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Methods for Quantifying Rework Risk to Make Efficient Schedule for a Project

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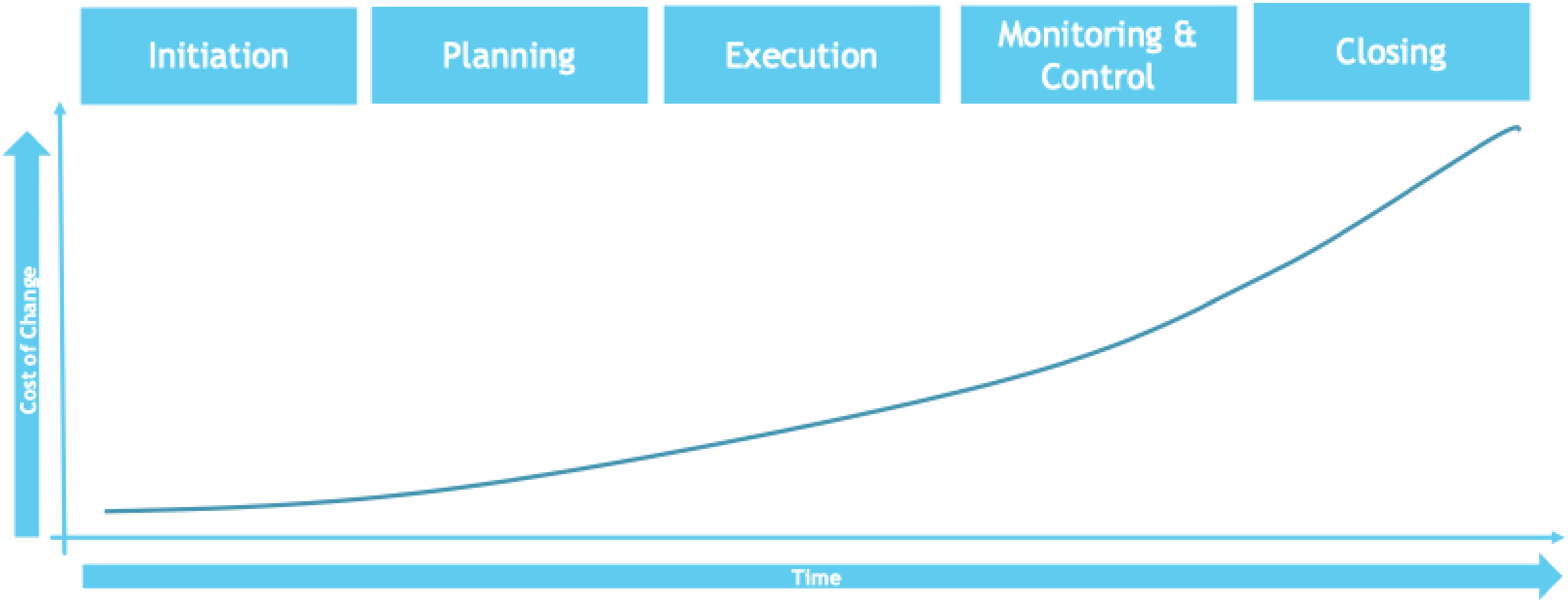
Today's Agenda

- Motivation & Background
- Objective
- Methodology
- Case Study
- Conclusion & Future Work

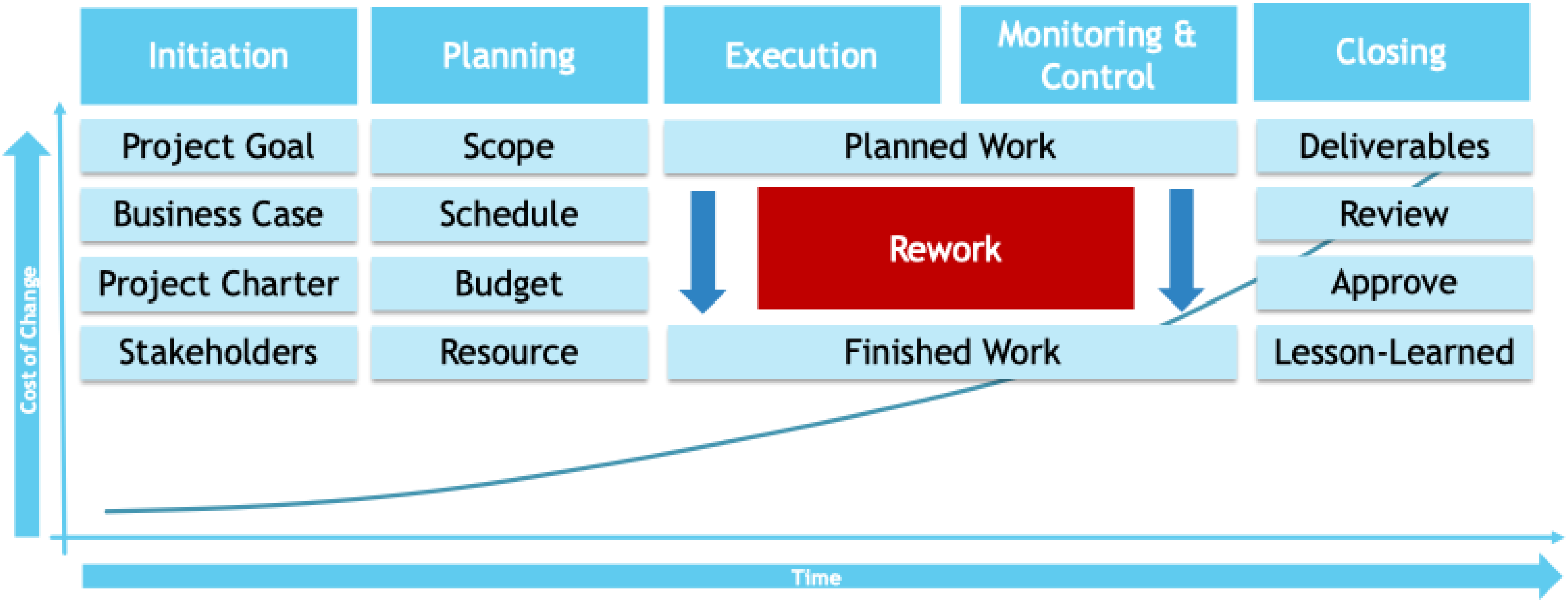
Motivation and Background

In Project Management, rework is referred as the unnecessary effort of redoing an activity that was incorrectly implemented at first, which is very difficult to avoid in projects.



