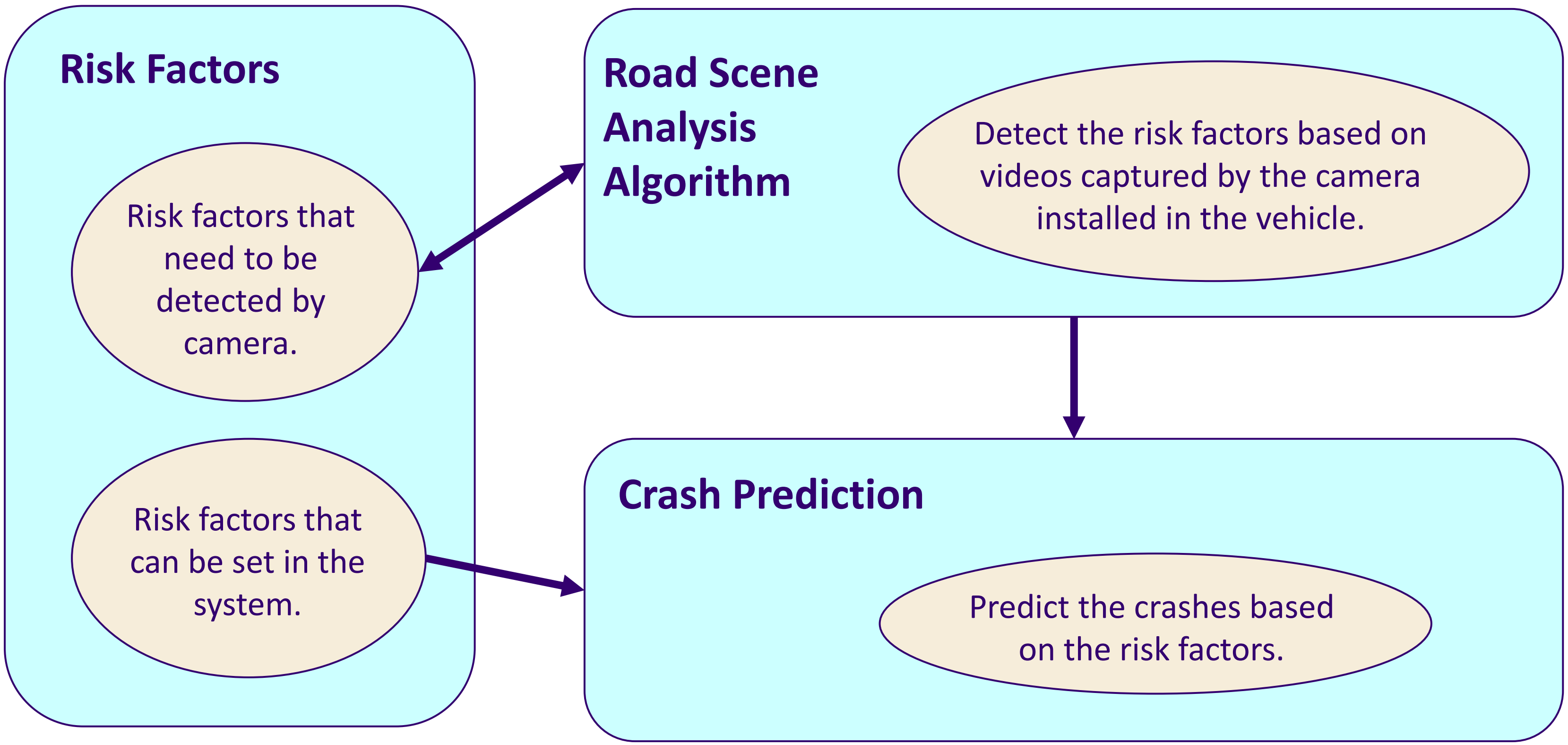
Indirect involved

37,000 fatalities

$800 million

Law enforcement officers, first responders, medical professionals, family members and friends

Data-driven, Vision-based, Real-time Risk Situational Awareness System



Overview of the System

OV-1

Algorithms for Recognize the Factors Recorded by Camera

Risk factor: Month
Risk factor: Weekday
Risk factor: Time(Hour)
Risk factor: Light visibility
Risk factor: Weather
Risk factor: Road Functional System
Risk factor: Large Truck Related or not
Risk factor: Type of Junction
Risk factor: Type of Intersection
Risk factor: Pedestrian Involved or not

Faster R-CNN(Region-based Convolutional neural networks)
Mask R-CNN(Region-based Convolutional neural networks)
FCIS (Fully Convolutional Instance-aware Semantic Segmentation)
MNC (Multi-task Network Cascades)

Collect Risk Factors for the System

Prediction Based on the Real Time Risk Factor

Neural Network
Regression
Decision Trees

Excel
OOXML

Produce the monthly Report

Visualization of the Warning

Tableau
Qlikview
Highcharts

Application A
Application B
Application C

Integrate All the Systems Capabilities.

Need statement: Develop a system to predict and warn a crash if a crash will happen in the next few seconds, so that the driver can proactively avoid it.

