INCOSE
Healthcare
Working Group

5th Annual Systems Engineering in Healthcare Conference

May 1-2, 2019
Minneapolis, MN

Performing Trade-Off Analysis within an MBSE Environment

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- MBSE Specialist

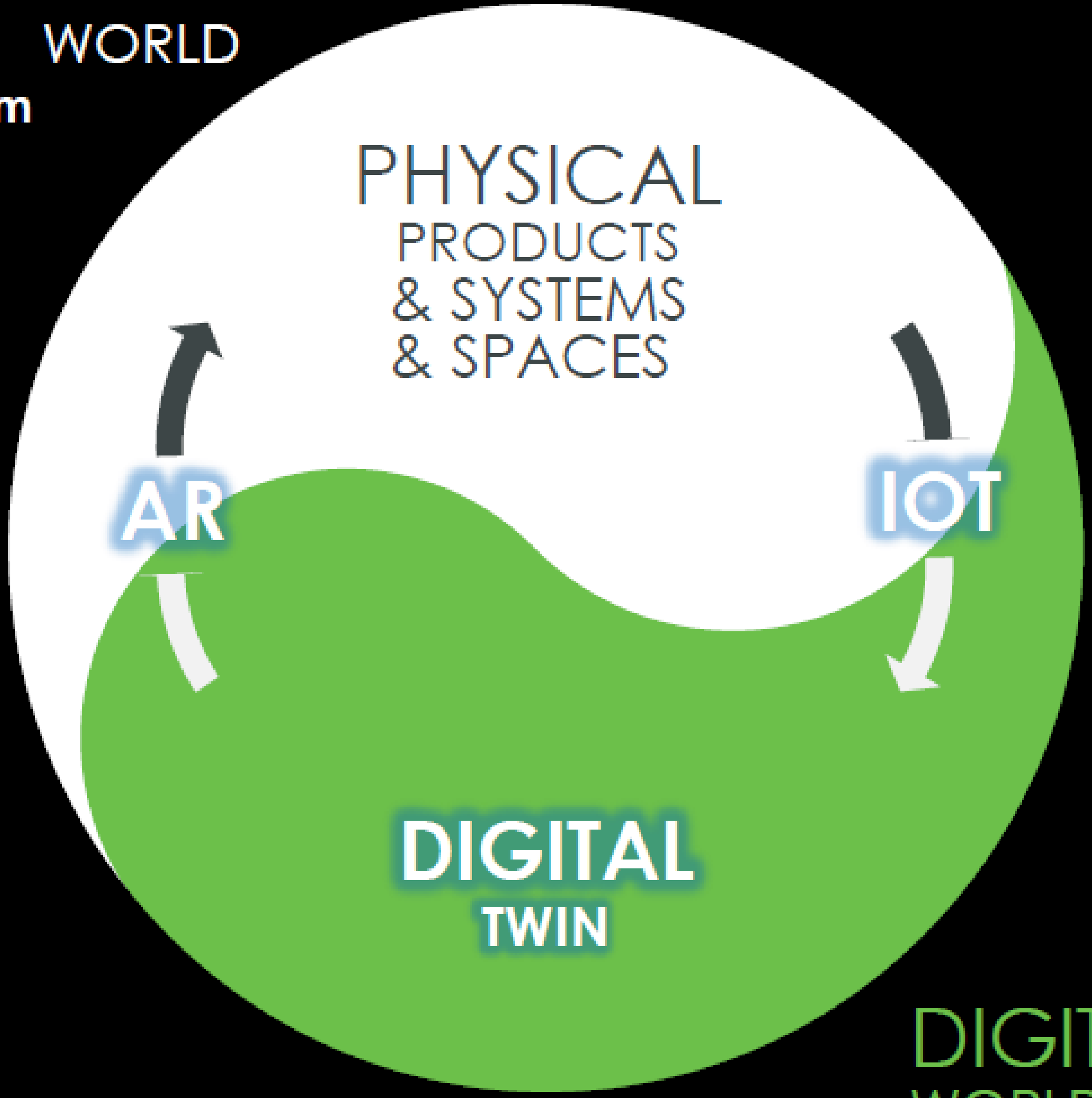
ptc

PHYSICAL
WORLD

Industrial Innovation Platform

>$100M Revenue
> 50% Bookings Growth FY16
1,200 End Customers
250 OEMs/Resellers
Ecosystem of SI's, partners

IoT & ANALYTICS | thingworx
AUGMENTED REALITY | vuforia
INDUSTRIAL CONNECTIVITY | kepware



PLM Solutions

>$1B Revenue
10% Bookings Growth FY16
28,000 End Customers
70% Direct Sales
30% VARs (~400)
Ecosystem of SI's, partners

CAD | creo
PLM | windchill
ALM | integrity
SLM | servigistics

DIGITAL
WORLD

AGENDA

- Trade-off Analysis
- Electric Quarry
- Parametrics
- Simulation
- Statistical Analysis

WHAT IS TRADE-OFF ANALYSIS?

- A trade-off study consists of "comparing the characteristics of each system element and of each candidate system architecture to determine the solution that best globally balances the assessment criteria. The various characteristics analyzed are gathered in cost analysis, technical risks analysis, and effectiveness analysis." (NASA 2007).
- Trade-off analysis is the set of techniques by which the "Best" solution is found for the customer weighing up cost, risk, effectiveness and other parameters. The weighting or importance of these parameters depends on the system goals and priorities, which are derived from stakeholder needs, which are gathered from stake-holders.
- As always good system solutions are derived from good systems engineering.

THE PROBLEM: CONVERTING A QUARRY TO ELECTRIC

27th annual INCOSE international symposium

Adelaide, Australia
July 15 - 20, 2017

Volvo Construction Equipment

From Empire Strikes Back to Electric Site

An industrial example of using Enterprise Architecture to speed up systems development