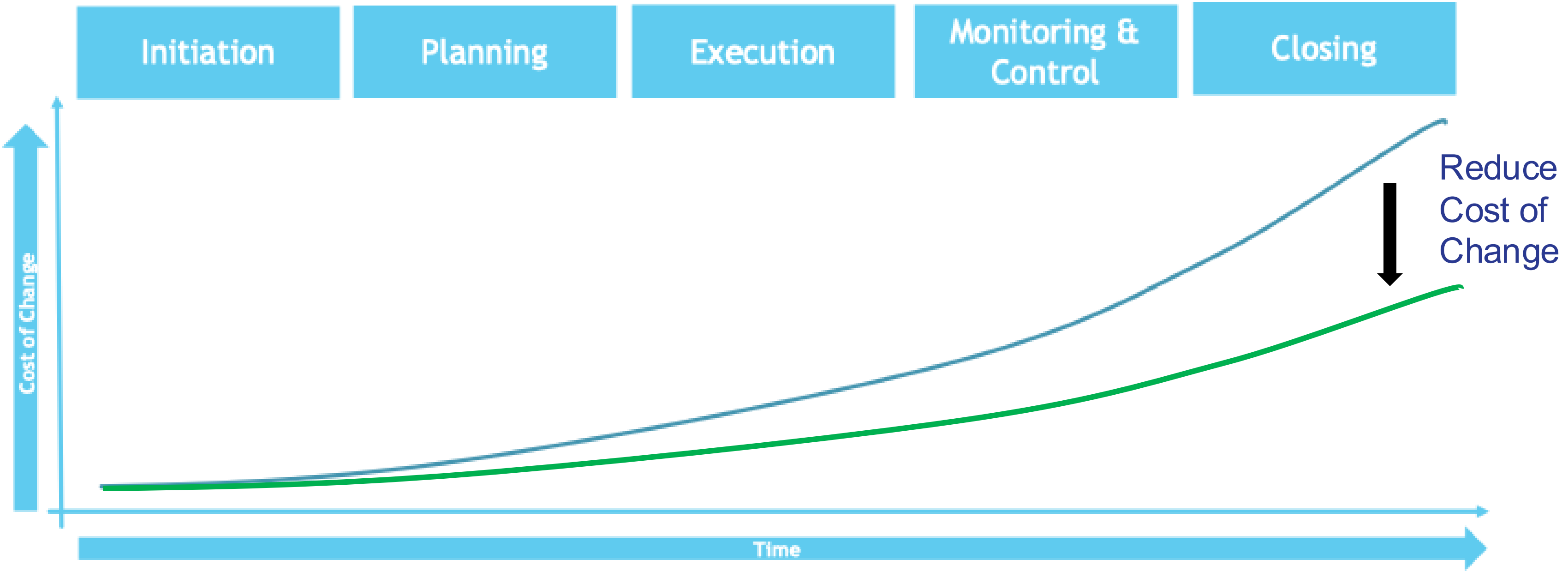
Motivation and Background

As per the Project Management Institute, projects can be managed in five phases. Rework usually occurs during the execution and monitoring & control phase. Considering the cost of change, the rework cost could be significant.



Motivation and Background

It is critical to consider rework during the project planning phase. By planning rework ahead of time, the cost of change could by reduced.



Motivation and Backgrounds

In practice: rework is often dealt with a lump sum buffer reserved for overall project risks.

Challenges in estimating the rework risk:

1. Heuristic characteristics of project management
2. Dependencies on the interactions between tasks
3. Variability on the human resource skills

Limitations of common scheduling techniques such as the critical path analysis, schedule network analysis, Monte Carlo simulation, etc.

Objective

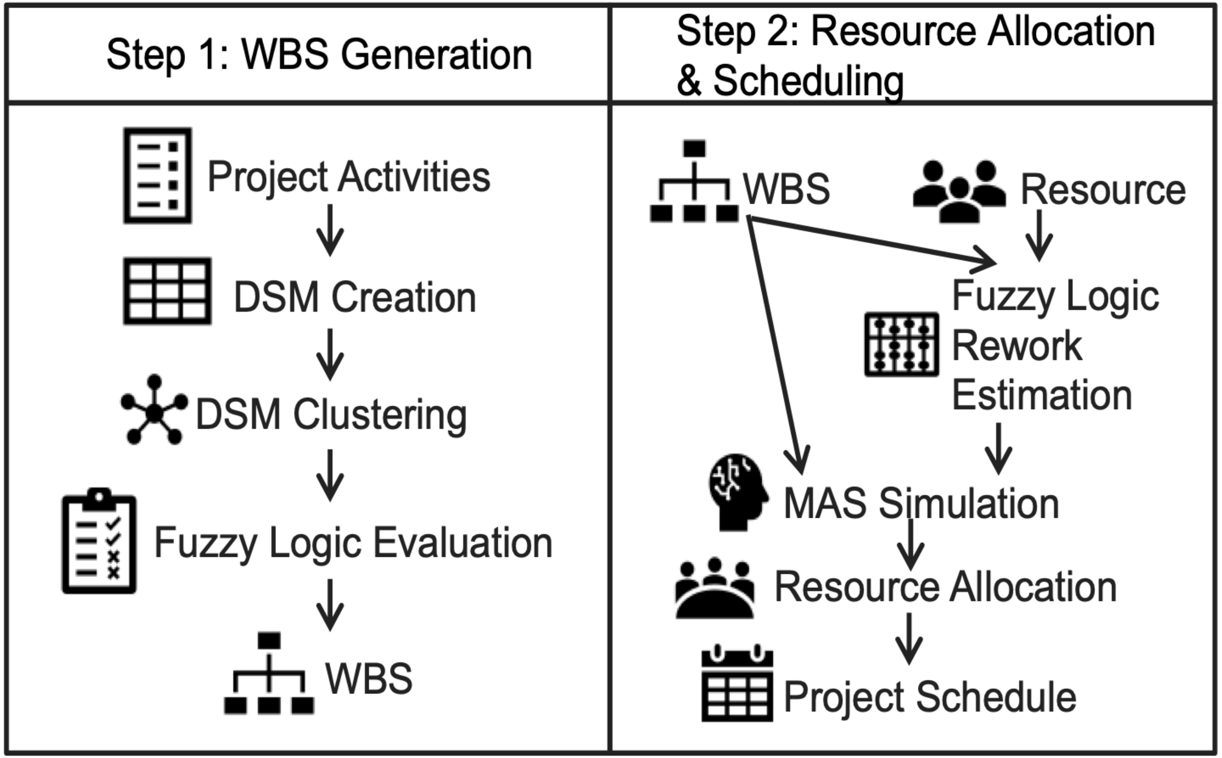
To design a comprehensive simulation model that can generate an efficient project schedule under rework scenarios considering the key elements of project planning: scope, resource, and cost.