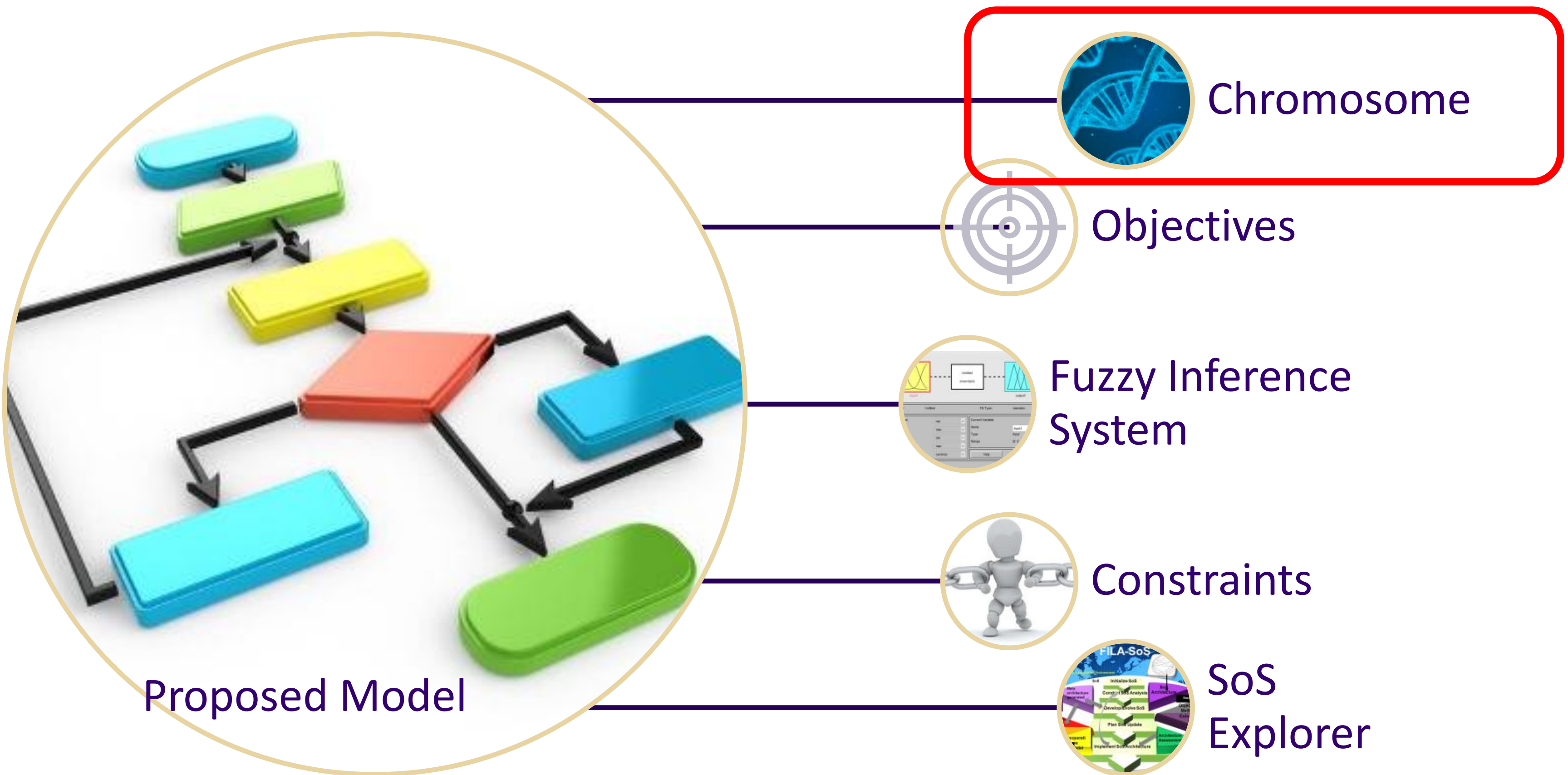
> Introduction

> **Proposed Model**

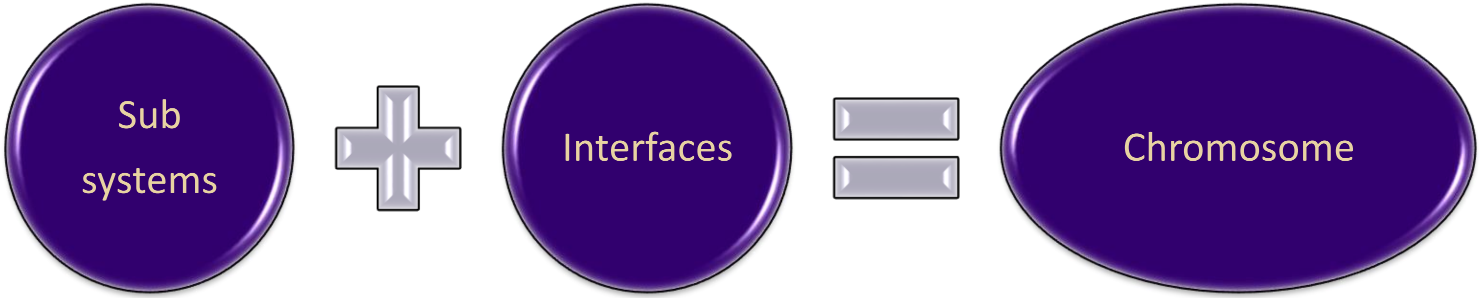
> Results

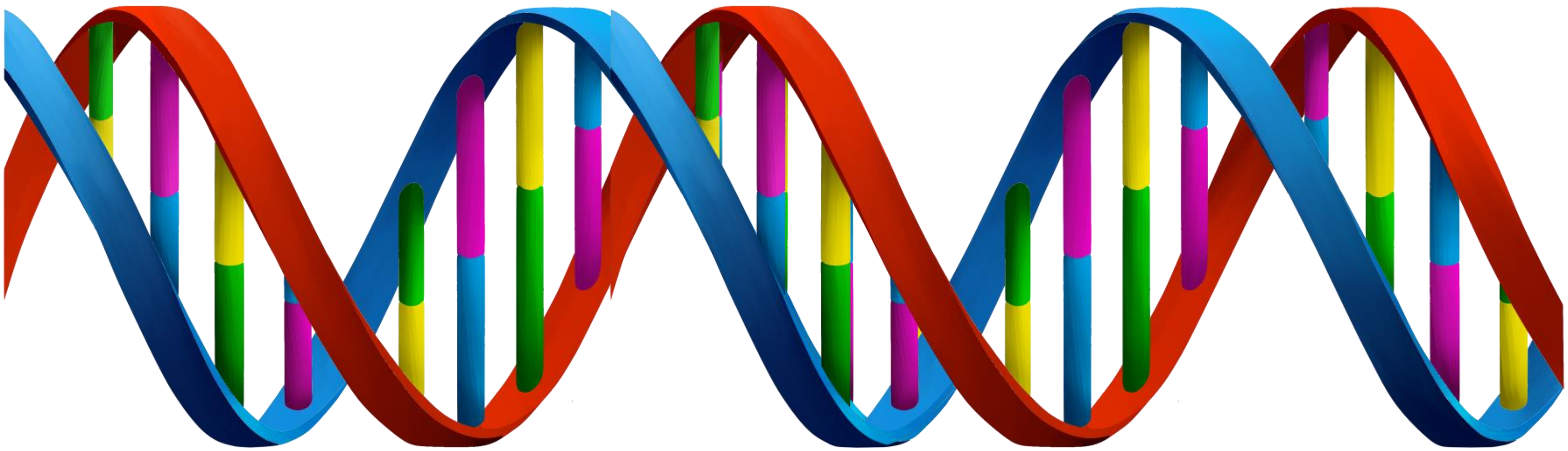
> Conclusions

Proposed Model



Chromosome





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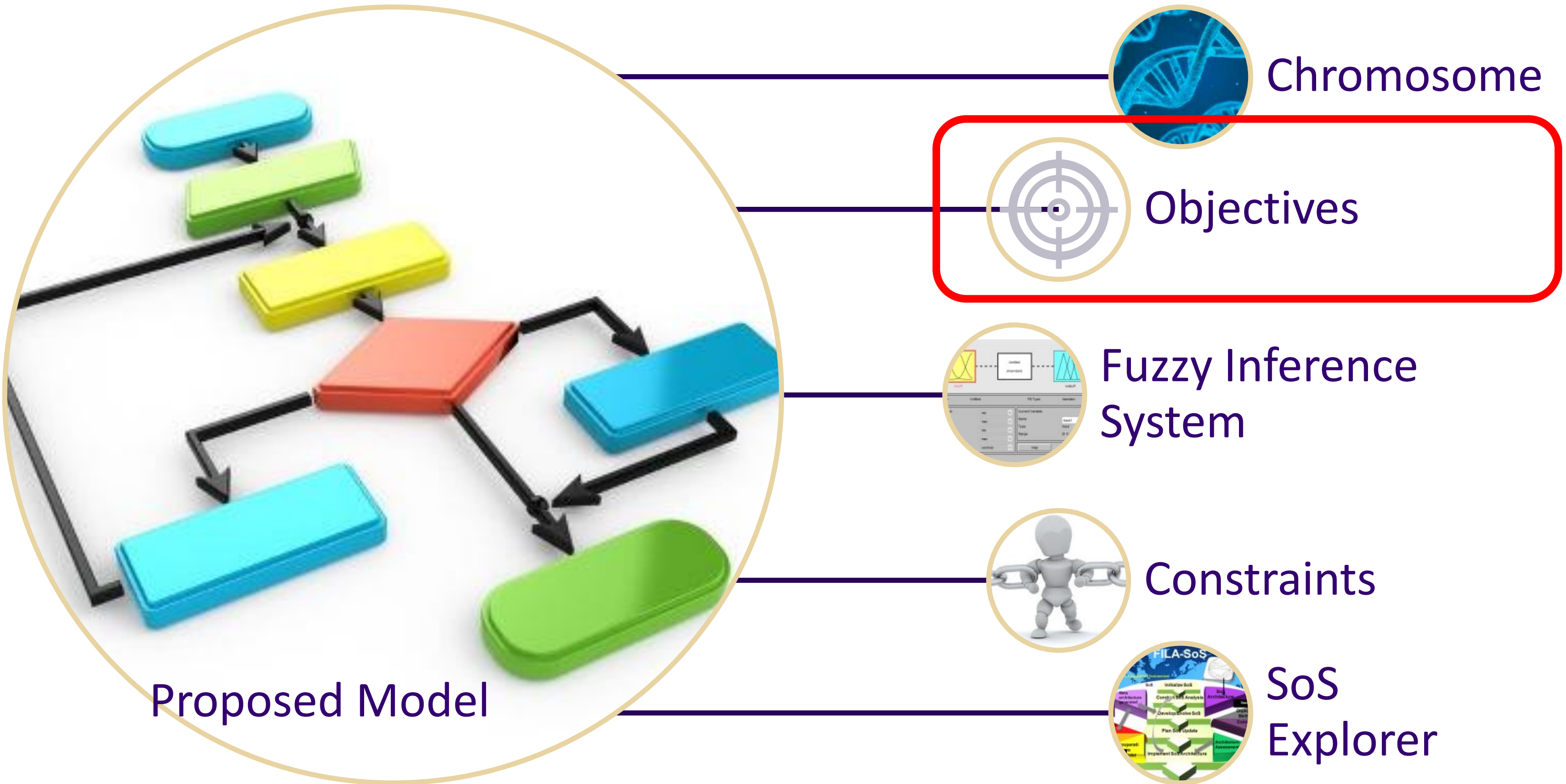
Chromosome

$$S(X,i)=\begin{cases}1, \text{ if the } i^{th} \text{ system is selected in } X, \\ 0, \text{ otherwise}\end{cases}$$

$$I(X,i,j)=\begin{cases}1, \text{ if the } i^{th} \text{ and } j^{th} \text{ system have an Interface in } X, \\ 0, \text{ otherwise}\end{cases}$$

