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Service Cost Estimation with Uncertainty Using Agent Based Simulation

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IMRC Innovative Manufacturing Research Centres

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Agenda

- Context: PSS-Cost project
- Introduction
- Methodology
- Service cost estimation approaches in Contracting for Availability
- Uncertainty based service cost estimation framework
- Validation
- Future work and Conclusions

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PSS-Cost Project

Aim: Improve

WLCC + Affordability for Availability contracts

In Defence and Aerospace Industries

Industrial Collaborators:

- BAE Systems
- Lockheed Martin
- GE Aviation
- Rolls-Royce
- MoD
- Galorath
- Cognition
- SBAC
- APMP

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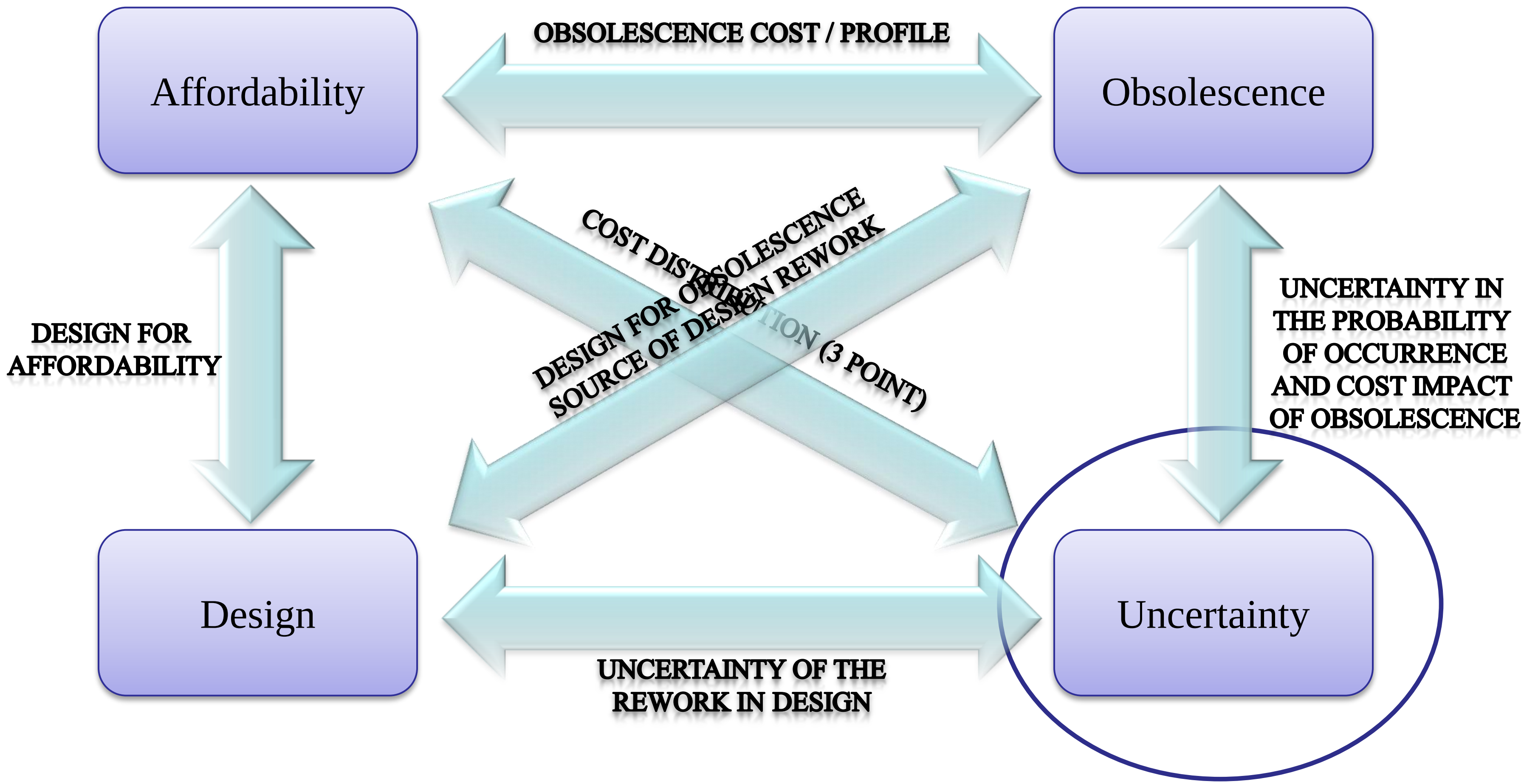
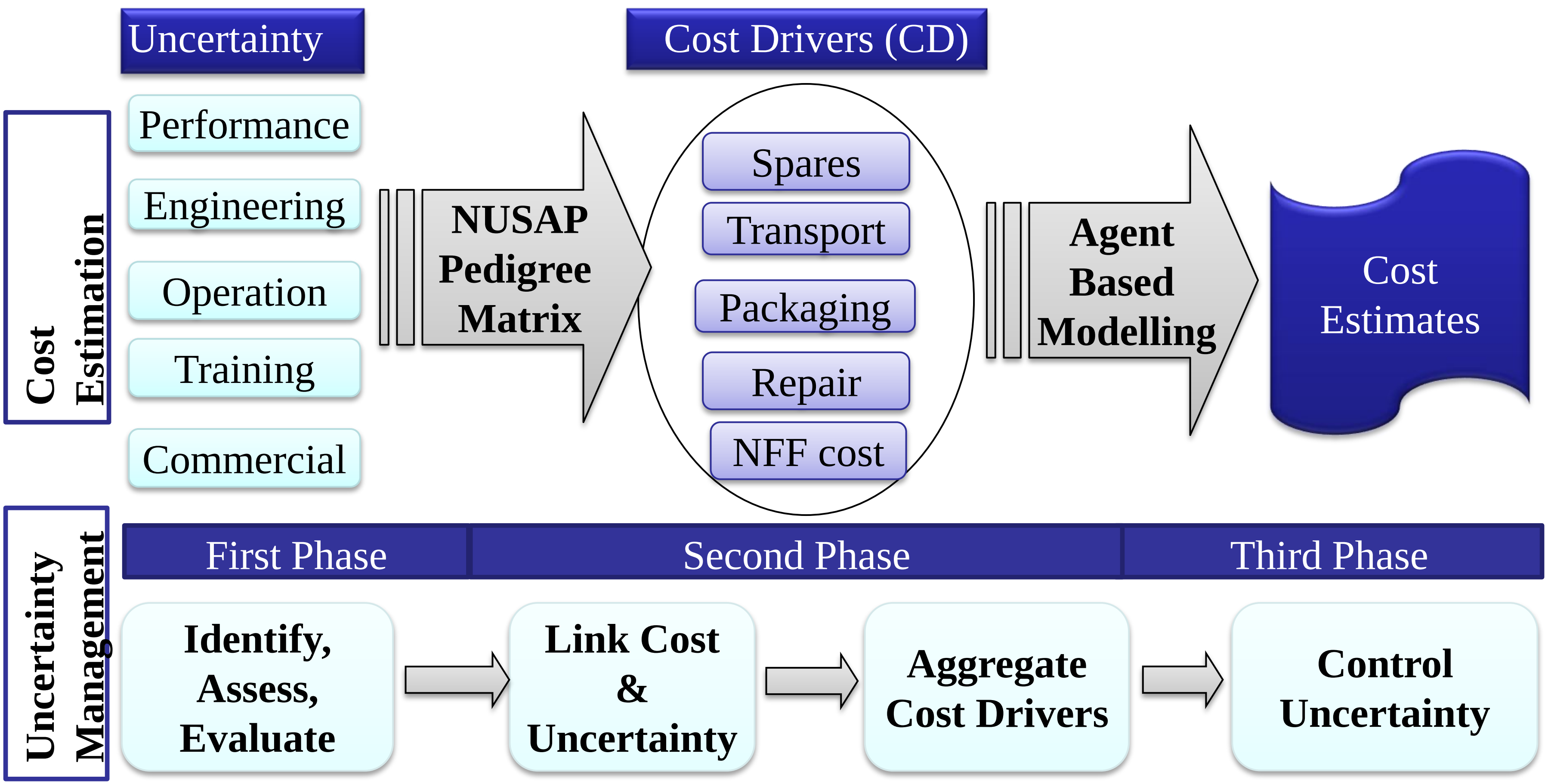
PSS-Cost Project