The new model shall perform the following functionalities:

Managing scopes to minimize the rework risk	Dynamically allocating resources based on their skills	Quantifying the rework risk and its impact on the schedule	Generating optimized schedule under budget constraint

Methodology

A two-step simulation and modelling process

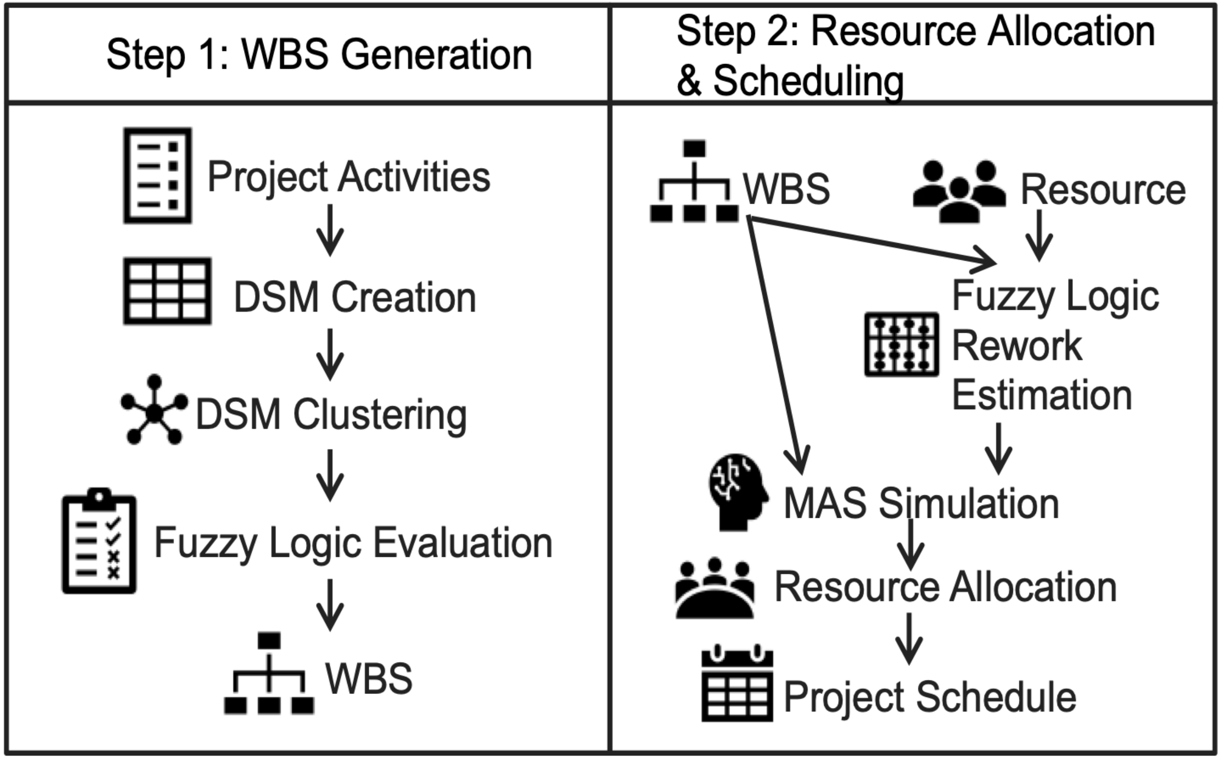


Step 1 WBS Generation (Scope Management)

- Design Structure Matrix (DSM) and DSM clustering algorism to group closely interacted activities into one WBS and constrain change propagation, thus reducing rework risk
- To tackle the challenge of estimating rework risk regarding dependencies on the interactions between tasks

Methodology

A two-step simulation and modelling process

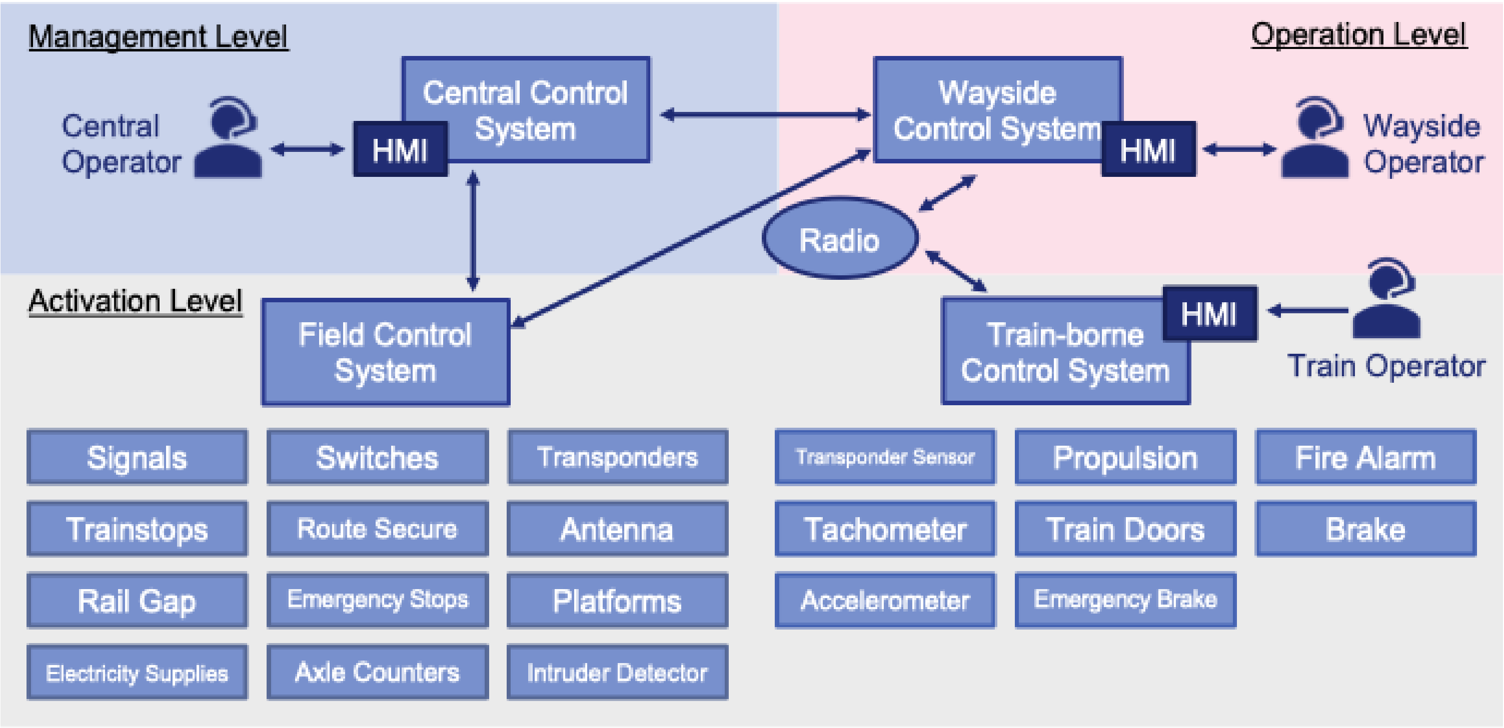


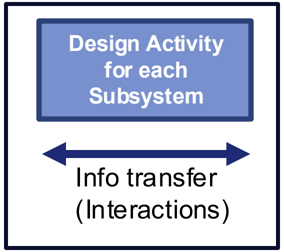
Step 2 Resource Allocation & Scheduling (Resource , Rework & Schedule Management)

- Fuzzy Logic Inference Model to quantify rework impact and include in project schedule.
- Multi-Agent System (MAS) model to establish the relationship between activity and resources to generate project schedule
- To tackle the challenge of estimating rework risk regarding heuristic characteristics of project management and variability on the human resource skills

Case Study Overview

Case study project for model illustration: System design project for a train control system including 26 subsystems which require design activity for each subsystem. Workload for each design activity is estimated using triangular distribution.





