All For The Want of a Horseshoe Nail
An Examination of Causality in DoDAF

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Agenda

- Causality
- The IDEAS Foundation
- Modeling Causality
- Modeling in UPDM
- Simulation
- Additional Concepts
- Conclusion

The Battle of Bosworth

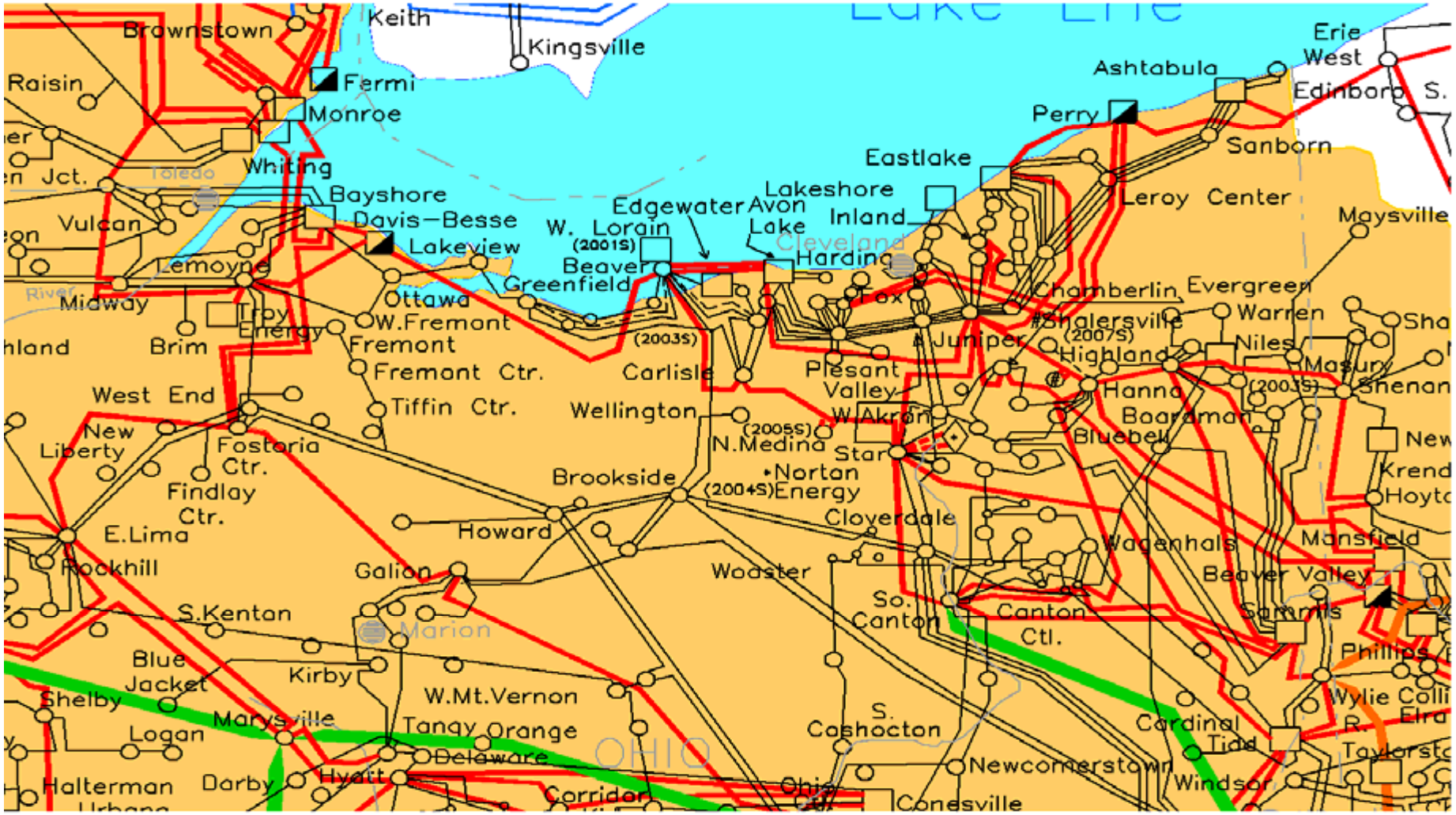
- For want of a nail the shoe was lost.
  For want of a shoe the horse was lost.
  For want of a horse the rider was lost.
  For want of a rider the message was lost.
  For want of a message the battle was lost.
  For want of a battle the kingdom was lost.
  And all for the want of a horseshoe nail.