Peter Sjöberg
Volvo Construction Equipment

Lars-Olof Kihlström
Syntell AB
Matthew Hause
PTC

www.incose.org/symp2017

ELECTRIC SITE, BACKGROUND

PROJECT GOAL

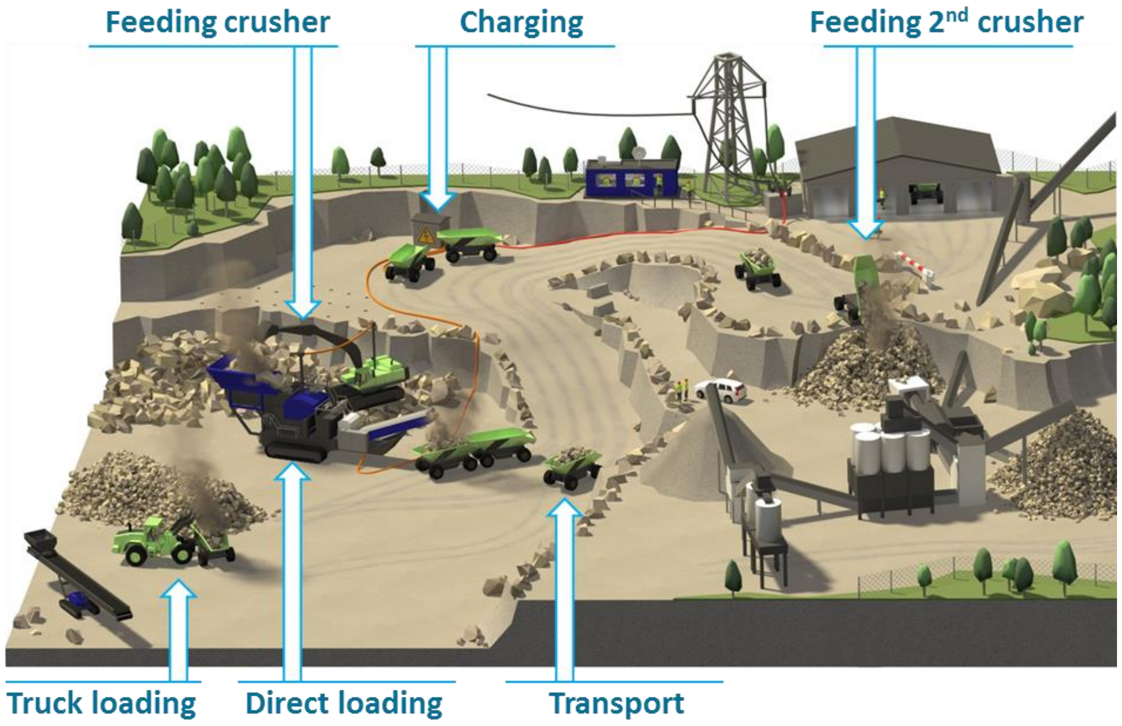
- The aim is to reduce CO_2 95% and the total cost of operation by 25%.
- Possible solutions:
  - Increase efficiency
  - Electrification
  - Hybrid