A: Senior
Productivity 100%

B: Senior
Productivity 100%

C: Intermediate
Productivity 80%

D: Junior
Productivity 60%

Step 1 WBS Generation

Design Structure Matrix (DSM) Generation

- Understand the rework change propagation based on interactions
- In the square matrix, the interactions are shown in DSM
  - Degree of Dependency: 1s & 2s (the changes of the preceding design for 2s has a higher impact on the succeeding design)

	Central Syste	Wayside Syst	Radio	Field System	Signals	Switches	Location Indic	Trainstops	Route Secure	Antenna	Rail Gap	Emergency St	Platforms	Electricity Su	Axle Counters	Intruder Dete	Onboard Syst	Location Indic	Propulsion	Fire Alarm	Tachometer	Train Doors	Brake	Acceleromete	Emergency Br	V&V
Central System	5	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wayside System	1	3.5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Radio	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Field System	1	1	0	3	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Signals	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Switches	0	0	0	1	1	2.5	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Location Indicator	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trainstops	0	0	0	1	0	0	0	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Route Secure	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Antenna	0	0	0	2	0	0	0	0	0	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rail Gap	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Emergency Stops	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Platforms	0	0	0	1	0	0	2	1	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity Supplies	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Axle Counters	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Intruder Detector	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	1.5	0	0	0	0	0	0	0	0	0	0
Onboard Systems	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	0	2	0
Location Indicator Sensor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Propulsion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Fire Alarm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1.5	0	0	0	0	1	0
Tachometer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1.5	0	0	0	0	0
Train Doors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	0	0	0
Brake	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0
Accelerometer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3.5	0	0
Emergency Brake	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
V&V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5

Step 1 WBS Generation

- Activities within the same cluster will be managed together. The interactions with other clusters should be minimized to reduce the rework change propagation.
- DSM Clustering - Idicula-Gutierrez-Thebeau Algorithm (IGTA) clustering algorithm

$$IntraClusterCost = (DSM(j,k) + DSM(k,j)) * ClusterSize(y)^{powcc}$$

$$ExtraClusterCost = (DSM(j,k) + DSM(k,j)) * DSMSize^{powcc}$$

$$TotalCost = \sum IntraClusterCost + \sum ExtraClusterCost$$

where:

$TotalCost$ = Coordination Cost

$IntraClusterCost$ = Cost of interaction within a cluster

$ExtraClusterCost$ = Cost of interaction occurring outside of any clusters

$DSM(j,k), DSM(k,j)$ = DSM interaction between element j & k

$ClusterSize(y)$ = Number of elements in the cluster y

$DSMSize$ = Number of elements in the DSM

$powcc$ = penalize the size of clusters

$$ClusterBid_j = \frac{(inout)^{powdep}}{(ClusterSize_j)^{powbid}}$$

where:

j = cluster number

$ClusterBid_j$ = Bid from Cluster j for the chosen element

$inout$ = sum of DSM interactions of the chosen element with each of the elements in cluster j

$powdep$ = exponential to emphasize interactions

$powbid$ = exponential to penalize size of the cluster

Parameters:

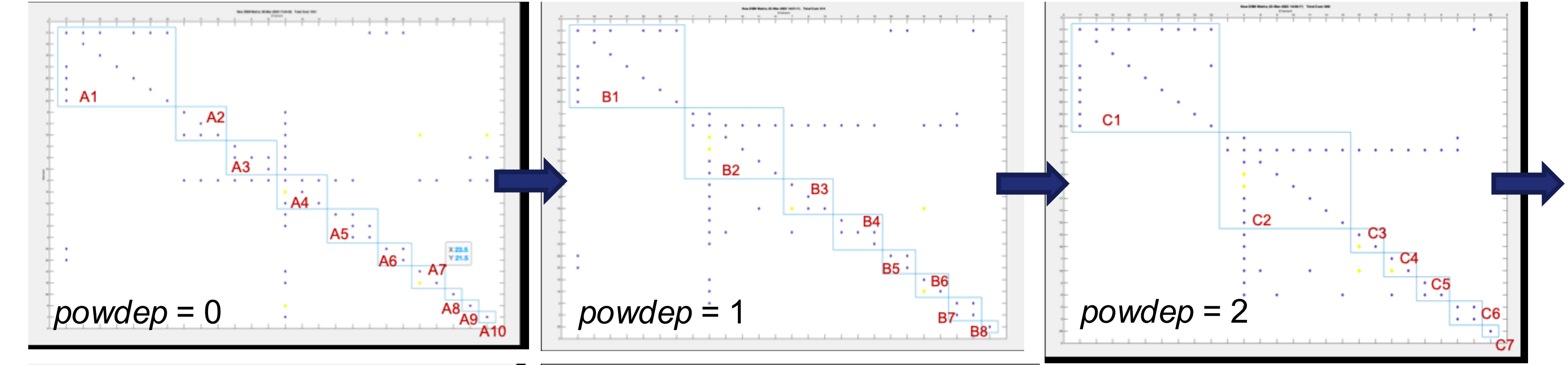
$powcc$ = penalize the size of clusters

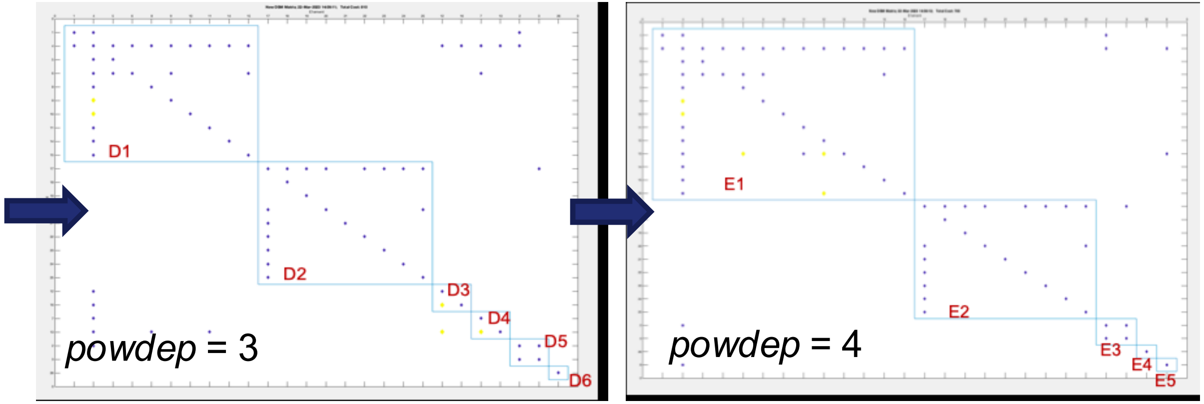
$powdep$ = exponential to emphasize interactions

$powbid$ = exponential to penalize size of the cluster

Step 1 WBS Generation

IGTA clustering results: As *powdep* increases from 0 → 4, the total number of clusters decreases, and the cluster size increases