Cost Uncertainty Modelling: Overall Framework



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Introduction

- In manufacturing there is a shift from selling products to services (e.g. Type 45, Harrier, Total Care): Contracting for Availability (CfA)
- Solution provider receives income and incentives based on equipment availability and performance over long term contracts: increased financial burden
- The delivery of spares and resources is the most common provision of services
- As a result challenges in cost modelling, due to the need for predicting the service requirements early on (issue of uncertainty arising from dynamism)
- This paper focuses on a Target Price Performance Incentive mechanism, to represent the uncertainty in cost modelling using agent based simulation

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Introduction

- Uncertainties move away from the sale of the equipment towards its utilization in a bundled and concurrent manner
- Availability contracts require a ‘left-shift’ of the point-in-time at which uncertainties are addressed at the bidding stage

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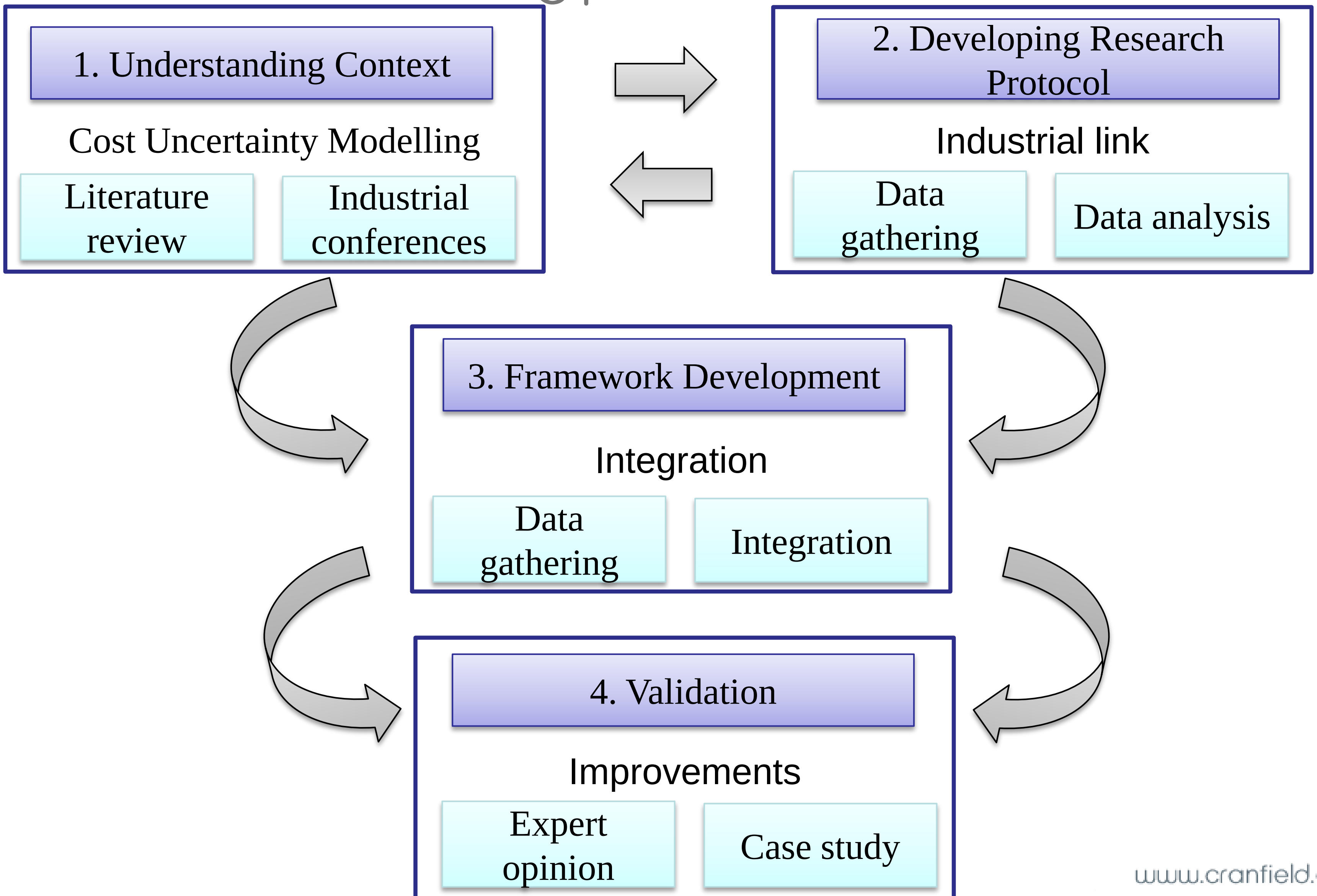
Research Methodology



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Research Methodology: Industry interaction

- Various level of interaction with three major companies and the customer in the defence and aerospace industries in the UK throughout research
- Collected information was transcribed and analysed using MindMaps.

Focus in research	Number of participants	Experience	Role(s)	Duration of interaction
Questionnaire piloting	1	Over 30 years	Engineering manager	Over 3 hours
Semi-structured interviews	Over 25	Between 5 and 35 years of experience	Cost estimators, risk and uncertainty modellers, project managers, support manager	Over 40 hours
Case studies	10	Between 20 and 30 years	Project manager, support manager	Over 20 hours
Validation	7	Between 5 and 30 years	Risk and uncertainty modeller, engineering manger	Over 15 hours

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Service Cost Estimation Approaches in CfA

- Wide selection of estimation approaches depending on (Datta and Roy, 2010):

  - Service life stage (e.g. design, delivery and adaptation)
  - Level of information available (e.g. low, medium, hi)

- Throughout bidding these aspects vary, suggesting a variation of approaches

  - e.g. early phases- expert opinion and simulation,
  - e.g. more mature phases- parametric or analogy

- Types of information required in CfA: user requirements, user budgets, supplier data, industry standards, historical data, expert opinion

Uncertainty in Cost Estimation

- Various approaches to consider uncertainty in cost estimation
- Quantitative approaches tend to have a static view of the world

Deterministic	**Qualitative**	**Quantitative (Statistical or probabilistic)**
Breakeven analysis	Risk matrix	Probability distribution
Net present value method	SWOT analysis	Simulation
PERT (Program Evaluation and Review Technique)	Brainstorming	Artificial intelligence
Sensitivity analysis	Influence diagram	Analytical techniques