Note: X is the chromosome, i and j are indices for subsystems

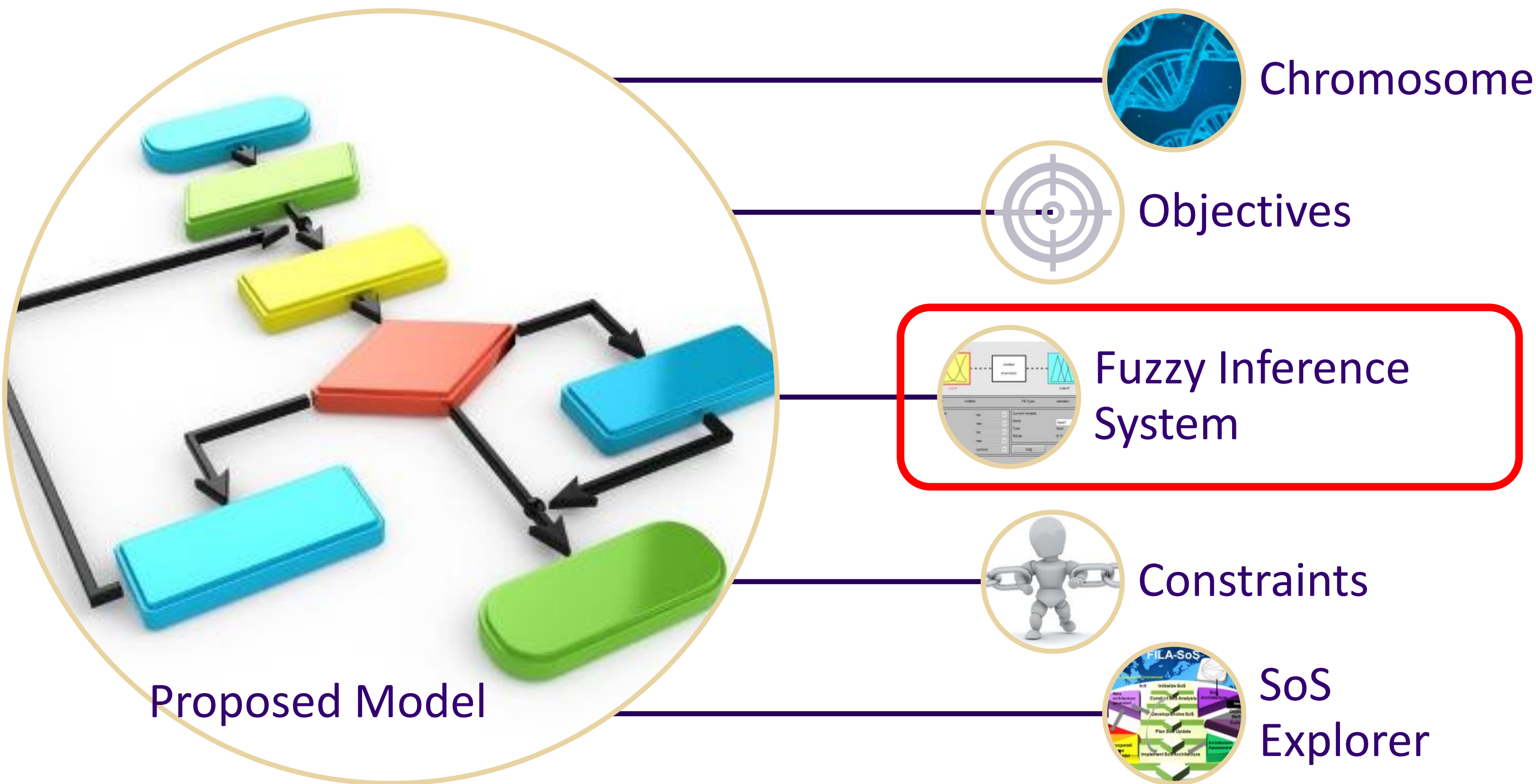
Proposed Model



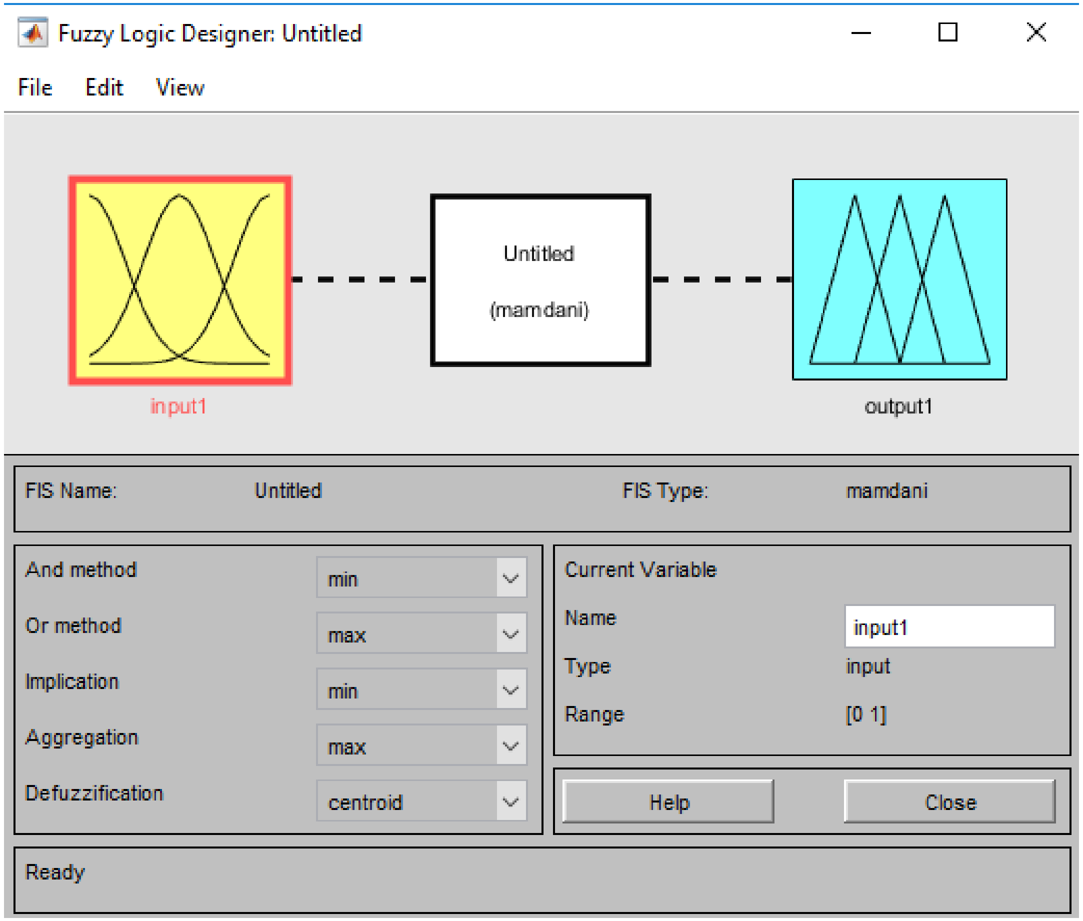
Objectives (Key Performance Attributes)

Key Performance Attributes	Explanations
Performance of the SoS Predicted Time	This is the speed of the prediction, which means the running time of the systems. The lower prediction time, the longer the time of the warning show up before the crash happen.
Performance of the SoS Predicted Decision Accuracy	This is the decision of the prediction. This is the accuracy of the perdition. The decision will show the risk factors around the vehicle and the crashes, such as: "Attention, pedestrian crossing" and "Attention, high-risk of crash."
Affordability	This is the lowest life cycle cost of the system, which means the totally cost of implementation and ownership of the SoS over its useful life.
Scalability	This is defined as the ability of the SoS to adapt to increasing demands. Demands include adding risk factors, speed up the prediction time.
Adaptability	This is the adaptability of the SoS to adapt to different kinds of the vehicle and more complex traffic environment.

Proposed Model

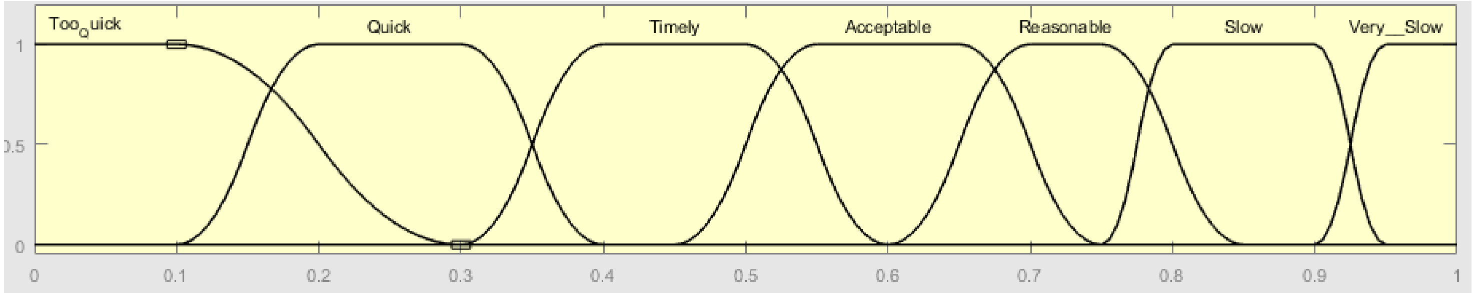


Fuzzy Inference System[6]