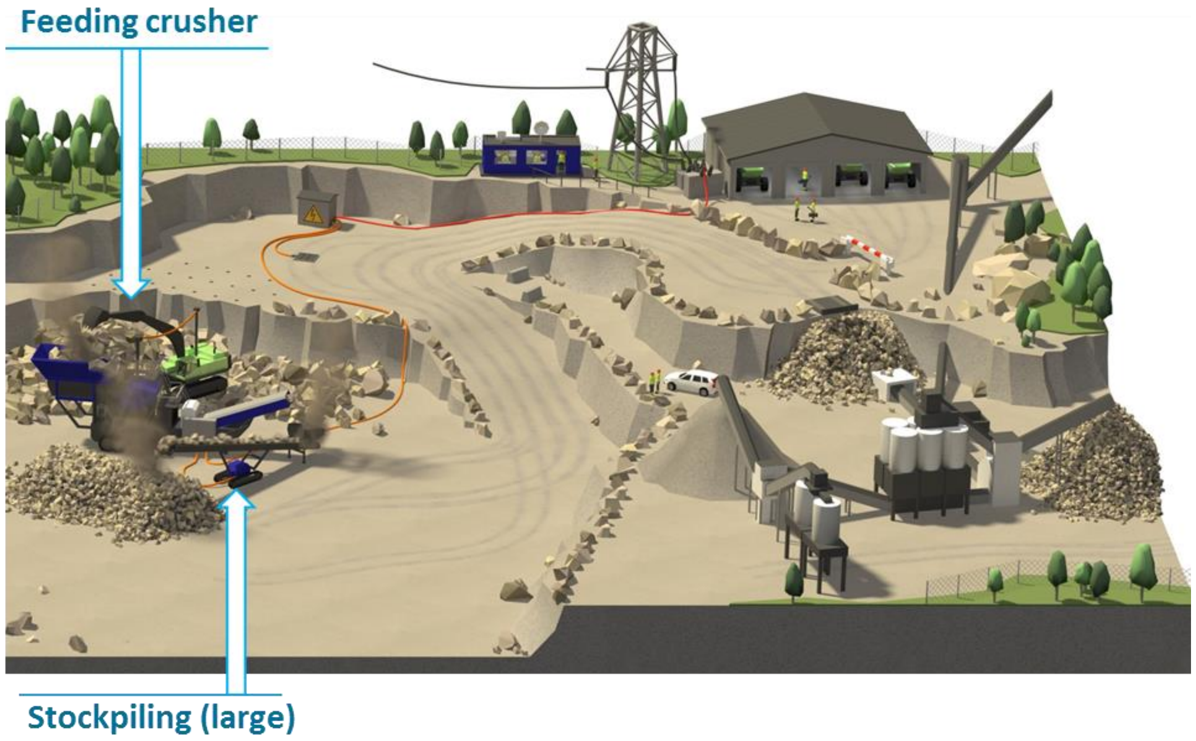
POSSIBLE SOLUTIONS

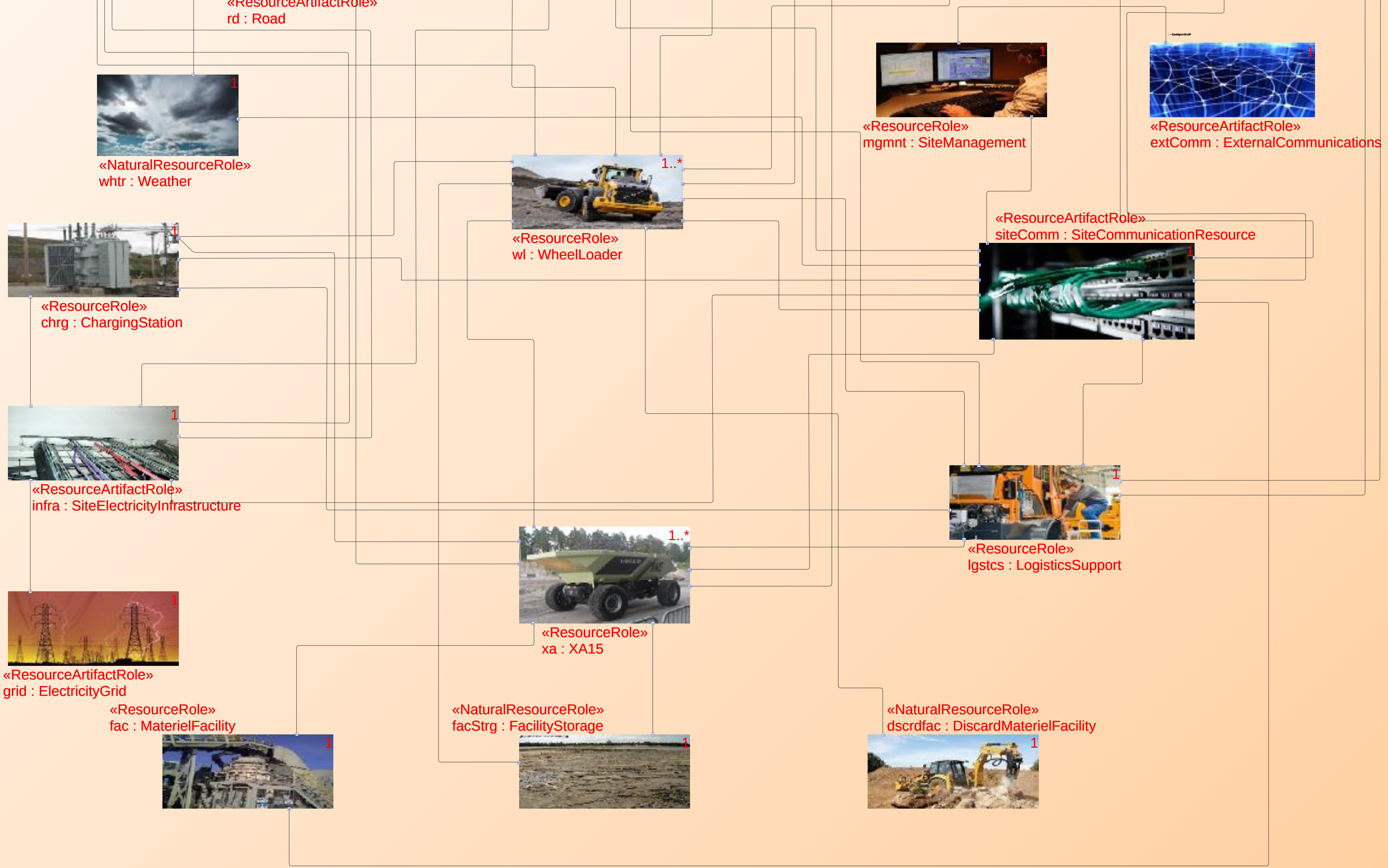
- Replace diesel engines with electric engines and batteries
  - Requires a battery package of 15 tons for a 50-ton truck.

- Make the haulers smaller, (15 tons) and have more machines to reach the productivity target.
  - More suitable given the battery performance of today and regarding the robustness of the total solution. It also scales better.
  - However, going from 2 to approximately 6 machines increases the workforce cost for the operation.
  - Requires the haulers to be autonomous. The need for the wheel loader to be able to perform several different tasks that change from shift to shift will not make a pure autonomous electric solution suitable.

ELECTRIC SITE, FALL 2018







«ResourceArtifactRole»
rd : Road
«NaturalResourceRole»
whtr : Weather
1
«ResourceRole»
mgmnt : SiteManagement
1
«ResourceArtifactRole»
extComm : ExternalCommunications
1
«ResourceRole»
wl : WheelLoader
1..*
«ResourceRole»
chrg : ChargingStation
1
«ResourceArtifactRole»
siteComm : SiteCommunicationResource
1
«ResourceArtifactRole»
infra : SiteElectricityInfrastructure
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«ResourceRole»
lgstcs : LogisticsSupport
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«ResourceRole»
xa : XA15
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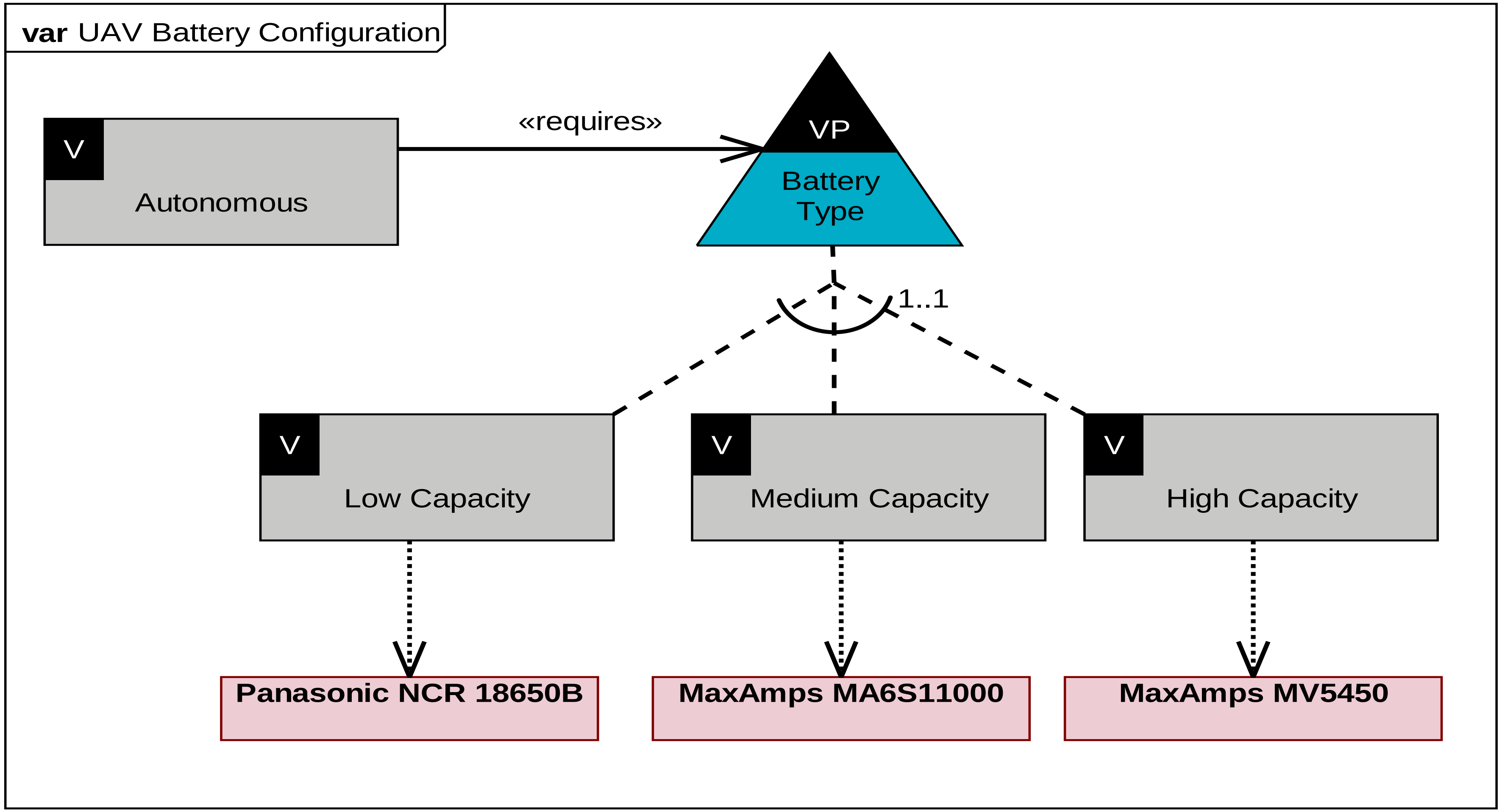
«ResourceArtifactRole»
grid : ElectricityGrid
1
«ResourceRole»
fac : MaterielFacility
1
«NaturalResourceRole»
facStrg : FacilityStorage
1
«NaturalResourceRole»
dscrdfac : DiscardMaterielFacility
1

ANALYSIS GOALS

- The initial configuration is complete
- Now trade-off analysis needs to be done
  - Battery size for transporters
  - Maximum capacity of the quarry
  - Total number of transporters
  - Total time between charges
  - Total cost of operations
  - Efficiency gained
  - CO_2 Emissions
  - Etc.