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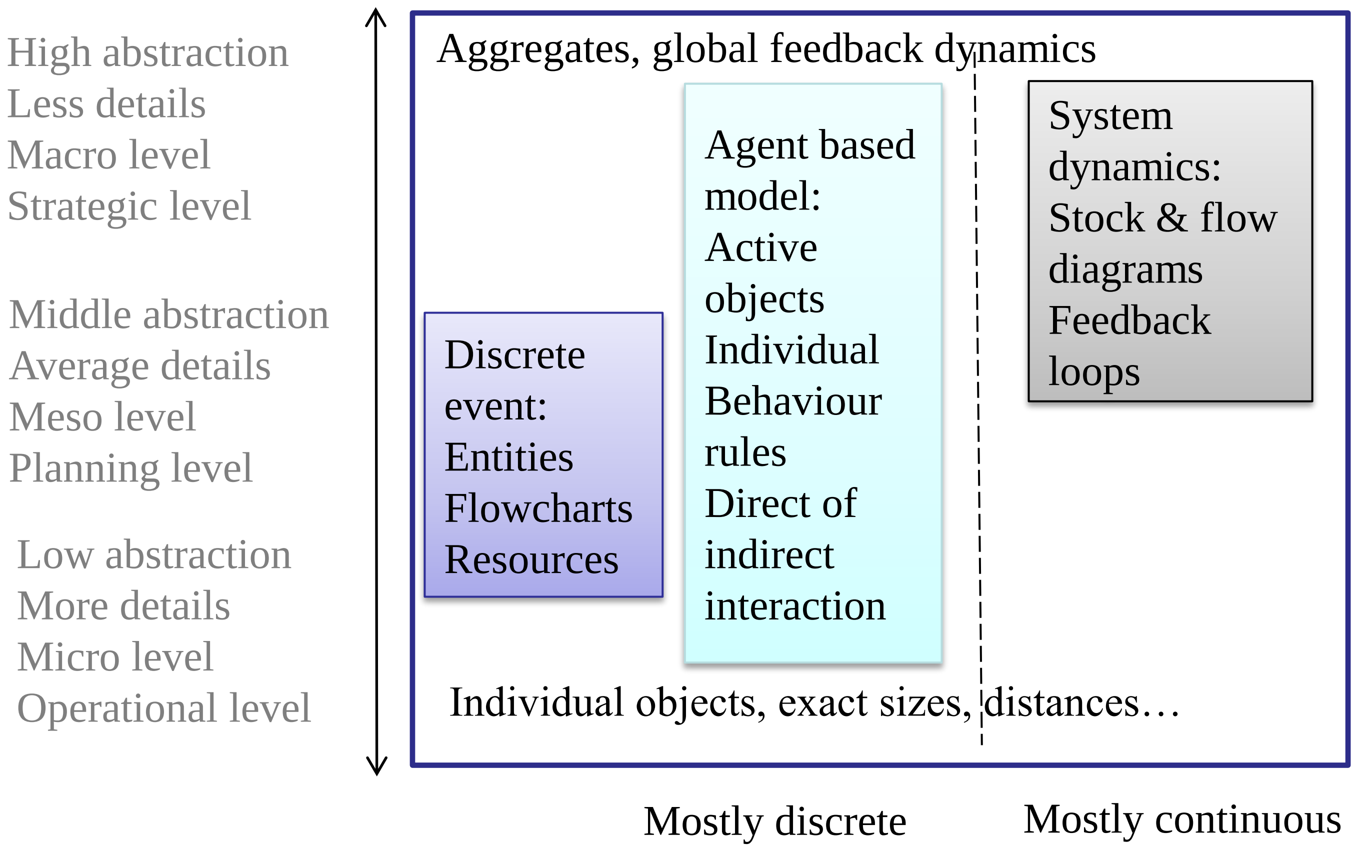
Application of Simulation Approaches

Interest growing in understanding stochastic models as opposed to static models (Buxton, 2010)



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Uncertainty Based Service Cost Estimation Framework

Phase 1

Asses cost uncertainty

- Uncertainty identification
- Cost driver identification

Phase 2

Revise cost estimate

- Cost uncertainty score and range definition
- Revise single point into three point estimate

Input to agent based model

- Estimates for classified cost drivers
- Fraction of resource and spares contribution to total cost
- Pain/gain share
- Cost uncertainty assessment to achieve three point estimates of cost drivers

Phase 3

Agent based model (ABM): cost impact of incentive mechanisms and different risk sharing approaches

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Phase 1: Assess Cost Uncertainty

- This phase involves identifying and assessing the uncertainties and cost drivers
- A typical list of uncertainties in CfA have been developed through 2 case studies (e.g. naval and air) and semi-structured interviews
- After the identification of uncertainties following provided list, the Numeral, Unit, Spread, Assessment and Pedigree approach (NUSAP Pedigree Matrix) is applied
- NUSAP is a scheme to quantify expert opinion by scoring types of uncertainties (e.g. 1, 3, 5, 7) based on three qualifiers: data availability, maturity of processes, validation
- The uncertainty scores are used to understand the uncertainty in specific cost drivers (e.g. uncertainties: customer misuse, labour availability, etc. =a cost driver: turnaround time)

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Phase 1. Assess Cost Uncertainty

Uncertainty Identification ①

Commercial: (e.g. customer misuse, labour availability)

Affordability: (e.g. customer ability to spend, whole life cost, equipment)

Performance: (e.g. key performance indicators)

Training: (e.g. trainee skill level, delays in training, trainer availability)

Operation: (e.g. complexity of equipment, quality of components)

Engineering: (e.g. capability upgrades, rate of rework, software failure rate)

Uncertainty Assessment ②

NUSAP Pedigree Matrix
Basis of estimate: data
Rigour in assessment: approach
Level of validation: validation

Cost Driver Selection ③

Failure rate, turnaround time, LRU cost, transport cost, packaging cost, repair cost, demand rate (spares), storage, emergent work, GFX supply, material availability, labour availability, customer estimate demand usage, customer actual usage, no fault found cost, beyond economical repair cost, number of students, number of trainers, facilities for training

Phase 2. Revise Cost Estimate

- In this phase three point estimates established from single point estimates
- The uncertainty score for each cost driver is used to apply a cost range to be used in the simulation
- The analytical hierarchy process (AHP) is used to define the cost significance of each cost driver
- AHP applies a pair wise comparison of the alternatives (Saaty, 2006)

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Phase 2. Revise Cost Estimate

Pre-defined guidelines from AACE (2003) have been adopted to define a range for each cost driver to reflect the influence of uncertainty

Estimate class	Level of project definition	Methodology	Lower uncertainty value	Upper uncertainty value	Range-Minimum	Range-Maximum
Class 1	50% to 100%	Deterministic	0	0.3	-10	15
Class 2	30% to 70%	Primarily deterministic	0.3	0.5	-15	20
Class 3	10% to 40%	Mixed but primarily stochastic	0.5	0.7	-20	30
Class 4	1% to 15 %	Primarily stochastic	0.7	0.9	-30	50
Class 5	0% to 2%	Stochastic or judgment	0.9	1	-50	100

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Phase 3: Agent Based Simulation Model