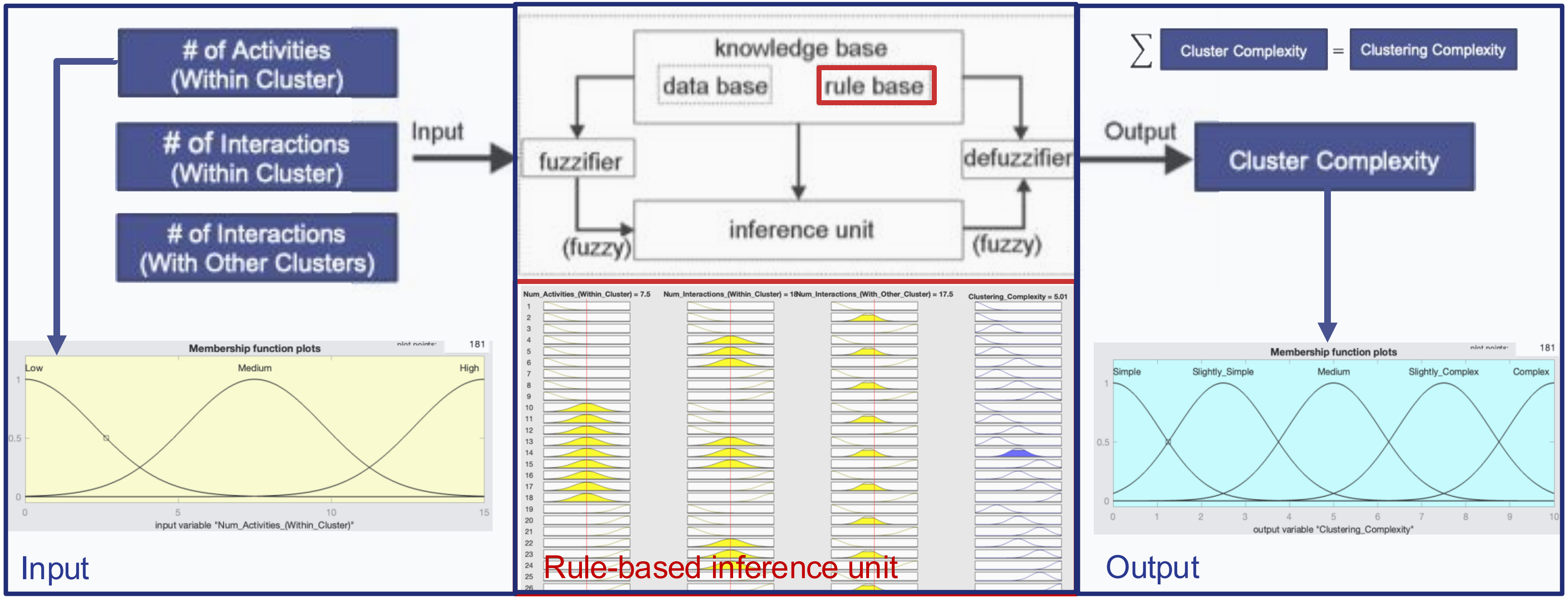
Which one is better?

- Higher # of clusters → Higher interactions between different clusters → Higher rework risk
- Larger Size of cluster→ More difficult to manage → Higher rework risk

How to evaluate?

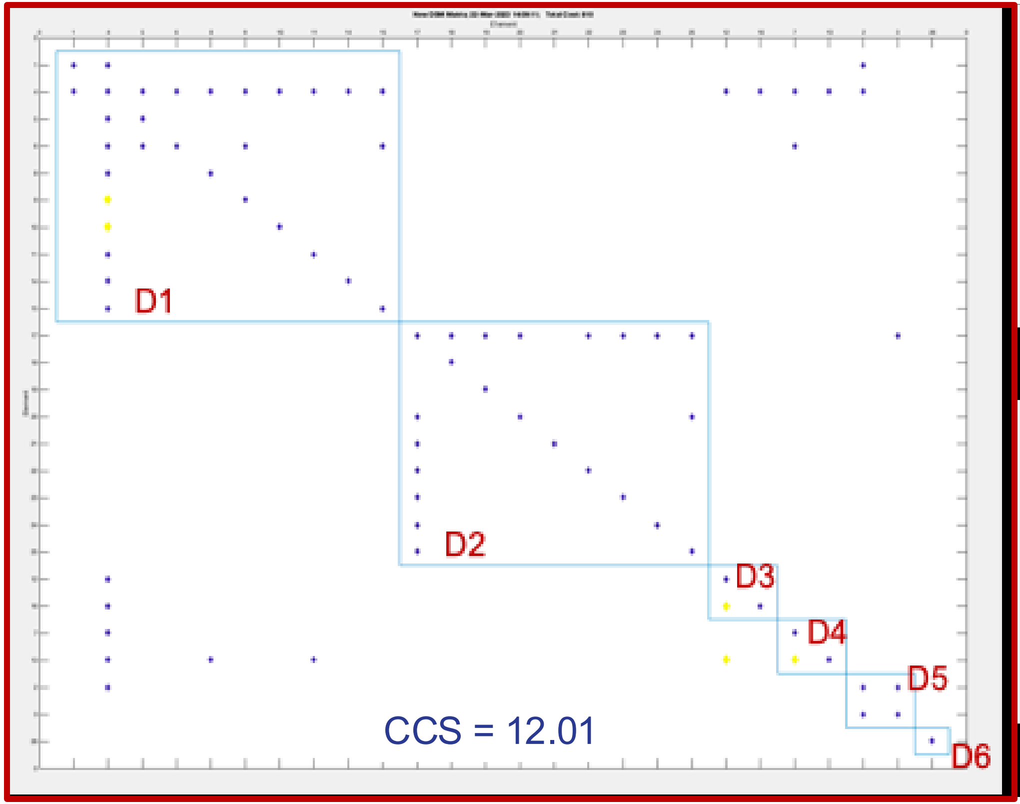
Step 1 WBS Generation

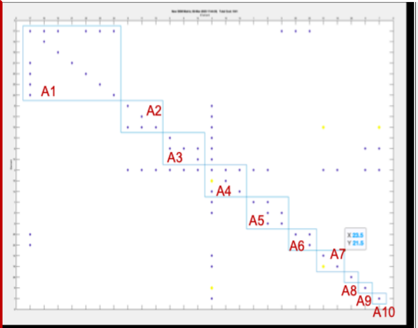
- Cluster Complexity Score (CCS) introduced to evaluate clustering result through analyzing the relationships between the cluster size/interactions and the rework impact from the change propagation.
- Fuzzy Logic Inference Model utilizes linguistic boundaries and membership functions to quantify the degree of membership where human expert's experiences could be used.