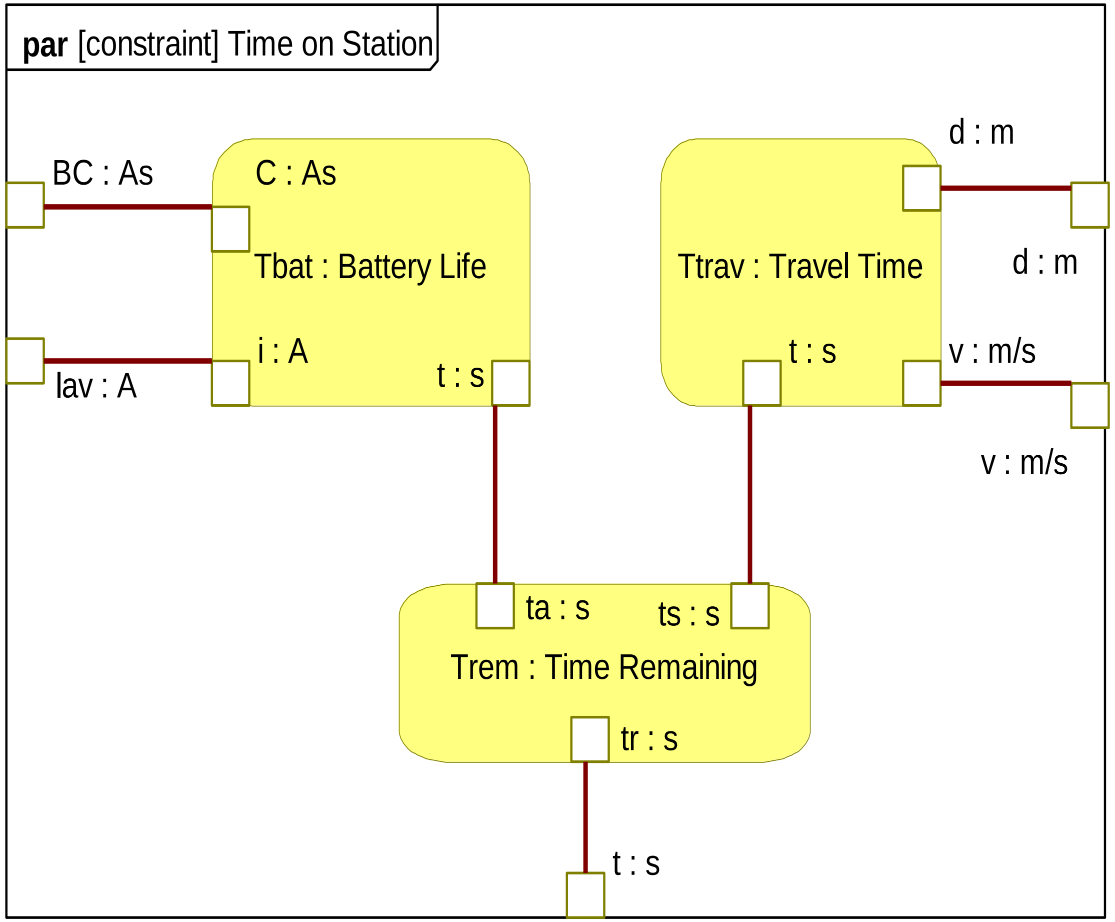
BATTERY CONFIGURATION

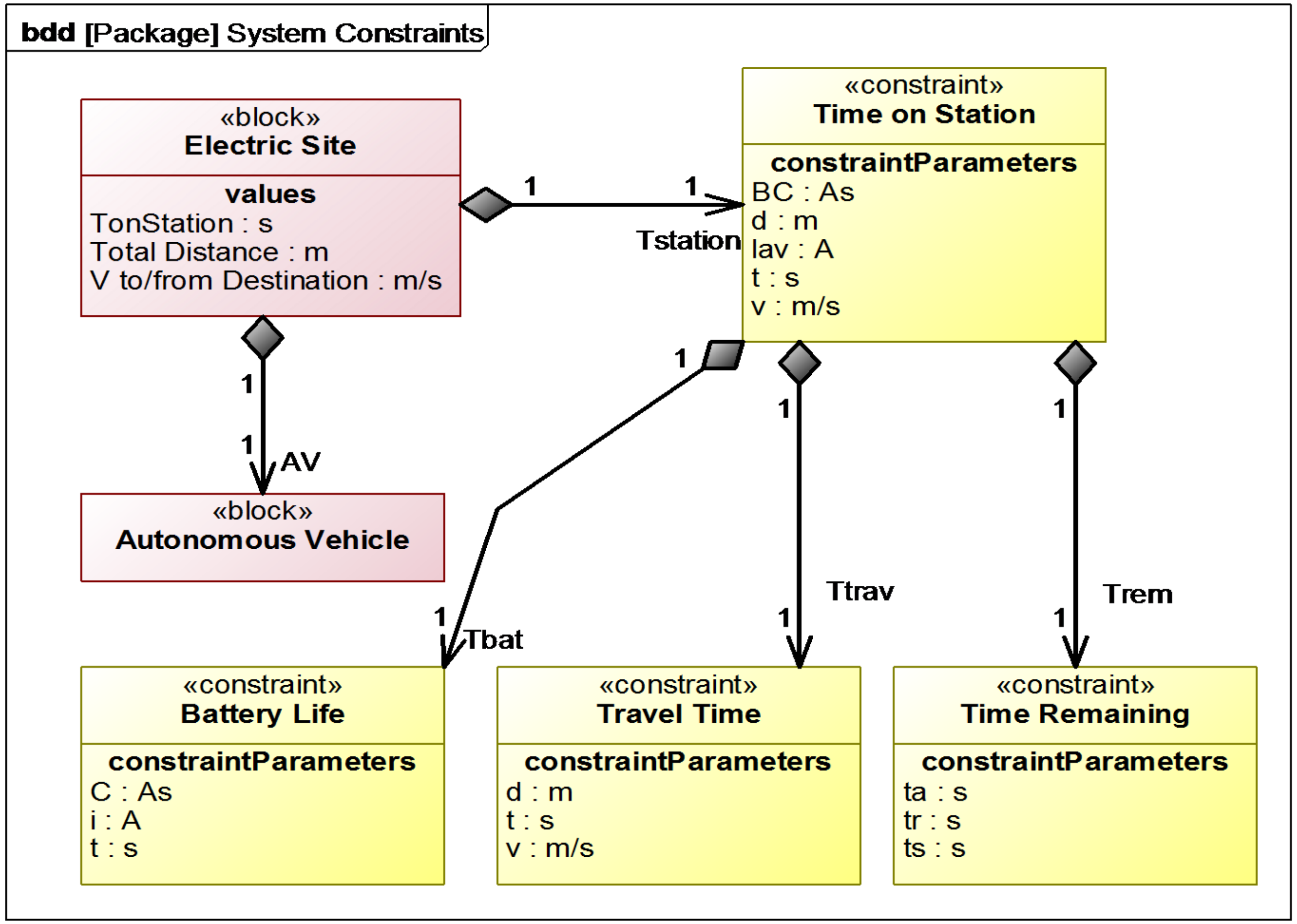
- Variability used to define choices of battery type