- In a Target Price Performance Incentive (TPPI) type arrangement, aims to capture the dynamic nature of cost impacts of incentive mechanisms and different risk sharing techniques
  - TPPI gives a price sufficiently stable at contract signature to allow internal MOD and Industry approvals
  - A price which changes with varying equipment usage and fixed unit prices with suppliers
  - A price which keeps risk allowances to a minimum by understanding and allocating risks as appropriate
  - Provides a financial motivation (and simple share-out mechanism) for both sides to want to work together

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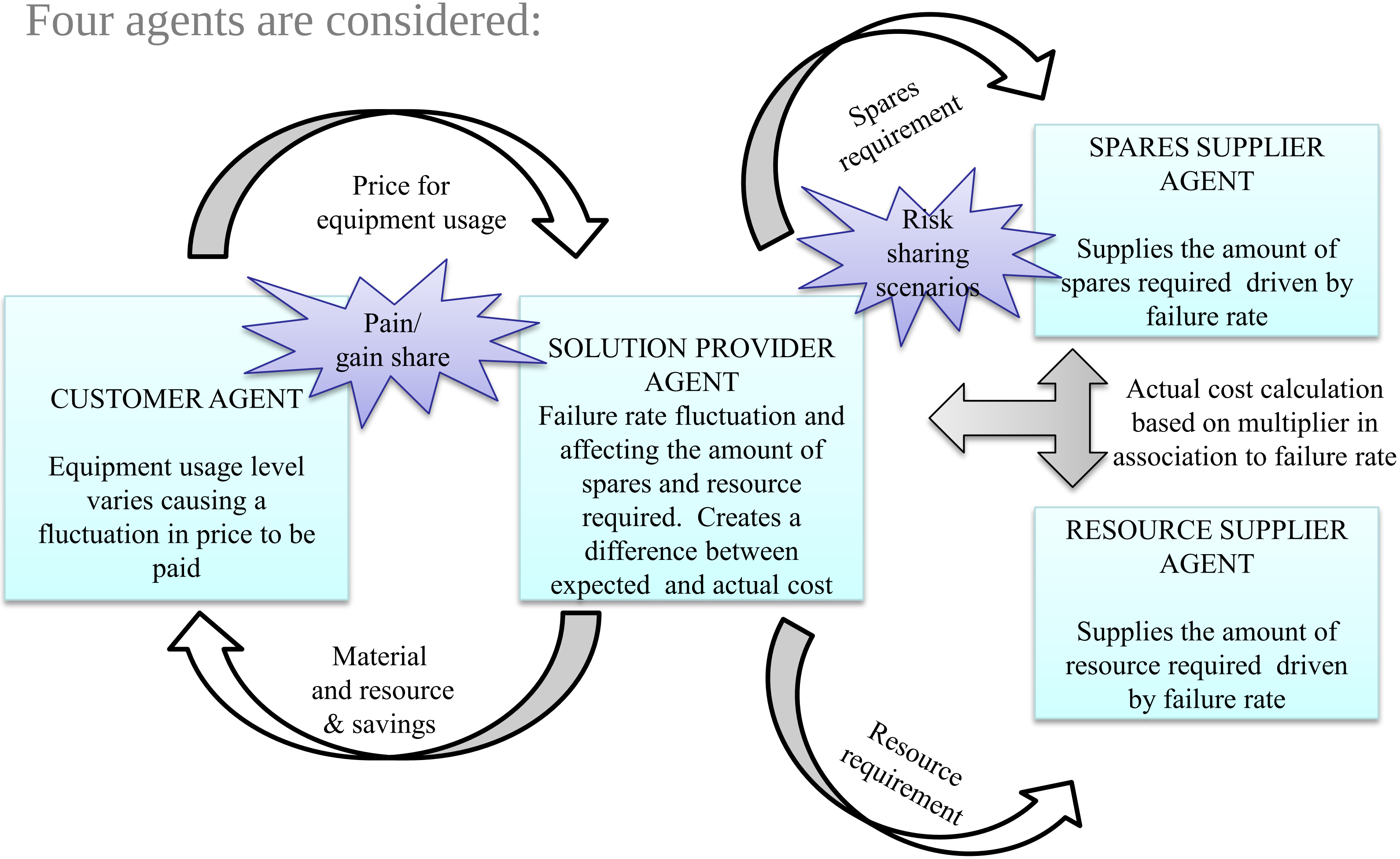
Phase 3: ABS Model Overview

- Four agents are considered:



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Phase 3: ABS Model Overview

- OEM and customer agrees a fixed price of which a certain fraction is assigned for spares and resource and that can be input by the user depending on actual figures
- These portions of total contract cost are the actual cost quoted by the suppliers to the OEM
- Every year the OEM gets a notification of actual parts to be repaired for maintaining the set amount of equipment usage
- This is stochastic and based on that, if the spares or repairs requirements exceeds the contracted amount the OEM first asks the supplier for this additional work

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Phase 3: ABS Model Overview

- Then the OEM evaluates the amount to be spent by calculating the TPPI adjusted payments (3 and 10% profit levels)
- For this purpose the estimate values from Phase 1 and 2 are used to compare with actual figures
- A variable "Technical Investment" is introduced which is normally kept at 10 to represent the number of events during a simulation run

  - If the Spare requirement rises Technical Investment should be equal to the new spare requirement multiplier

  - Based on the pain and gain share %, the customer agrees to share a fraction of that investment and rest is paid by the OEM

  - So if Spare requirement rise is 1.5, Technical Investment should be 1.5 to avoid any extra spending in procuring from supply chain and facilitating in-house repairs (e.g. more stringent inspection to avoid)