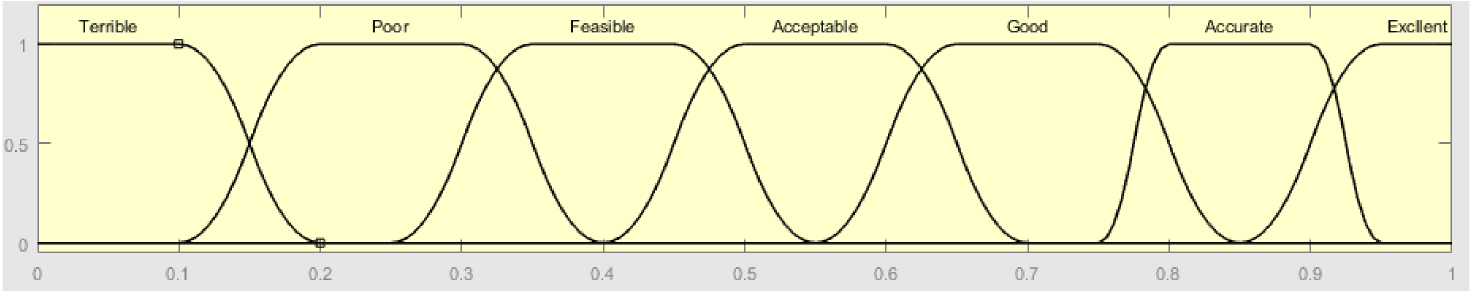


Membership Functions in FIS

- Performance of the SoS predicted Time: Too Quick, Slow, Quick, Timely, Acceptable, Reasonable, Very Slow:

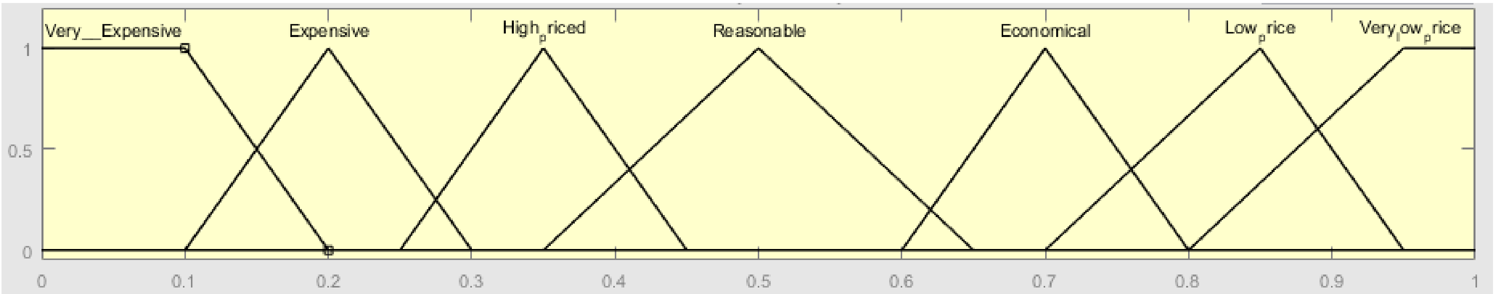


- Performance of the SoS predicted Decision Accuracy: Terrible, Poor, Feasible, Acceptable, Good, Accurate, Excellent;

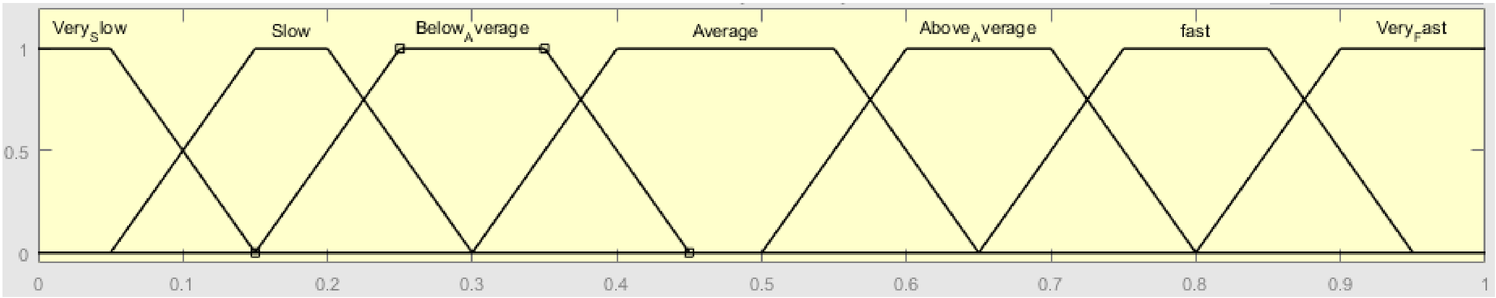


Membership Functions in FIS

- Affordability: Very Expensive, Expensive, High priced, Reasonable, Economical, Low priced, Very Low priced:

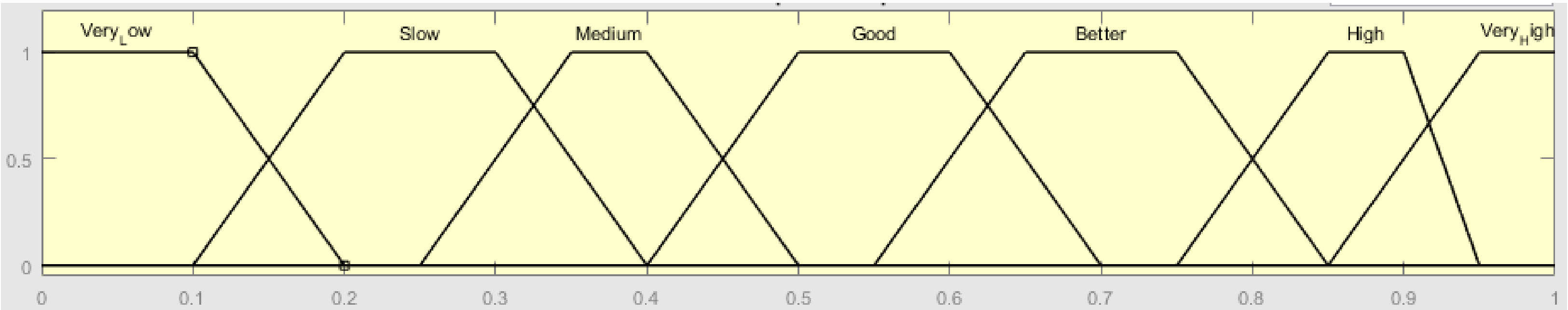


- Scalability: Very Slow, Slow, Below Average, Average, Above Average, Fast, Very fast:

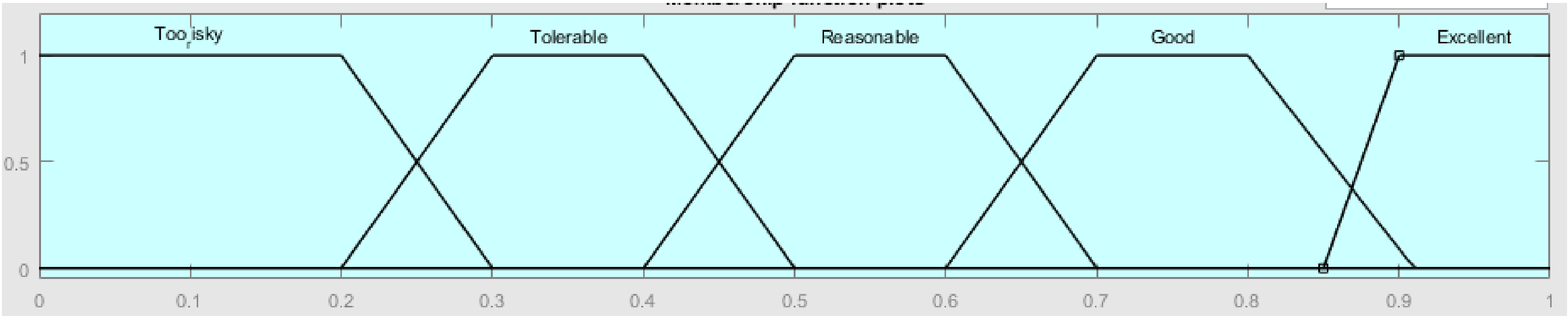


Membership Functions in FIS

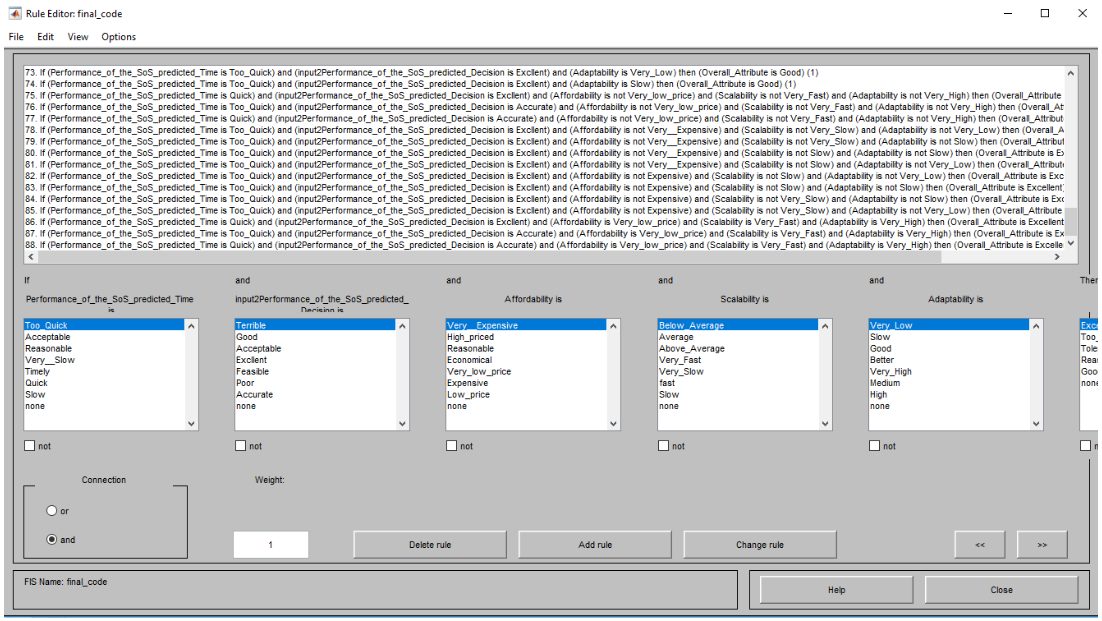
- Adaptability: Very Low, Low, Good, Medium, Better, High, Very High;



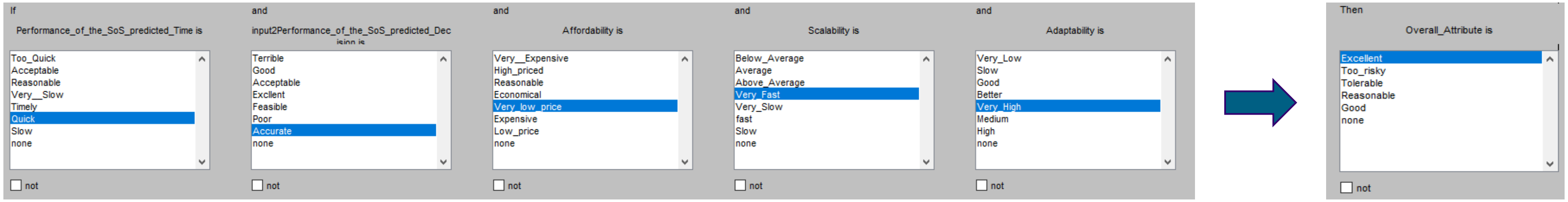
- Output:



Rules in FIS



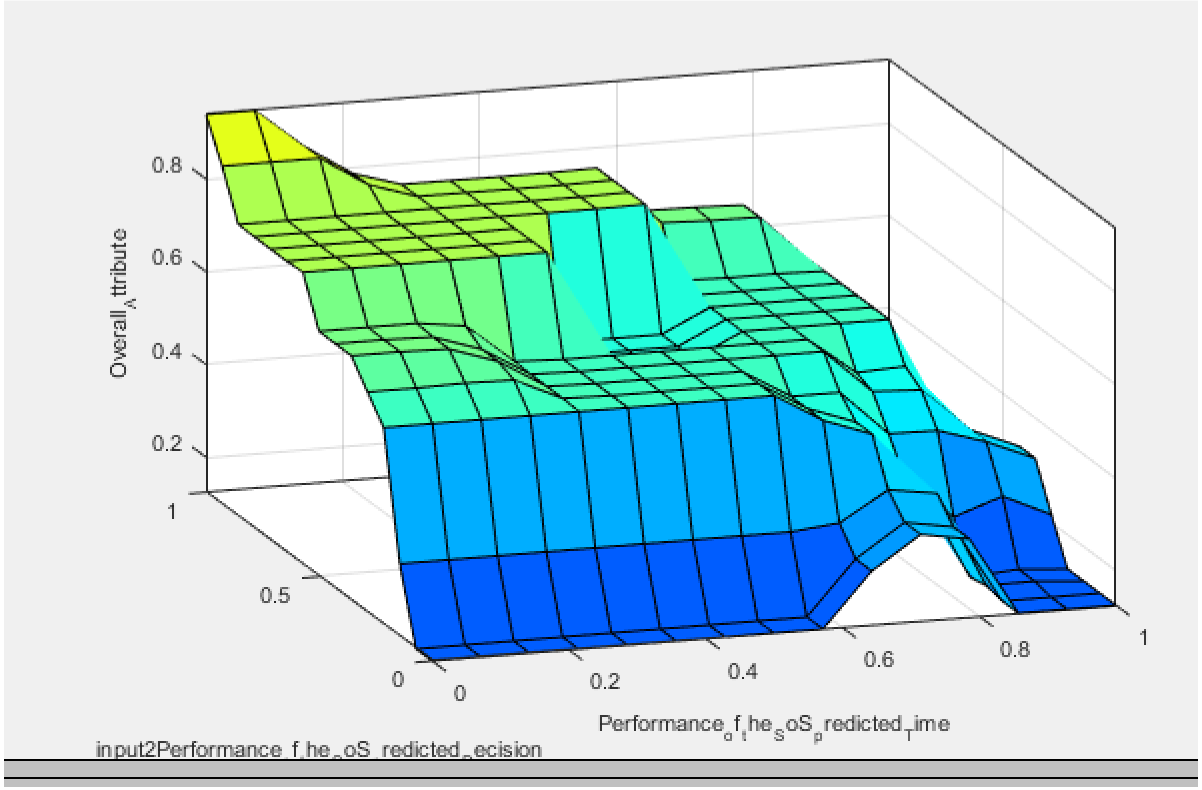
Example:



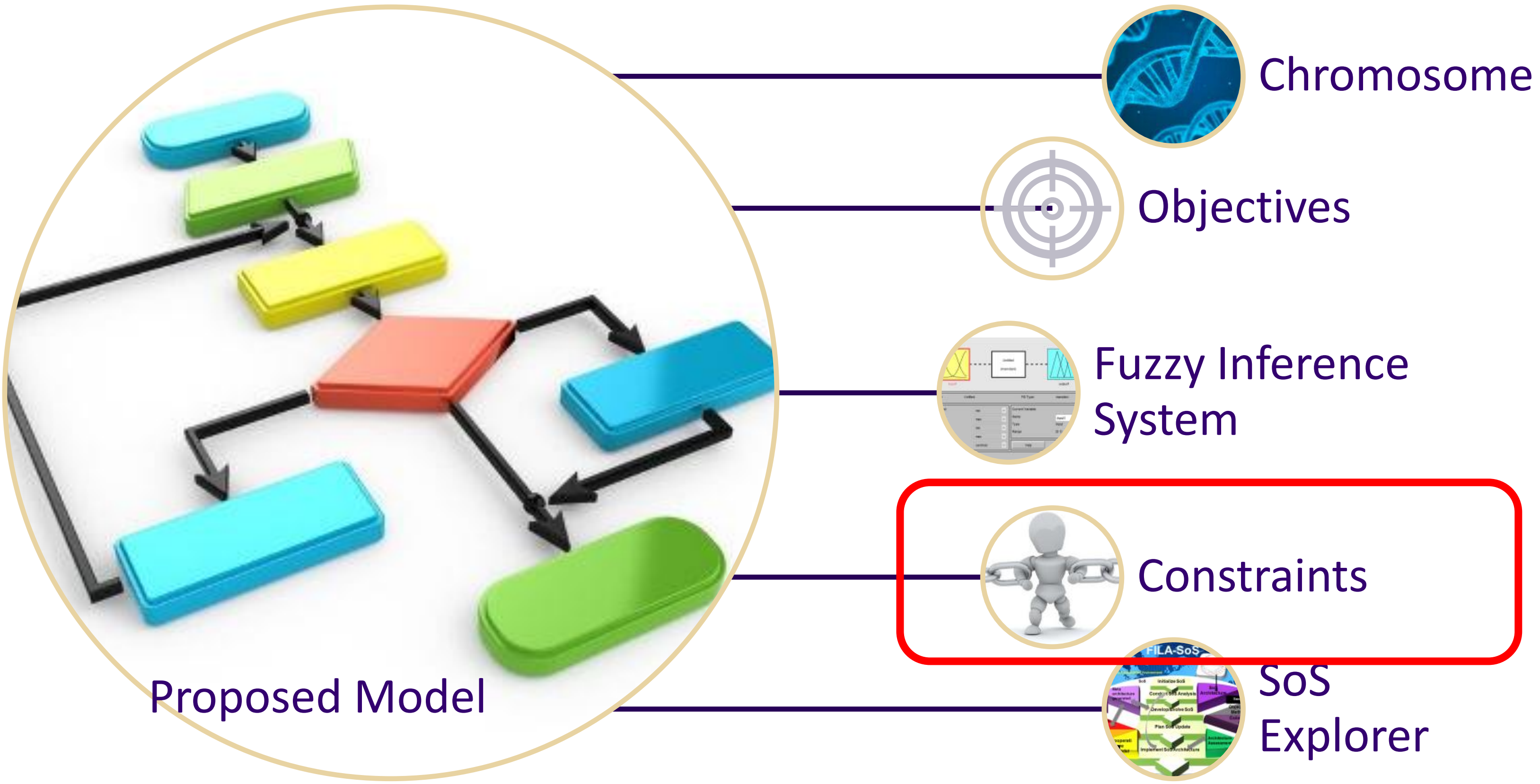
Surface of the Objectives

Example:

> The surface of the objective “the performance of the SoS predicted time” and “the performance of the SoS predicted decision accuracy”.