PARAMETRIC EQUATIONS FOR BATTERY LIFE

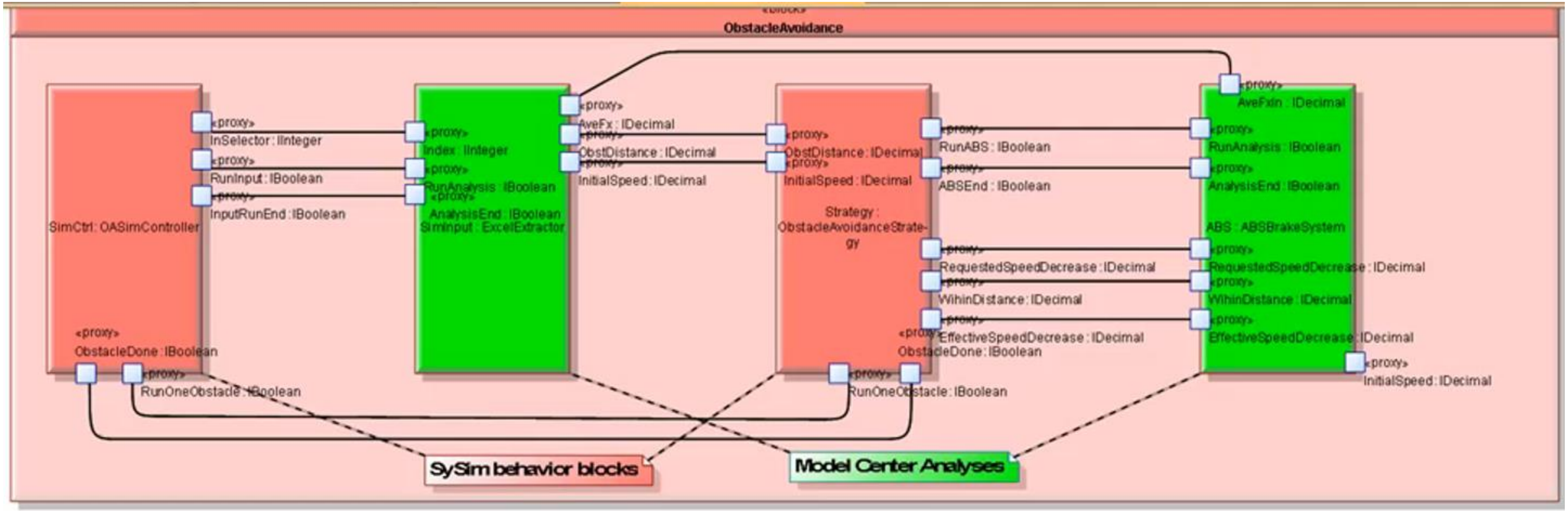
- Parametric equations runs with different values to determine total distance/load vs. battery size and cost. Used in simulations