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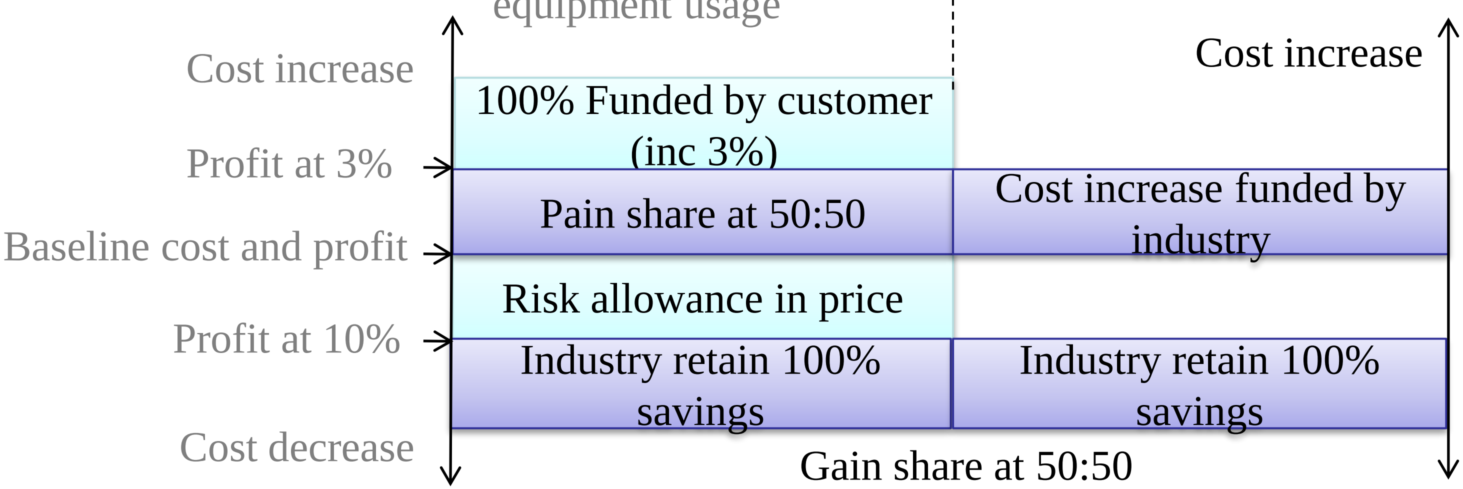
Phase 3: TPPI Mechanism

- Price and payment for variable costs is adjusted annually from baseline if projected equipment usage differ to contract assumptions
- Annual adjustment also compares baseline cost/risk against actual cost/risk spend to calculate either pain share or gain share

Variable costs
- Spares inclusive repairs
- Man power sensitive to equipment usage

Fixed costs
- Fixed management team
- Training



Phase 3: Input

- initial total cost (single point estimate)
- Pain/Gain share
- GFX labour rate
- spare cost fraction on overall support cost
- resource cost fraction on overall support cost
- OEM and spares risk sharing level (for the scenario of OEM and spares supplier share risk)
- rate of cannibalisation
- an equipment usage boundary and associated cost level
- uncertainty assessment of cost drivers using Phases 1 and 2 (embedded in an Excel based tool)

Phase 3: Uncertainties considered in the model

- equipment usage level,
- spares and resource arising,
- obsolescence,
- other (emergent work, cannibalisation etc.)
- stock capacity at the OEM,
- technical investment that arises from the incentive mechanism.

Output of the model

- Estimation over time for:

  - comparison of costs across systems/subsystems,
  - cost estimates for the OEM and integrating the influence of uncertainty,
  - uncertainty implications for specific cost drivers that are represented in the Excel based model

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Phase 3: Assumptions

- The customer and OEM have TPPI (Target price performance incentive) arrangement between them
- The spare consumption rate is assumed to be stochastic and expressed by a probability distribution attaining values from 1 onwards
- It is assumed that spare consumption rate is independent of equipment usage and may increase even if equipment usage reduces due to other reasons.
- A certain amount of technical investment is necessary to reduce spare-repair costs both in case of supplier and OEM