Proposed Model



Constraint 1 ：

At Lease Four Risk Factors Variables Should be Selected

Algorithm 1. At least four risk factors variables should be selected

procedure REQUIREFATLEASTFOURRISKFACTORS (X, N_r)
    $Num\_seleted \leftarrow 0$ ▷ The number of selected risk factors
    $List\_N_r \leftarrow [1, 2, \ldots, N_r]$ ▷ The index list of the risk factors
    for $i \leftarrow 1$ **to** N_r **do** ▷ For each risk factor
        if S(X, i) **then** ▷ if the risk factor i is selected
            $Num\_seleted \leftarrow Num\_seleted + 1$ ▷ count the number of the selection
            $List\_N_r \leftarrow List\_N_r$ delete i ▷ delete the index of the selection
        end if
    end for
    $X' \leftarrow X$ ▷ copy chromosome
    While $Num\_seleted < 4$ **do** ▷ while the selected risk factor is less than 4
        $element \leftarrow$ rand ($List\_N_r$) ▷ random select a risk factor
        $X' \leftarrow$ SETSYSTEM (X, $element$, true) ▷ add this random risk factor into system
        $List\_N_r \leftarrow List\_N_r$ delete $element$ ▷ delete random risk factor
        $Num\_seleted \leftarrow Num\_seleted + 1$ ▷ count the number of the selection
    end while
    return X'
end procedure

Constraint 2 :

Identify and Add Missing Capabilities

Algorithm 2. Add missing capabilities

```
procedure REQUIREFALLCAPABILITIES (X, C′)
    for i ← 1 to N_c′ do                                  ▷ For each capability
        j ← 0                                             ▷System index
        k ← −1                                            ▷ Non-selected system with capability i
        hasCapability ← false
        While ¬ hasCapability ∧ (j ≤ N_s) do
            if C′_ij then                                 ▷ If system j has capability i
                if S(X, j) then                           ▷ If system j is prrsent
                    hasCapability ← true                  ▷ If capability i is prrsent
                else
                    k ← j                                 ▷ Remember non-selected system with capability i
                end if
            end if
            j ← j + 1                                     ▷ Next system
        end while
        if ¬ hasCapability ∧ (k ≠ −1) then                ▷ If capability i is missing
            X′ ← SETSYSTEM (X, k, true)                   ▷ Add system k with capability i
        else
            X′ ← X
        end if                                            ▷ No change to chromosome
    end for
    return X′
end procedure
```

Constraint 3 ：

Remove Infeasible Interfaces from Architecture

Algorithm 3. Remove infeasible interfaces

procedure REMOVEINFEASIBLEINTERFACES (***X*, *F***)
    $X' \leftarrow X$ ▷ copy chromosome
    for $i \leftarrow 1$ **to** N_s **do** ▷For each system i
        for $j \leftarrow 1$ **to** N_s **do** ▷For each system j
            if $i \neq j$ **then** ▷ Only consider different systems
                if $\mathrm{I}(\mathbf{X}, i, j)$ **then** ▷ If interface is present
                    if $\neg(\mathrm{S}(\boldsymbol{X}, i) \land \mathrm{S}(\boldsymbol{X}, j) \land \boldsymbol{F}_{ij})$ **then** ▷ If not feasible
                        $X' \leftarrow$ SETINTERFACE (X', i, j, false) ▷ Remove interface
                    end if
                end if
            end if
        end for
    end for
    return X'
end procedure

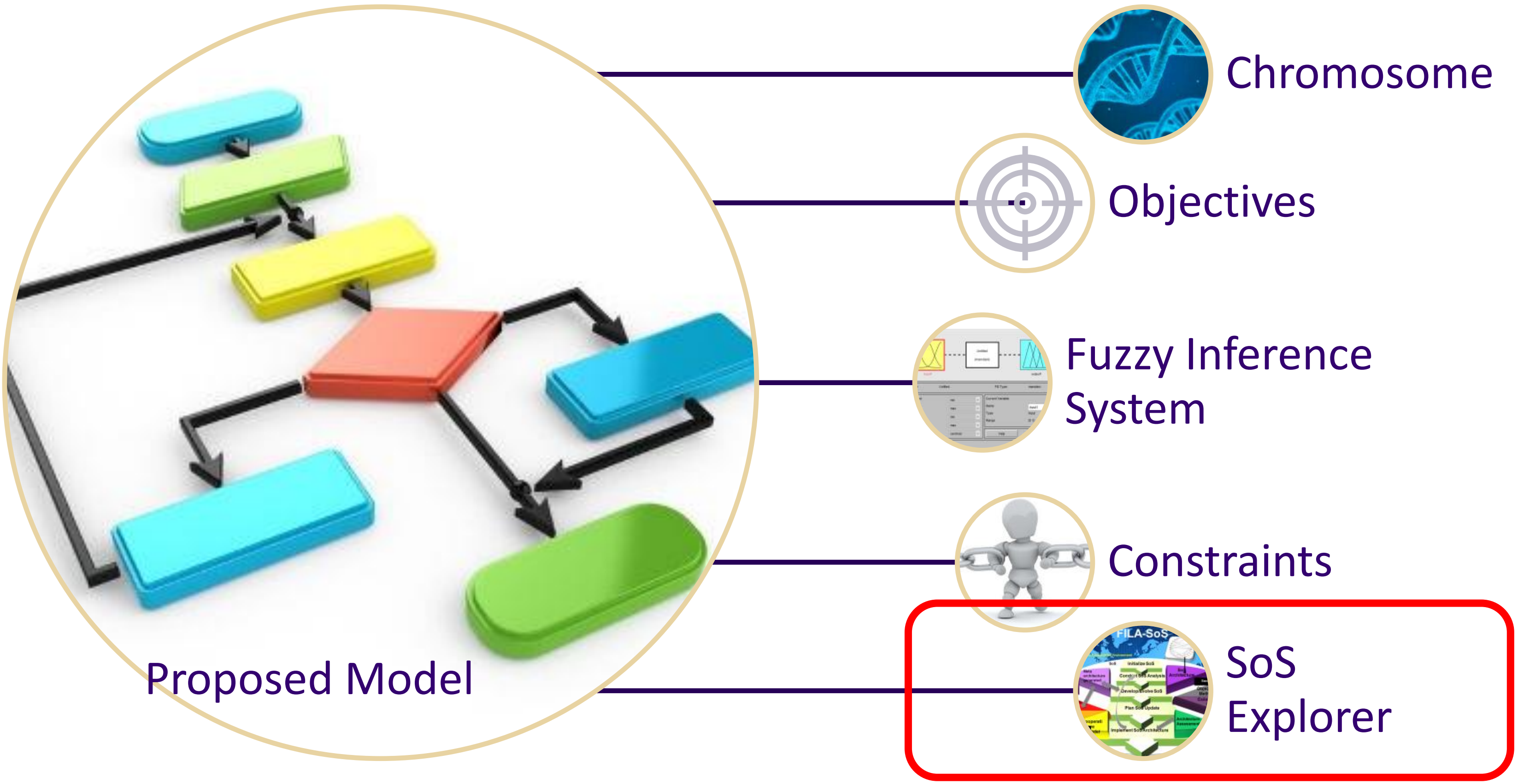
Constraint 4 ：

Add Missing Feasible Interfaces From Architecture

Algorithm 4. Add missing feasible interfaces

procedure ADDMISSINGFEASIBLEINTERFACES **(X, F)**
    $X' \leftarrow X$ ⊳ copy chromosome
    for $i \leftarrow 1$ **to** N_s **do** ⊳For each system i
        for $j \leftarrow 1$ **to** N_s **do** ⊳For each system j
            if $i \neq j$ **then** ⊳ Only consider different systems
                if $(\mathrm{S}(\boldsymbol{X}, i) \wedge \mathrm{S}(\boldsymbol{X}, j))$ **then** ⊳if system i and j are present
                    if $(\neg \mathrm{I}\ (\mathbf{X}, i, j)) \wedge \boldsymbol{F}_{ij}$ **then** ⊳If interface is not present but it's feasible
                        $X' \leftarrow$ SETINTERFACE (X', i, j, *true*)
                    end if
                end if
            end if
        end for
    end for
    return X'
end procedure