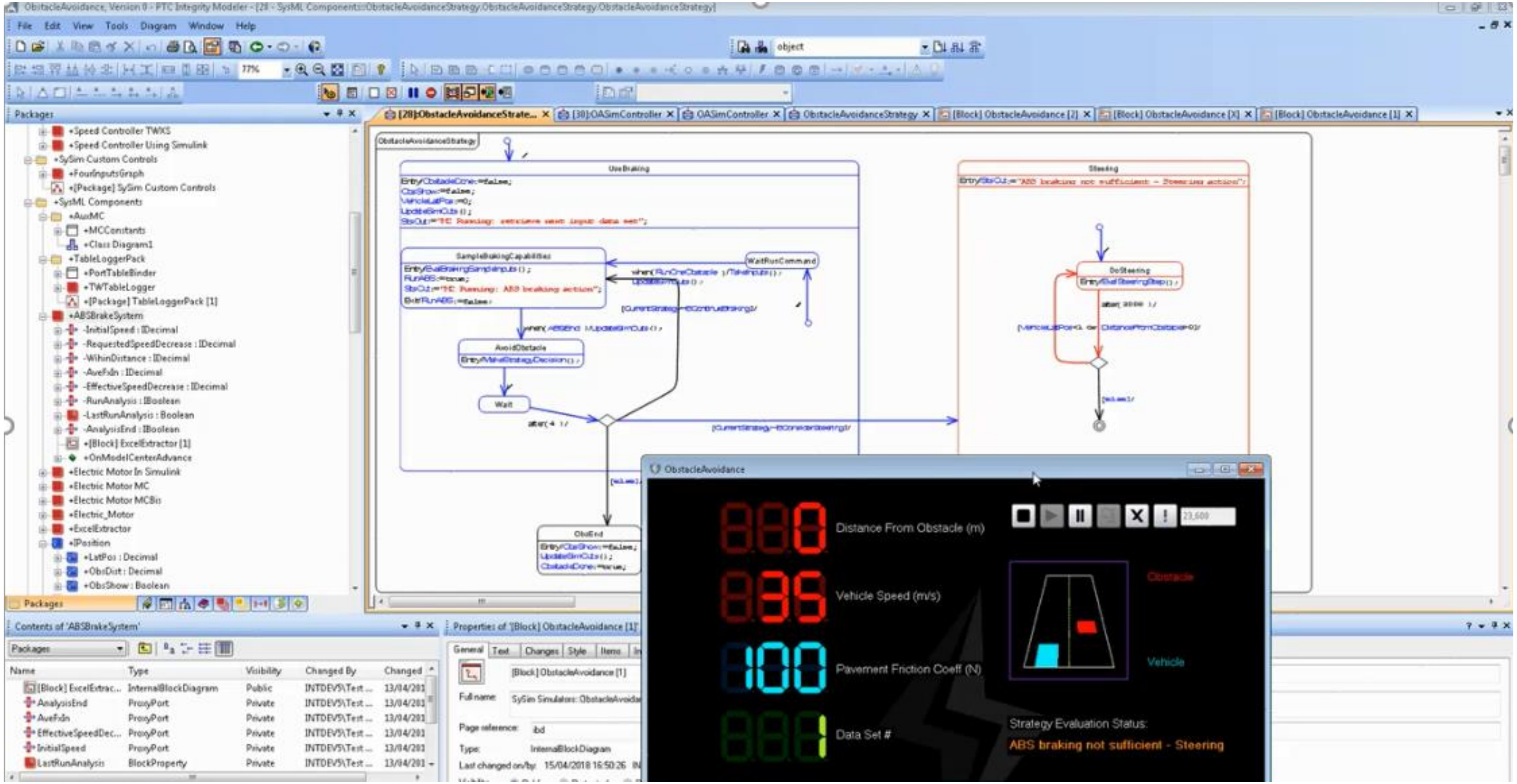


SIMULATION OF COLLISION AVOIDANCE FOR TRANSPORT

- Definition of Model behavior
- Definition of UI, Scenarios

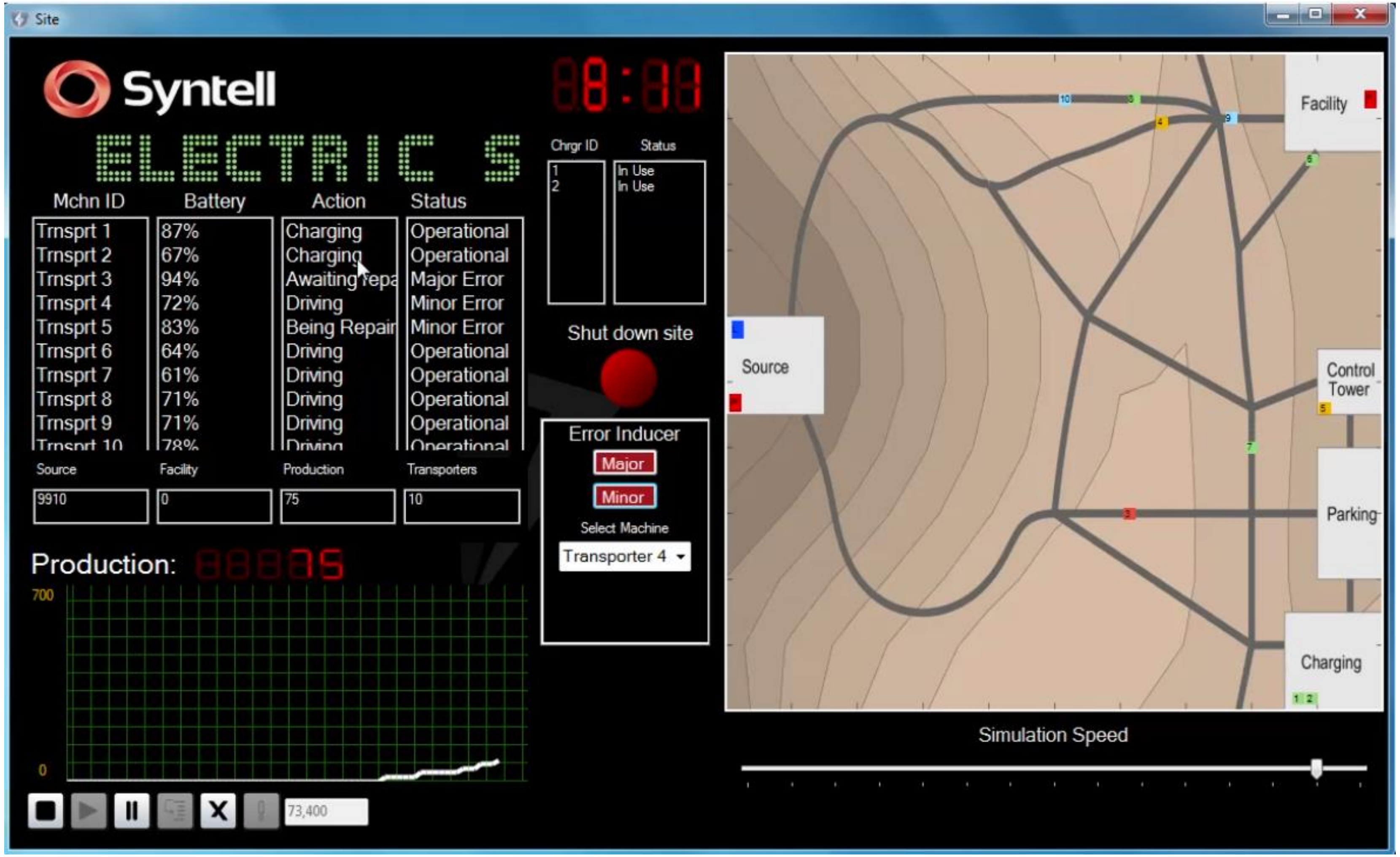


SIMULATION OF COLLISION AVOIDANCE FOR TRANSPORT (2)



SIMULATION OF THE ELECTRIC QUARRY ENTERPRISE

- Chen, Karlsson (2018).