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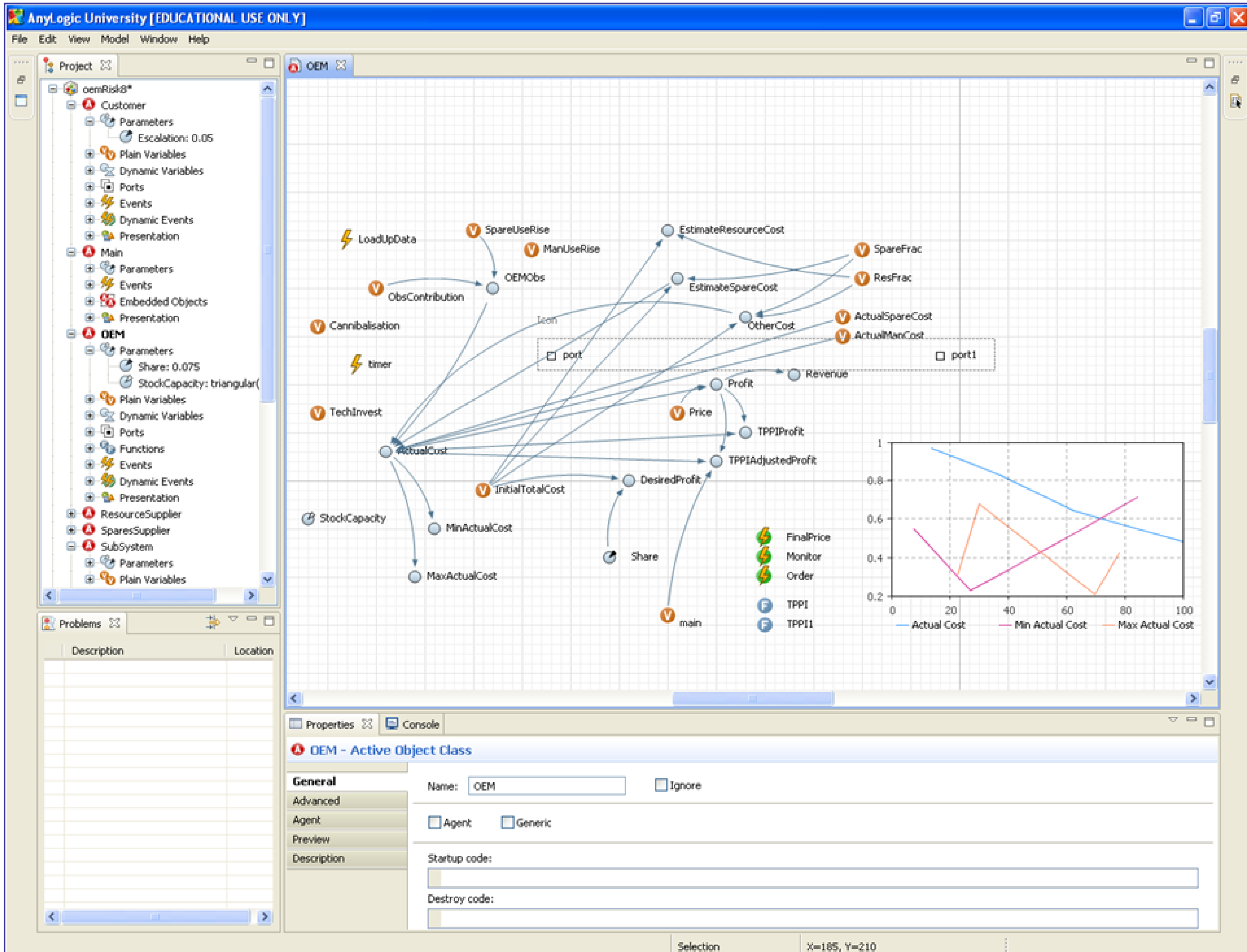
Phase 3: Implementation

- AnyLogic
- Java programming



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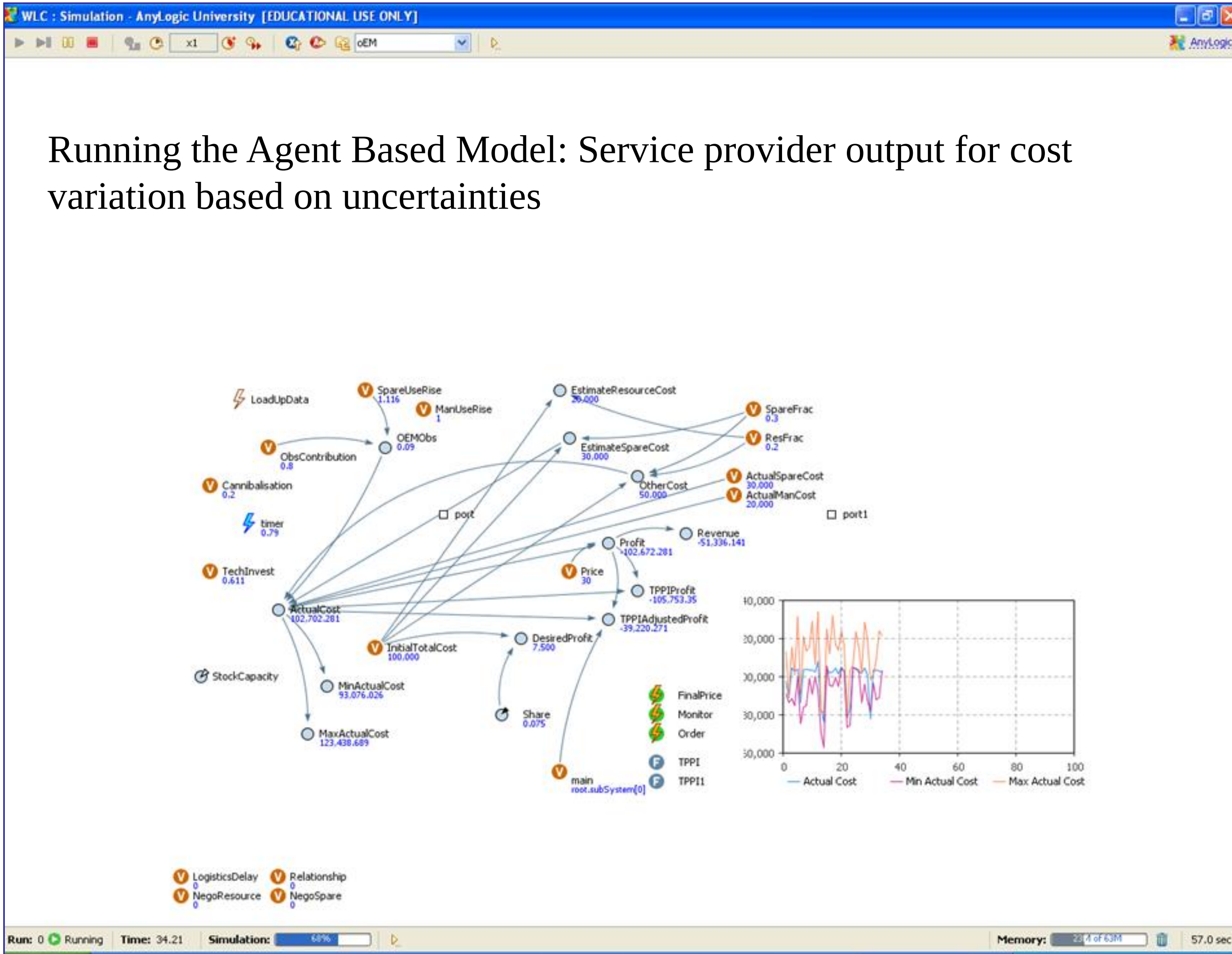
Phase 3: Implementation