Proposed Model



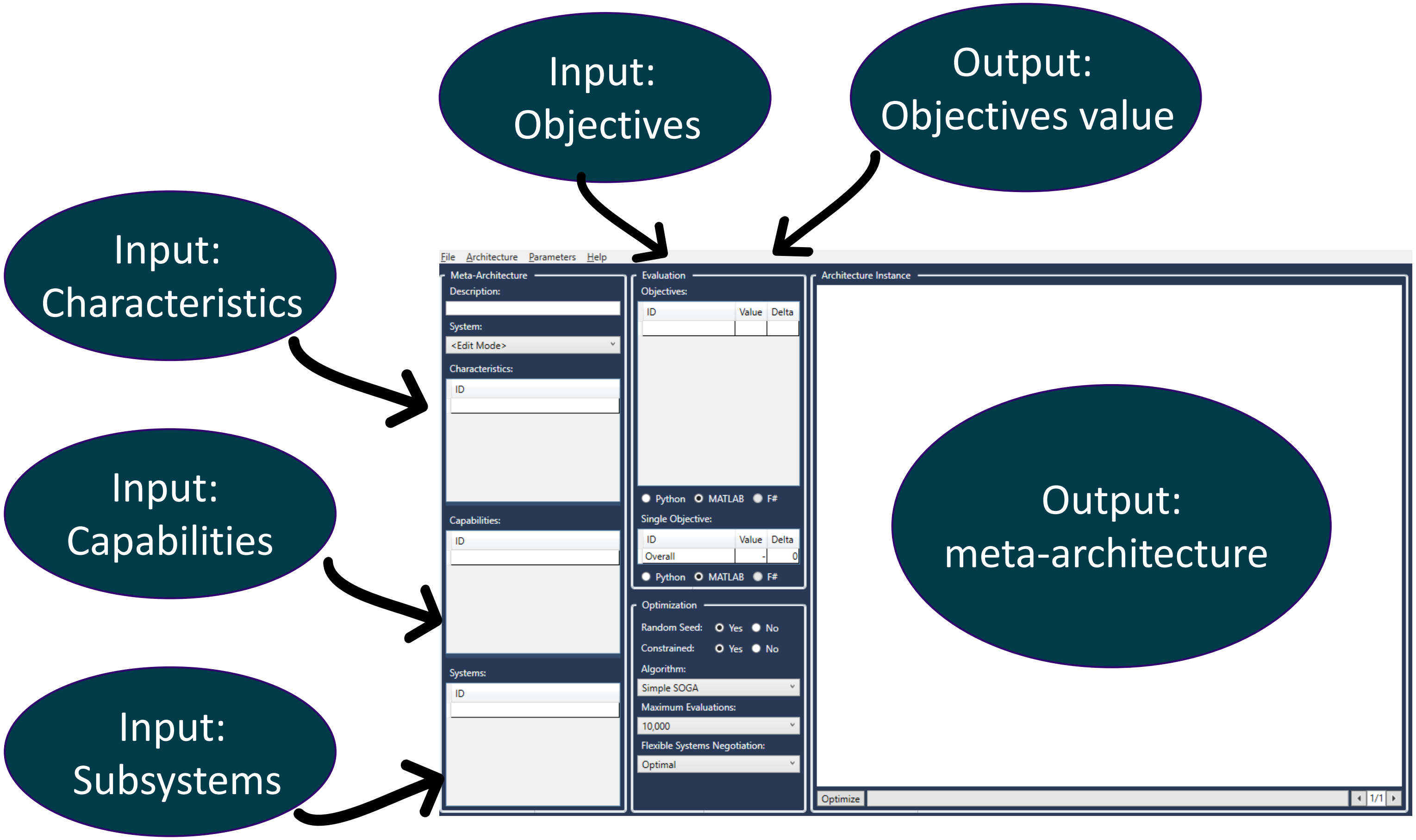
> Introduction

> Proposed Model

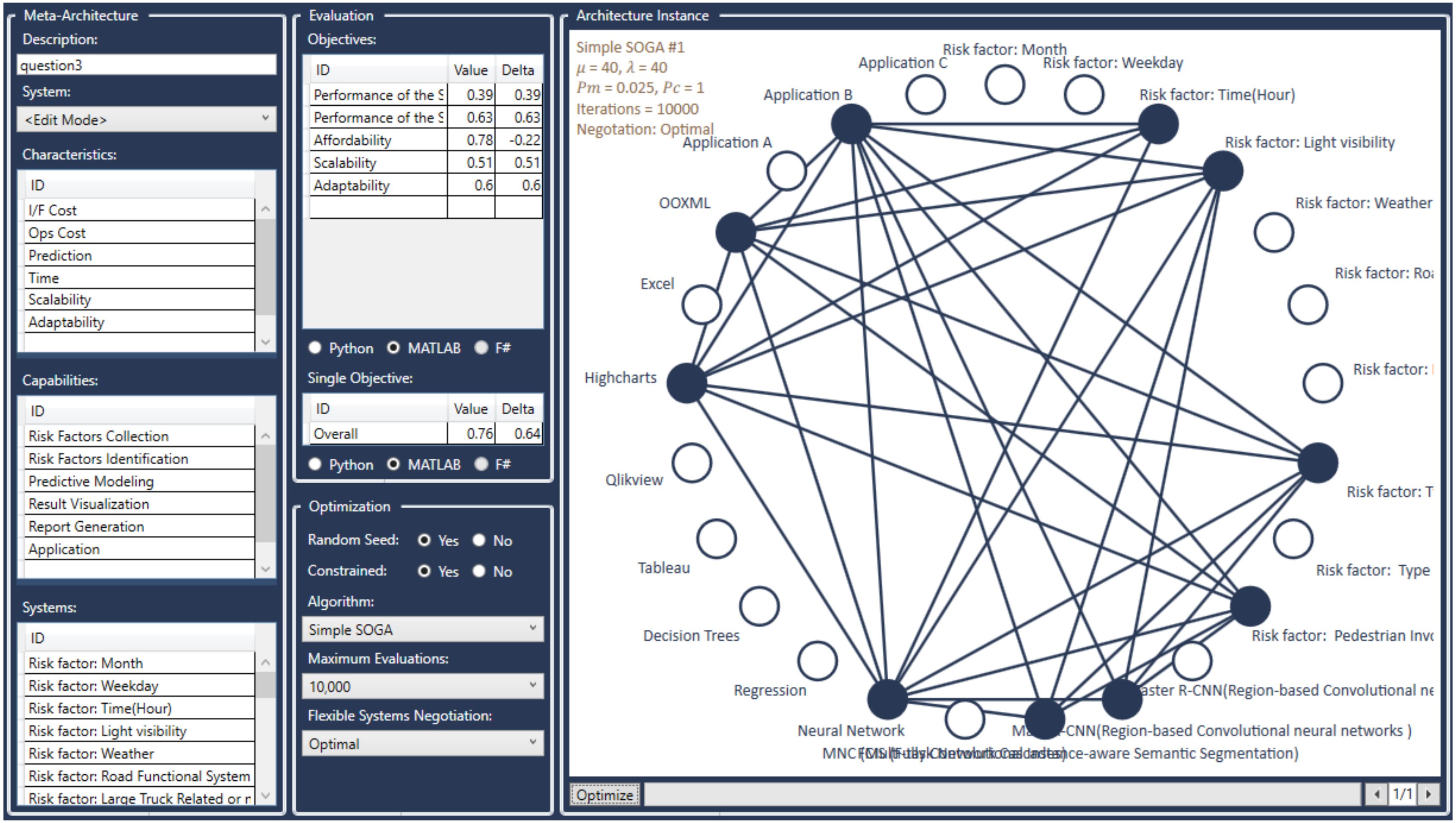
> **Results**

> Conclusions

SoS Explorer Architecting Tool

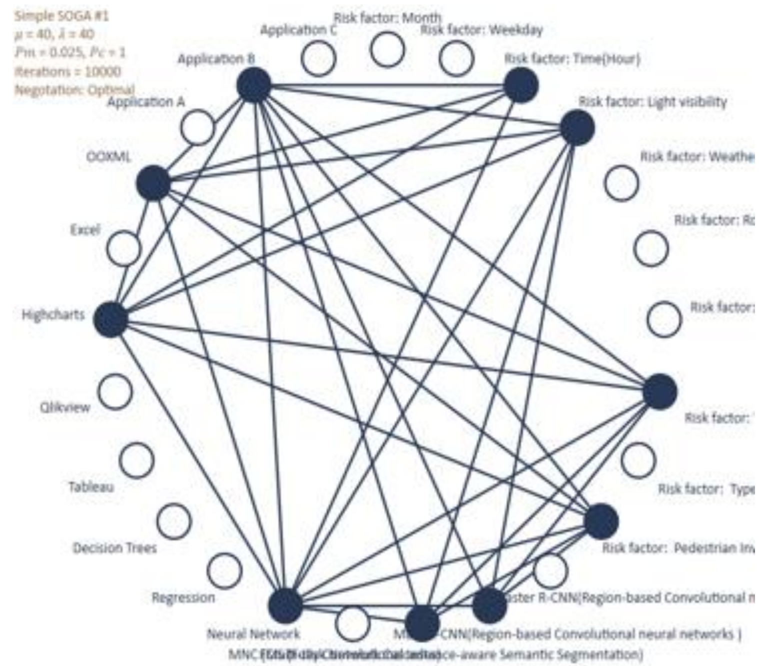


Meta-architecture



Meta-architecture

Systems									
Risk factor: Month	Risk factor: Weekday	Risk factor: Time(Hour)	Risk factor: Light visibility	Risk factor: Weather	Risk factor: Road Functional System	Risk factor: Large Truck Related or not	Risk factor: Type of Junction	Risk factor: Type of Intersection	Risk factor: Pedestrian Involved or not
0	0	1	1	0	0	0	1	0	1
Faster R-CNN(Region-based Convolutional neural networks)	Mask R-CNN(Region-based Convolutional neural networks)	FCIS (Fully Convolutional Instance-aware Semantic Segmentation)	MNC (Multi-task Network Cascades)	Neural Network	Regression	Decision Trees			
0	1	1	0	1	0	0			
Tableau	Qlikview	Highcharts	Excel	OOXML	Application A	Application B	Application C		
0	0	1	0	1	0	1	0		



The Comparison of Different Algorithms in SoS Explorer

Objectives	**MaOEA-DM**	**NSGA-III**	**Simple SOGA**
Performance of the SoS predicted Time	0.61	0.6	**0.39**
Performance of the SoS predicted Decision Accuracy	0.46	0.53	**0.63**
Affordability	0.69	0.67	**0.78**
Scalability	0.46	0.52	**0.51**
Adaptability	0.53	0.63	**0.6**
Overall	0.55	0.55	**0.76**

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Conclusions

> Evaluate the performance of the Real-time Risk Situational Awareness System by selecting the different sub-systems, which will benefit drivers;

> Fuzzy Inference System (FIS) was applied for the evaluation by setting rules and membership functions;

> FILA SoS was adopted as the tool for the system optimization using the simple genetic algorithm;

> The proposed model can be used for designing and developing the system.

Future Work

- Add more subsystems for optimization problem;
- Achieve more convincing characteristics value;
- Different demands of vehicles with various types should be taken into account during system optimization.
- Extend the application on other optimization systems;
- Advance the FILA SoS tool with more different optimization algorithms.

Thanks!
Comments and Questions?

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Characteristics Matrix

	Systems	I/F Cost	Ops Cost	Prediction	Time	Scalabilit	Adaptabilit
X1	Risk factor: Month	0.04	0.1	0.4	0.8	0.3	0.3
X2	Risk factor: Weekday	0.03	0.1	0.6	0.6	0.4	0.5
X3	Risk factor: Time(Hour)	0.03	0.1	0.7	0.55	0.5	0.6
X4	Risk factor: Light visibility	0.03	0.8	0.4	0.5	0.3	0.3
X5	Risk factor: Weather	0.03	0.8	0.2	0.55	0.1	0.2
X6	Risk factor: Road Functional System	0.03	0.3	0.2	0.6	0.1	0.2
X7	Risk factor: Large Truck Related or not	0.01	0.4	0.2	0.2	0.1	0.2
X8	Risk factor: Type of Junction	0.03	0.5	0.3	0.55	0.2	0.2
X9	Risk factor: Type of Intersection	0.03	0.5	0.3	0.55	0.2	0.2
X10	Risk factor: Pedestrian Involved or not	0.01	0.6	0.9	0.2	0.6	0.7
X11	Faster R-CNN(Region-based Convolutional neural networks)	0.04	0.5	0.6	0.4	0.4	0.6
X12	Mask R-CNN(Region-based Convolutional neural networks)	0.05	0.6	0.9	0.5	0.3	0.4
X13	FCIS (Fully Convolutional Instance-aware Semantic Segmentation)	0.06	0.4	0.8	0.6	0.6	0.5
X14	MNC (Multi-task Network Cascades)	0.06	0.4	0.7	0.6	0.5	0.6
X15	Neural Network	0.06	0.5	0.8	0.6	0.2	0.1
X16	Regression	0.04	0.5	0.5	0.4	0	0.5
X17	Decision Trees	0.05	0.5	0.6	0.5	0.7	0.3
X18	Tableau	0.02	0.2	0	0.2	0.2	0.8
X19	Qlikview	0.02	0.2	0	0.2	0.3	0.8
X20	Highcharts	0.02	0.2	0	0.2	0.1	0.8
X21	Excel	0.01	0.1	0	0.1	0.8	0.8
X22	OOXML	0.01	0.2	0	0.1	0.7	0.8
X23	Application A	0.03	0.6	0.8	0.3	0.6	0.5
X24	Application B	0.02	0.5	0.9	0.2	0.6	0.4
X25	Application C	0.03	0.6	0.8	0.3	0.6	0.3

Capabilities Matrix

	Systems	Risk Factors Collection	Risk Factors Identification	Predictive Modeling	Result Visualization	Report Generation	Application
1	Risk factor: Month	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
2	Risk factor: Weekday	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
3	Risk factor: Time(Hour)	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