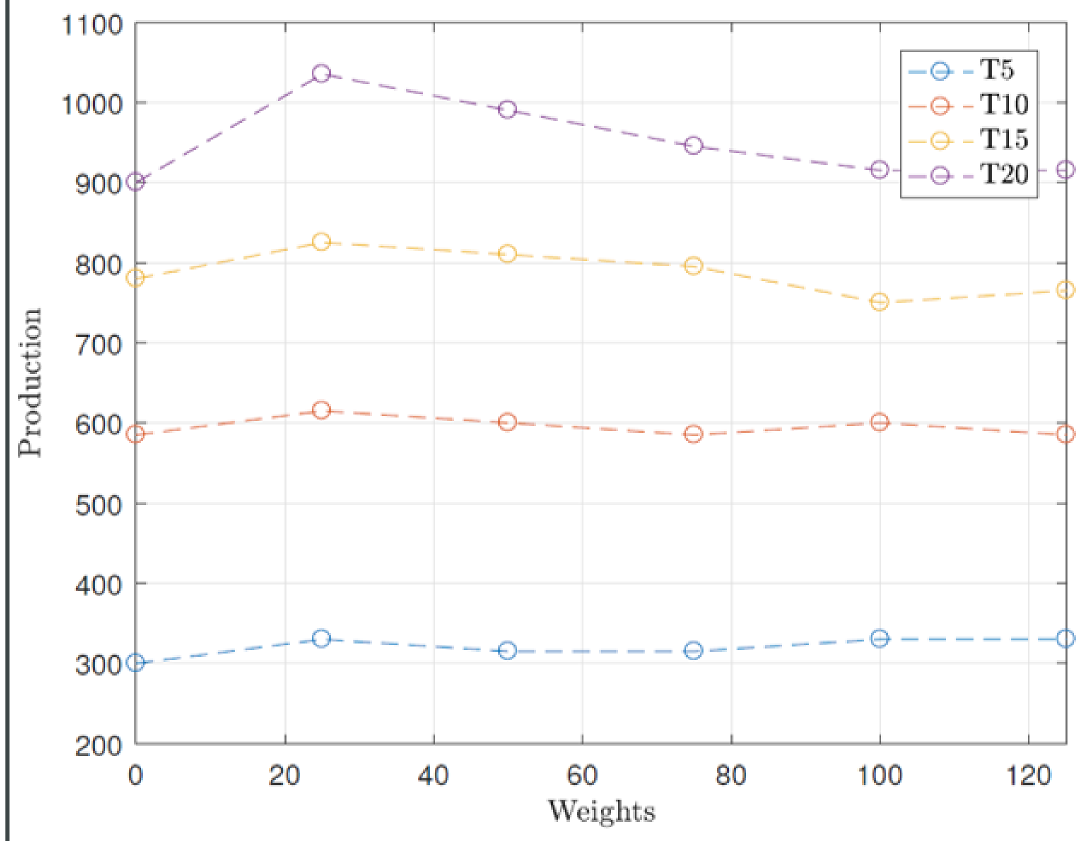
SIMULATION PARAMETERS

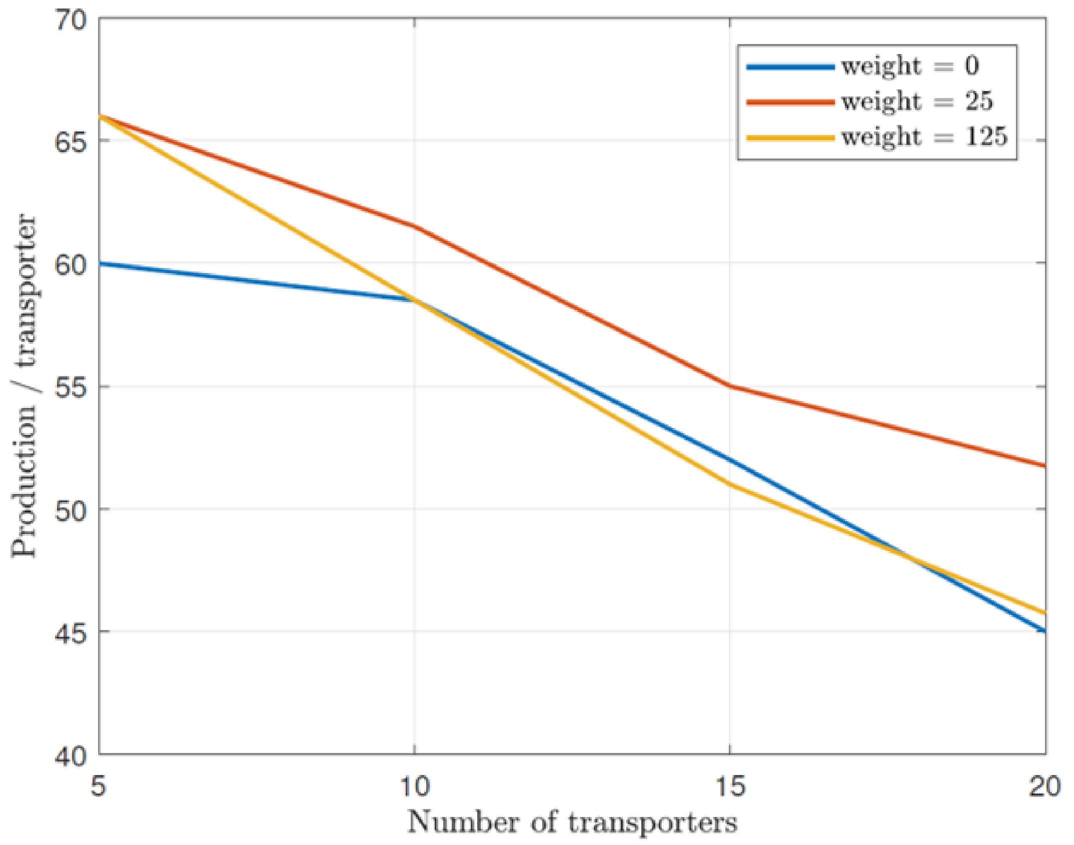
- Scenarios varied parameters, including the layout of the area, number of haulers, charging stations and more.
  - Allows the user to identify and test which ones to modify to maximize the site performance and avoid bad investments.
  - Number of haulers and chargers, the size of the batteries, etc. vs. production capabilities.
- Error inducing functionality which can target any hauler during the simulation to replicate a breakdown scenario. This can further be used for spare parts optimization.
- Trade-off analysis comparing a large hauler fleet contrast to having a few haulers on standby from a profitability perspective.
- Includes a scheduling algorithm to reduce traffic congestions while still attempting to minimize travel distance.
- Production greatly affected depending on how the site is configured and on the weight of the traffic in the optimization,
- The trade-off between traffic reduction and minimizing travel distance became the most apparent with an increased hauler fleet.