- Dynamic interplay is visualised



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Communication between agents

Customer and OEM

Expected equipment usage = 20,000 hours;
Cost= £10,000;

If equipment usage raises to 25,000 hours then the cost to customer is £12,500
If equipment usage reduces to 15,000 hours then the cost to customer is £7,500

OEM and resource supplier

If the multiplier for the resource arising is different to 1 then the initial estimate cost is multiplied to calculate the actual cost

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Communication between agents

OEM and Spares suppliers

If there is no difference between actual cost and initial total cost then technical investment does not change

If the rate of cannibalisation is higher than the spares arising rate then a negotiation occurs between these agents based on the technical investment rate

Else

If Spares arising rate is higher than cannibalisation rate then the technical investment is equal to (1-Pain/gain share)

The multiplication of the spares arising with initial total cost estimate gives the actual cost

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Validation: Expert Opinion

- Validation involved expert opinion and a pilot case study
- Four expert opinion with varying backgrounds and level of experience

	Experience	Role	Comments
Expert 1	20 years	Project manager	maintenance events for the early stages represented realistically
Expert 2	25 years	Maintenance cost modeller	the approach was suggested to be a useful way forward to model maintenance costs
Expert 3	30 years	Life cycle costing	the ability visualise changes in costs was suggested to be beneficial
Expert 4	5 years	Risk and uncertainty modelling	the framework is an integrated approach useful for the early stages of bidding

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Validation: Case Study

- The pilot case study is in the naval domain involving over 60 sub-systems of which only a minority are manufactured in-house
- Currently engaging with the customer to establish the maintenance requirements; three experts participated
- Three scenarios considered based on OEM contribution to sharing uncertainty with spares supplier (0,1, 0,5, 0,7)

Input to the model					
Initial total cost	GFX Labour	Cannibalisation	Pain/gain share	Spares cost fraction	Resource cost fraction
£10,000	0,8	0,1	0,3	0,45	0,35
Cost drivers: failure rate (£430,48), turnaround time (£207,32), LRU cost (£131,53), transport (£1458,08), packaging (£184,05), repair (£170,0), demand rate-spare (£436,56), storage (£430, 58), emergent work (£430,58), GFX supply (£410,95), material availability (£826,34), labour availability (£1643,21), customer demand usage (£92,70), customer actual usage (£207,32), NFF cost (£430,58), BER cost (£933,14), number of students (£863,87), number of trainers (£282,24), facilities for training (£430,58)					

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Validation: Case study

- A comparison of cost and uncertainty across the scenarios, while also able to change the input for cost drivers
- 100 runs were conducted in the simulation

	Scenario 1	Scenario 2	Scenario 3
OEM Share in sharing uncertainty with spares supplier	0.1	0.5	0.7
Mean	11,170.30	11,268.43	11,293.78
Standard deviation	720.374	685.101	594.207
Lower cost limit at 95% confidence	97,29.59	98,98.23	10,105.37
Upper cost limit at 95% confidence	12,611.12	12,638.63	12,482.24

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Validation: Case Study Outcomes and Limitations

Goal of case study: assess the suitability of the ABM framework in terms of comparing different scenarios for the early phases of the bidding stage where there is a lack of information

- Large uncertainty in cost estimates due to limited information at bidding

	Limitations	Outcomes
Expert 1	suits only the early stages of bidding	Comparison of costs for scenarios for specified periods
Expert 2	Requires a more sophisticated view of the supply chain (e.g. Cost effectiveness, quality, relationship)	Intelligent management of the influence of uncertainty over cost early on
Expert 3	Needs to understand the influence of uncertainties other than ‘failure rate’ on cost drivers	Helpful to understand the relation between performance requirement and cost

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Future work

The application of ABM will need to focus on the current issues in cost estimation

- The need for improving the prediction of uncertainties such as failure rates (mean time between failure), repair time (mean time to repair), etc over cost estimates
- Difficulties that derive from the lack of useful data and poor timeliness of its availability. This particularly enhances the importance of expert opinion
- Limited time that is available to build uncertainty based cost estimates
- Service delivery particularly depends on the service supply chain, where challenges arise from lack of homogeneity across suppliers (e.g. cost effectiveness, timeliness)
- Difficulties in systematic representation of uncertainty driven by the be-spoke nature of offerings.

Conclusions

- A systematic framework has been presented to integrate uncertainty to service cost estimation, which suits the early bidding stage of CfA within the context of a TPPI arrangement
- The framework combines applications in Excel and AnyLogic
- The Agent Based Simulation helps to visualise the cost impact of incentives across the supply chain
- The developed framework has been validated through expert opinion and a pilot case study

THANK YOU & ANY QUESTIONS??

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