- Refers to the death of Richard III of England.
- A simple event kicks off a causal sequence resulting in catastrophic consequences (if you were a Plantagenet)

Causality

- "Causality (also referred to as causation) is the relation between an event (the cause) and a second event (the effect), where the second event is understood as a consequence of the first."
  Random House Unabridged Dictionary
- Causes and their effects are typically related to changes or events. Also caused by objects, processes, properties, variables, facts, and states changes, etc.
  - These concepts can be modeled in DoDAF/MODEM
- Characterizing the causal relation can be difficult.
  - Correlation is not causation
  - I.E. Sacrificing an animal to the gods does not cause a good harvest.

Northeast USA and Canada Electric Blackout 2003



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Investigating a Historical Chain of Events

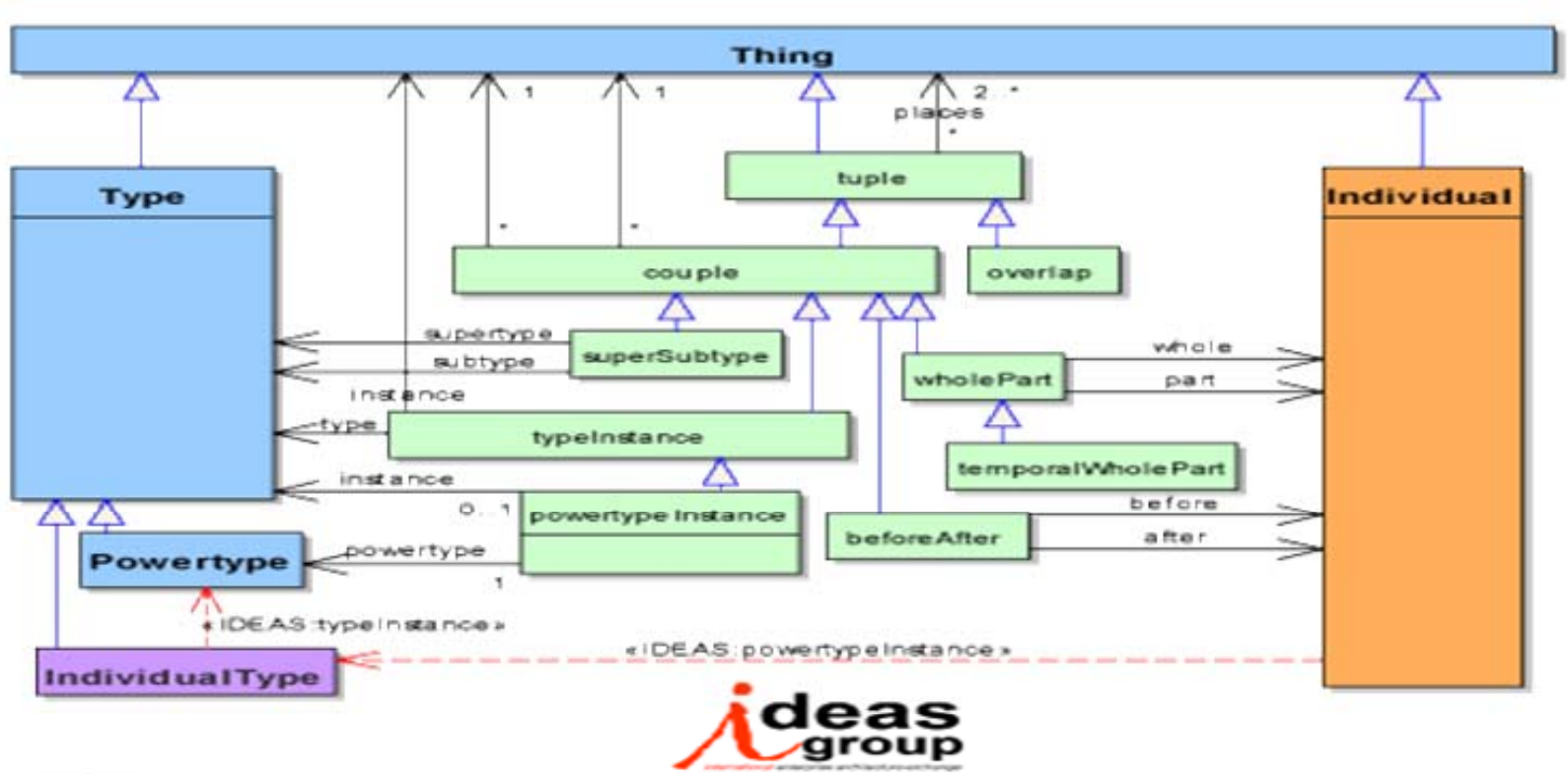
- What was the causal sequence?
  - Abnormally hot weather increased A/C load causing
    Power load to increase causing
    Power lines to sag and contact trees causing
    Line faults causing
    Electrical outages causing a massive outage
- What circumstances enabled this sequence?
  - The trees were taller than they should have been because the power company cut the tree trimming budget to save money to remain competitive because of deregulation caused by a change in the political environment caused by…. (You get the idea.)
  - Human factors were also directly involved because the operators had sufficient advanced warning of the problem but ignored the warning messages.
  - Sensors measuring power flow were faulty.
  - Other causes were also documented
- Well documented and understood due to extensive data logging