SIMULATION RESULTS

Total production value when using 5-20 transporters/haulers

Production value per transporter for 5-20 units





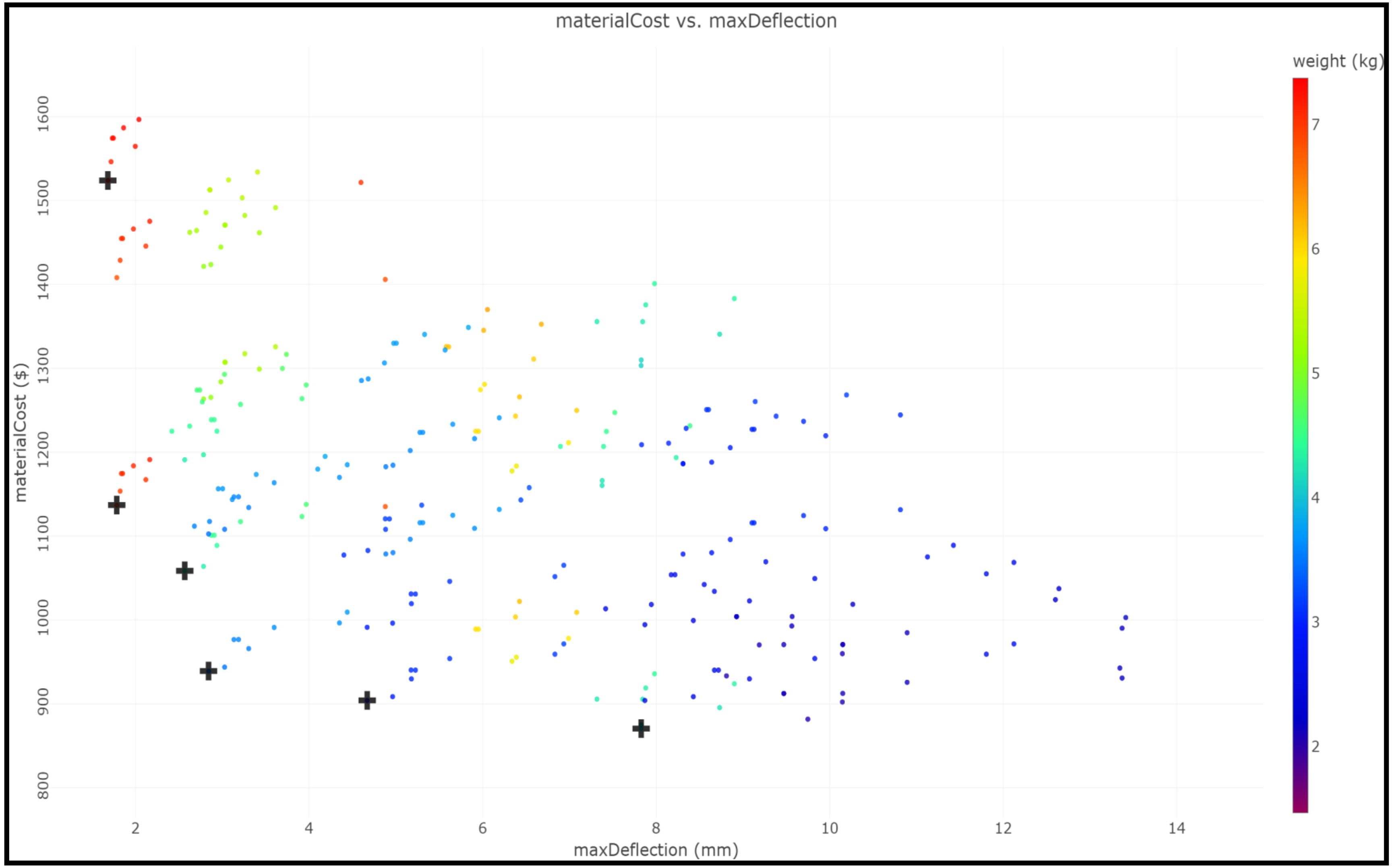
SIMULATION RESULTS FOR 5-20 UNITS (2)

- Total production value
  - A function of a weight "w" in the algorithm to account for traffic intensity and reduce queue times at charging stations, load/unload etc.
  - To maximize the production level, must regulate the traffic and hauler flow on the site.
  - The initial improvement is around a 16% increase in production when increasing the weight from 0 to 25.
  - But if the weight is too large, the objective function becomes heavily geared towards reducing traffic, which means taking longer routes and more battery usage. I.e. fewer trips between source area and the production storage (facility).

- Production value per transporter, also for 5-20 units.
  - When the fleet size increases, the production per unit actually decreases.
  - With w = 25, the algorithm improves the performance for all fleet sizes when compared to the simple routing with w = 0.
  - w = 0 implies is the algorithm no longer accounts for the current traffic situation on the site. Shows that it is not profitable to increase the fleet size to maximize production.

PARETO FRONT GRAPHS

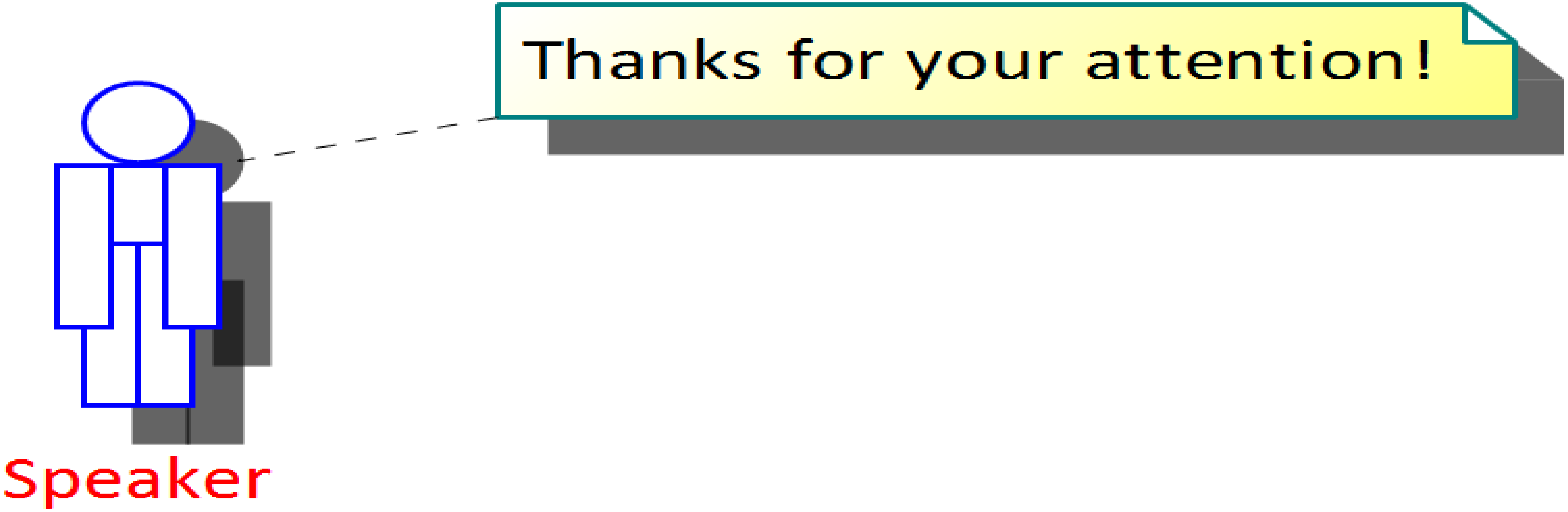
- Visual representation of the different parameters
- Allows the engineer to trade off systems across multiple parameters and configurations
- Material Cost vs. Deflection
- ASME's 2018 Human Powered Vehicle Competition (HPVC).



CONCLUSIONS

- Many different types of trade-off analysis are used by systems engineers when analyzing, designing and evaluating systems.
- At the heart of ***this*** effort is the SysML model which defines the requirements, structure and behavior of the system.
- Analysis requires an eco-system of tools to perform the trade-off analysis of the variety of possible system configurations and provide the customer with the “best” system that meets their needs, at an optimum price.
- Not a medical systems example, but useful nonetheless to illustrate the techniques.

QUESTIONS AND ANSWERS



THE DIGITAL ENGINEERING JOURNEY

Thank you for attending!

Share your experiences at #HWGSEC