4	Risk factor: Light visibility	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
5	Risk factor: Weather	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
6	Risk factor: Road Functional System	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
7	Risk factor: Large Truck Related or not	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
8	Risk factor: Type of Junction	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
9	Risk factor: Type of Intersection	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
10	Risk factor: Pedestrian Involved or not	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
11	Faster R-CNN(Region-based Convolutional neural networks)	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
12	Mask R-CNN(Region-based Convolutional neural networks)	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
13	FCIS (Fully Convolutional Instance-aware Semantic Segmentation)	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
14	MNC (Multi-task Network Cascades)	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
15	Neural Network	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
16	Regression	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
17	Decision Trees	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
18	Tableau	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
19	Qlikview	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
20	Highcharts	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
21	Excel	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
22	OOXML	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
23	Application A	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE
24	Application B	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE
25	Application C	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE

Performance of the SoS Predicted Time

$$Time\ Performance\ (X,i) = -\sum_{i=1}^{N_s} S(X,i) C_{Time,i}$$

- The minimize time performance is 0 if no system is selected. The maximize time performance is *Max_T*, which means when all the systems are selected.
- To calculate crisp numeric values within the universe of discourse [0 1], Let:

$$Crisp\_\ Time\ (X,\ i) = \frac{Max\_T - Time\ Performance\ (X,\ i)}{Max\_T - 0}$$

Performance of the SoS Predicted Decision Accuracy

$$Decision\ Performance\ (X,i)=\frac{\sum_{i=1}^{N_s} S(X,i)C_{\Pr edition,i}}{\sum_{i=1}^{N_s} S(X,i)}$$

> The maximize performance of the SoS predicted decision accuracy is Max_P, which is the maximum accuracy of all subsystems. To calculate crisp numeric values within the universe of discourse [0 1]. Let:

$$Crisp\_Decision\ (X,\ i)=\frac{Decision\ Performance\ (X,i)-0}{Max\_P-0}$$

Affordability

$$Affordability\ (X,i) = -\sum_{i=1}^{N_s} S(X,i)\left[C_{operation,i} + \sum_{j=1 \& j \neq i}^{N_s} S(X,i)S(X,j)C_{I/F\cos t,i} \right]$$

> where the $C_{operation,i}$ is the operation cost of system i and is the interface cost between any one of other subsystem and subsystem i. The summary of the interface cost will be calculated if both the subsystem i and j are selected. The maximize affordability is 0 if none of the subsystem is selected. The minimize affordability is -Max_AF when all subsystems are selected. To calculate crisp numeric values within the universe of discourse [0 1]. Let:

$$Crisp\_Affordability\ (X,\ i) = \frac{Affordability(X,\ i) - (-Max\_AF)}{0 - (-Max\_AF)}$$

Scalability

$$Scalability\ (X,\ i) = \frac{\sum_{i=1}^{N_s} S(X,i) C_{Scalability,i}}{\sum_{i=1}^{N_s} S(X,i)}$$

> The maximize Scalability is Max_S, which is the maximum scalability of all subsystems. To calculate crisp numeric values within the universe of discourse [0 1]. Let:

$$Crisp\_Scalability\ (X,\ i) = \frac{Scalability\ (X,\ i) - 0}{Max\_S - 0}$$

Adaptability

$$Adaptability\ (X, i) = \frac{\sum_{i=1}^{N_s} S(X, i) C_{Adaptability, i}}{\sum_{i=1}^{N_s} S(X, i)}$$

> The maximize adaptability is *Max_AD*, which is the maximum adaptability of all subsystems. To calculate crisp numeric values within the universe of discourse [0 1]. Let:

$$Crisp\_\ Adaptability\ (X,\ i) = \frac{Adaptability\ (X,\ i) - 0}{Max\_AD - 0}$$