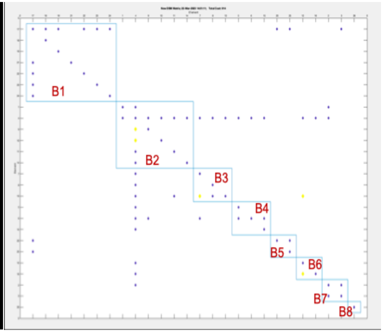
Step 1 WBS Generation

- Clustering Evaluation – WBS Selection with the lowest Cluster Complexity Score (CCS)

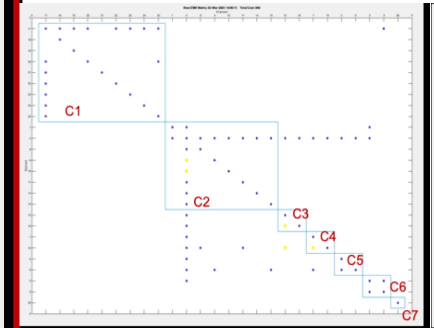




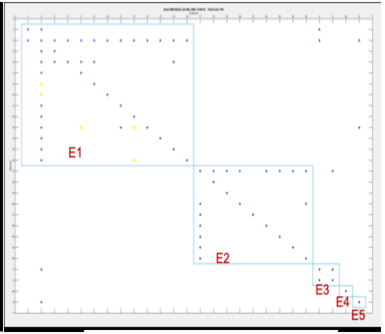
CCS = 24.26



CCS = 16.47



CCS = 14.98



CCS = 18.83

Step 2 Scheduling

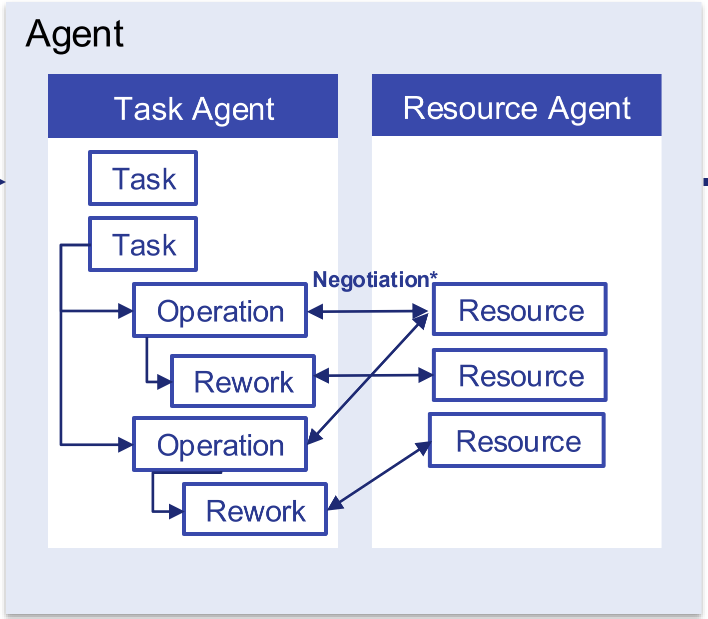
With MAS, resource allocation can be much more dynamic in terms of minimizing the rework impact through the dispatching rule.

MAS Model

Input

1. DSM (Interactions and Sequences)
2. Resource (Productivity)
3. Task (Workload)

Dispatching Rule (Operation → Resource) : Resource with higher productivity is preferred



Output

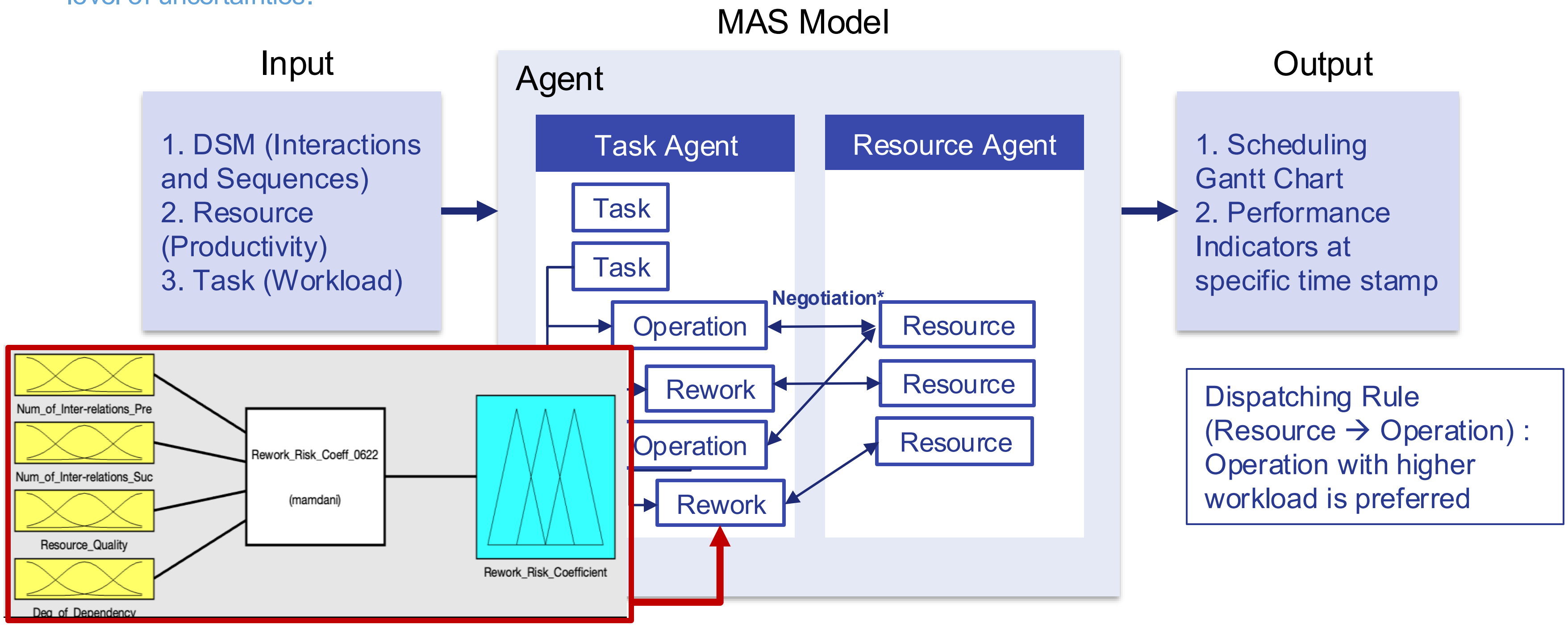
1. Scheduling Gantt Chart
2. Performance Indicators at specific time stamp

Dispatching Rule (Resource → Operation) : Operation with higher workload is preferred

* Negotiation Mechanism: Contract Net Protocol (CNP) - task-sharing protocol in multi-agent systems, which is used to allocate tasks among autonomous agents.

Step 2 Scheduling

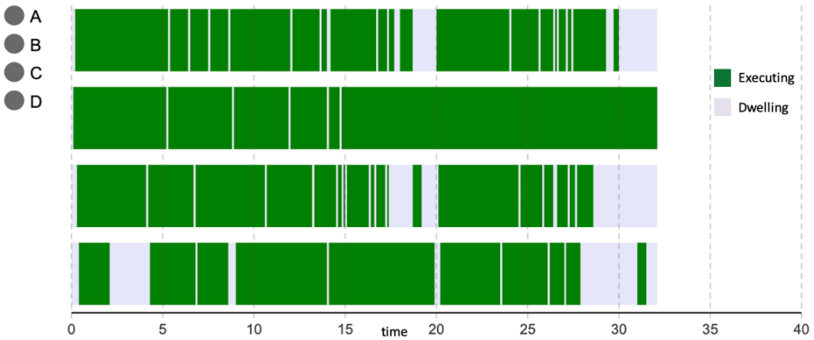
Rework impact on schedule is estimated separately using fuzzy logic inference model due to its heuristic characteristics and high level of uncertainties.



* Negotiation Mechanism: Contract Net Protocol (CNP) - task-sharing protocol in multi-agent systems, which is used to allocate tasks among autonomous agents.

Step 2 Scheduling

- Scheduling Results: Gantt Chart generated by estimating the completion time of the project (i.e. makespan) based on specific execution order and resource allocation plan
- Efficiency evaluated by total makespan, rework impact (how much time spent on rework), resource utilization



Total Makespan: 32.1 Days
Rework Impact: 31%

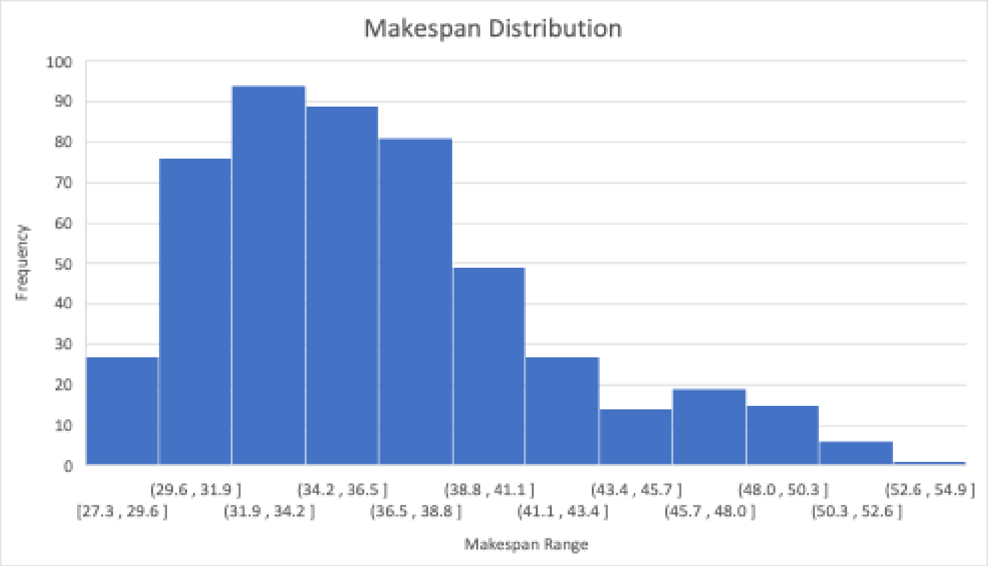
(with most likely workload)

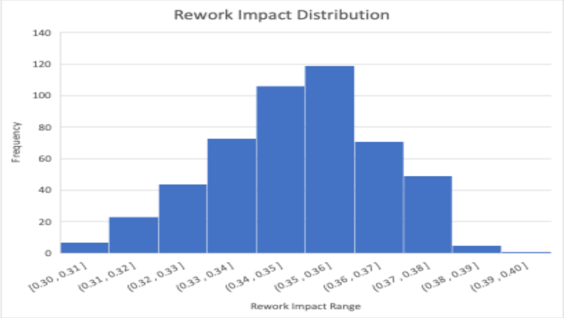
Overall Resource Utilization: 82.9%
Senior Workers Utilization Rate: 89.7%
Intermediate Worker Utilization Rate: 76.2%
Junior Worker Utilization Rate: 75.9%

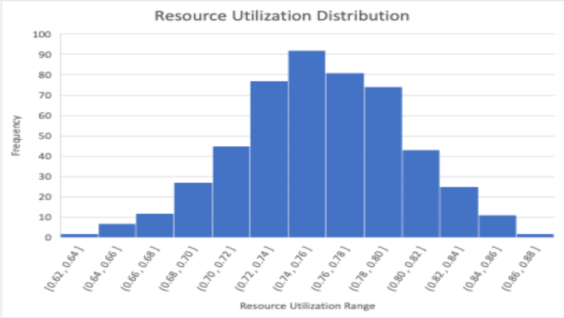
→ Fully exploit the senior workers to reduce the rework risk and project schedule

Step 2 Scheduling

Considering the uncertainties generated from the workload and the dispatching rule, 500 simulations were conducted to better estimate the schedule for the case study.





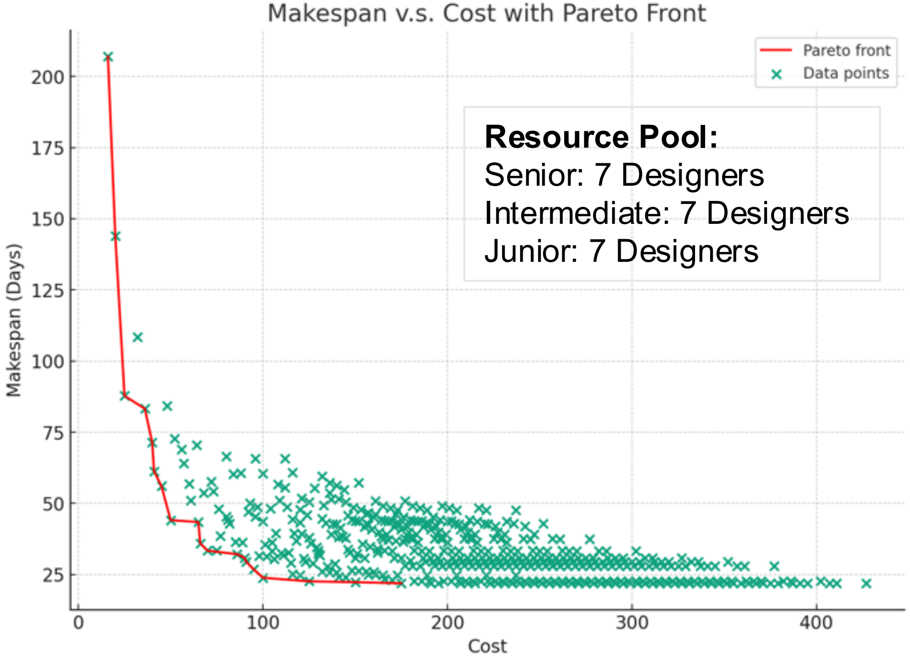


Total makespan range: 27.3 – 53.1 days with average of 36.3 days
(With 95% confidence interval, the total makespan likely between 26 – 46.8 days)
Rework Impact: 29.8% to 38.9%, Resource utilization: 62.1% to 86.9%

Step 2 Scheduling

Resource Optimization under Schedule and Cost Constrains

- By variating the number of human resources at different productivity, the project makespan and the labour cost could be affected significantly.
- Minimum 1 resource and maximum 21 resources with cost ratio of 16:20:25.



Using this diagram, PM can select the most optimum resources under specific constrains

Optimization Goal: To form the most efficient design team under rework scenario with schedule/cost constrains

Input: Resource Pool with all possible team combinations

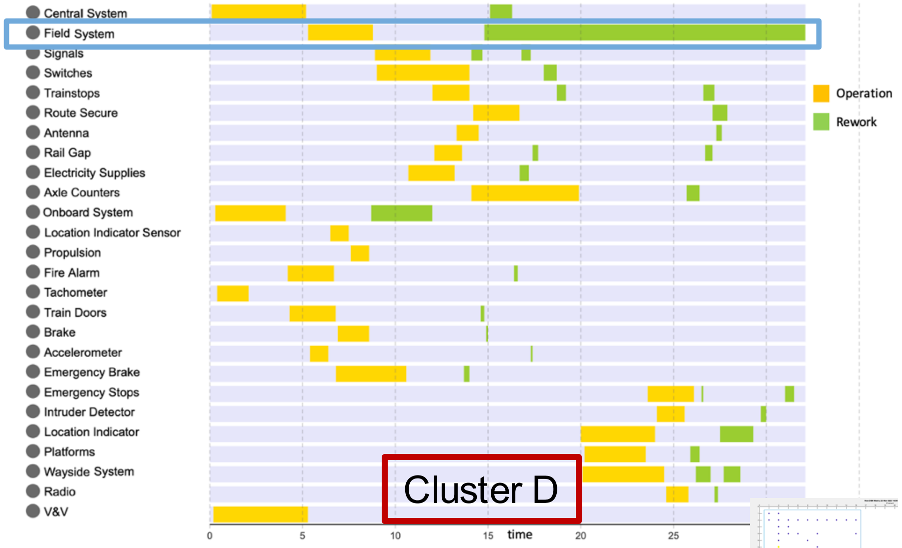
Output: The number of resources & associated skill levels which meet the goal

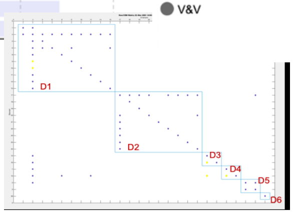
Example: Contract indicates a deadline of completing the project within 30 days, 3 senior and 1 junior designer were chosen with makespan of 29.4 days and incurs the lowest cost.

Step 2 Scheduling

WBS Efficiency Evaluation

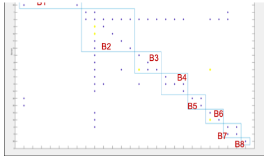
- Cluster D was selected using Fuzzy Logic Inference Model for its ease in management and low complexity score, thus lowering the rework risk
- Cluster B, C and D with the similar complexity score were compared to evaluate the efficiency of the selected WBS.





Average Makespan: 32.1 days
Average resource utilization 82.9%
Rework Impact 31%

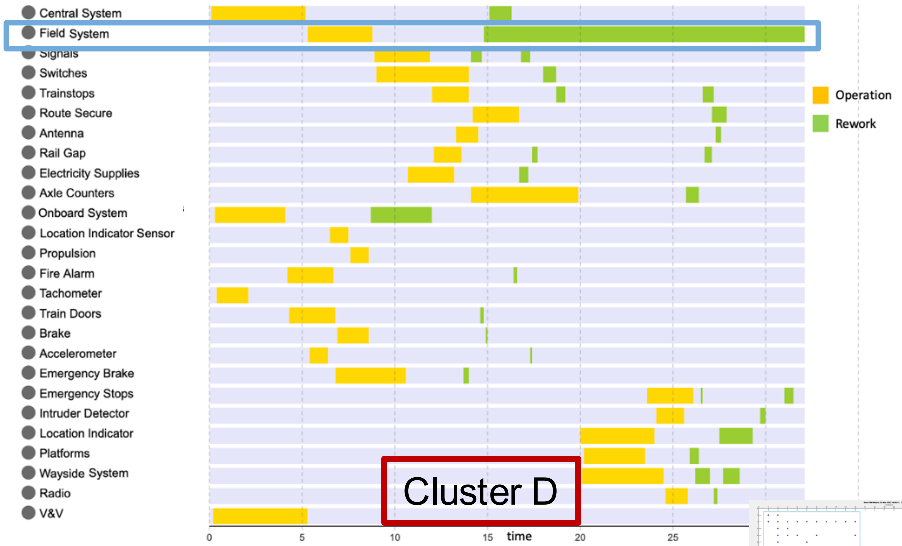
Average Makespan: 33.2 days
Average resource utilization 81.7%
Rework Impact 34%

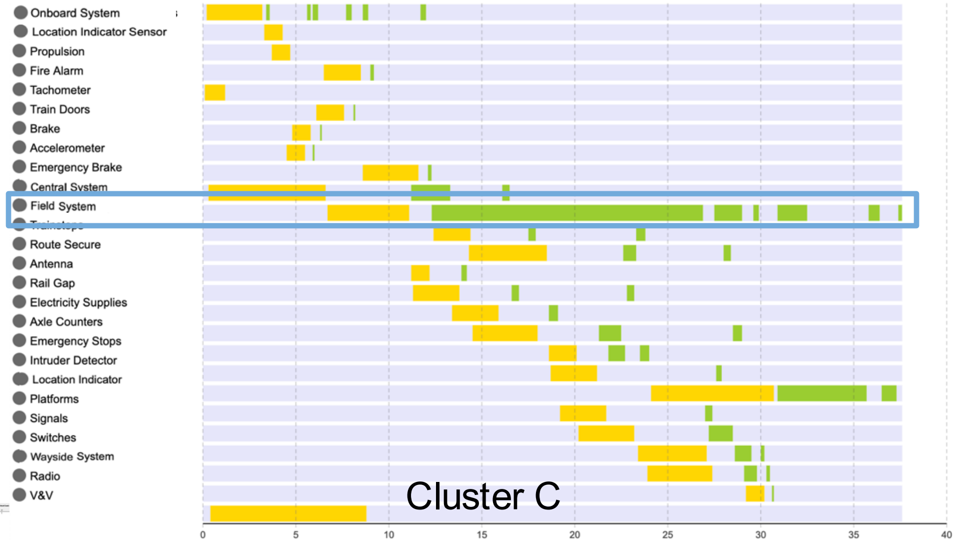


Step 2 Scheduling

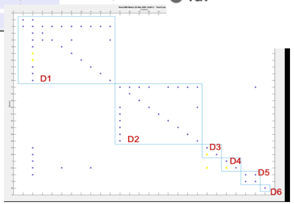
WBS Efficiency Evaluation

- Rework generated from Cluster B and Cluster C tends to be broken down into many segregated tasks, and the number of rework cycle increases due to large number of interactions between different clusters.
- Cluster D is preferred for a more efficient scheduling result

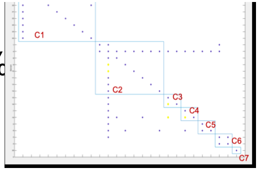




Average Makespan: 32.1 days
Average resource utilization: 82.9%
Rework Impact: 31%



Average Makespan: 37.6 days
Average resource utilization: 75.4%
Rework Impact: 36.4%



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Conclusion and Future Work

Conclusion

- A two-step simulation model is designed to generate an efficient project schedule under rework scenarios considering key elements of project planning
- Leveraging DSM, MAS simulation, and fuzzy logic inference system to overcome the challenges
- Consider rework risk directly and indirectly throughout the project planning phase

Limitation

- Not consider the specific skill sets and knowledge background of each resource, which can play a crucial role in project outcomes
- Only the internal rework initiation (i.e. feedback) is studied

Future Work

- Applying the MAS model to more complex system design projects enabling a more comprehensive test of the model's functionality on megaprojects
- Development of a more nuanced resource categorization system that considers specific skill sets in addition to experience
- External rework such as requirement change could be added

Q & A

Thank you for listening!

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