Using Causality in Decision Making

- A decision is made to conduct a tactical strike on an insurgent base as they have been attacking allied forward operating bases.
- First ask the question: “Why does the insurgent base exist?”
  - The locals are unhappy because they have no money because they cannot bring their crops to market because the roads have been washed out because heavy allied trucks have been travelling on the roads weakening the structure so that monsoon rains washed out the roads so they are no longer navigable so farmers can’t bring their crops to market. The insurgents provide the locals with money so they are allowed to operate.
  - So fixing the roads will allow locals to bring their crops to market providing them an income causing them to withdraw support for the insurgents causing the insurgents to withdraw removing the need for a tactical strike with potential collateral loss of life.
  - In reality, a systems engineer’s approach to problem solving.
  - The question is, How do you model this?

IDEAS - Top-Level Foundation

- Developed by an international group of computer scientists, engineers, mathematicians, and philosophers under defense sponsorship.
- See http://www.ideasgroup.org or http://en.wikipedia.org/wiki/IDEAS_Group



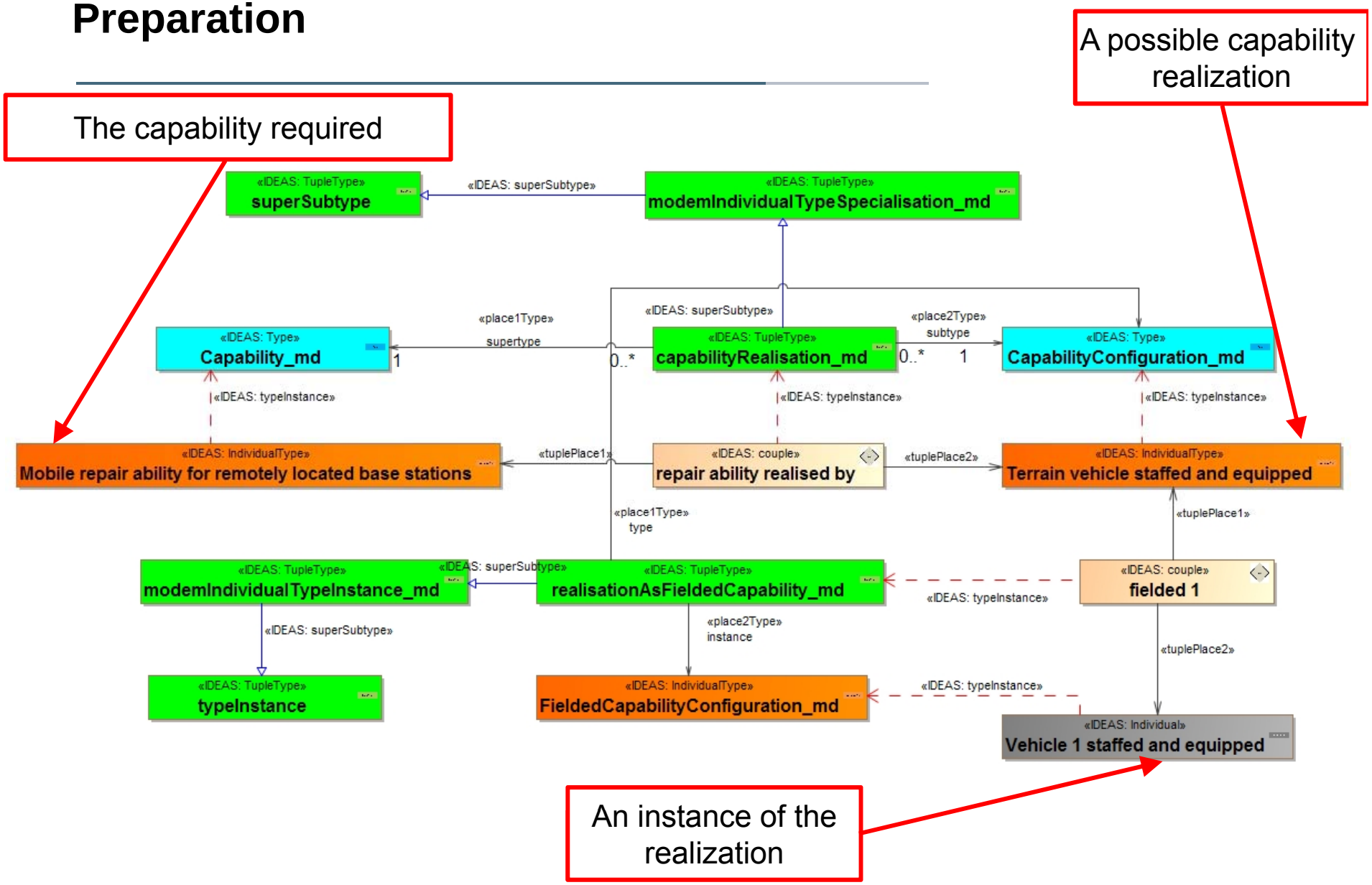
Causality as such

- Semantically, causality is a fairly tricky subject.
- There is causality that is due to the laws of physics: If a stone is dropped from a height, gravity will **cause** the stone to fall to the ground below.
- There is causality that is due to a law prescribed by society: If I park my car in a no-parking zone, the **cause** of me getting a parking ticket was that I broke a law regarding car-parking (and that I was unlucky enough to get caught doing it).
- There is causality where someone has determined that something caused something to happen: The black-out was **caused** by budget cuts concerning tree-trimming, warning messages being ignored and faulty sensors.
- The last was in a after-the-fact determination but brings up another issue namely results that are **desired** by someone or intended results when making use of something or in other words **effects**.

Let us look at this from the point of a scenario

- A severe storm has devastated parts of the normal mobile communication infrastructure, including remote base stations.
  - They are accessed by road through dense forests.
  - A mobile base station repair ability was considered as required.
    - The aim of the operator is to reach an infrastructure fully operational availability in excess of 99.5%.
- In order to manage the repair ability, a set of fairly rough terrain going vehicles equipped with a large set of technology have been procured.
  - It can be staffed with personnel with the appropriate training and dispatched to the place where repair is needed.
    - Since there are four base-stations that need repair, four instances of this type of vehicle with appropriate staff were dispatched.

Modeling cause and effect for base station repair: Preparation



Let us look at this from the point of a scenario

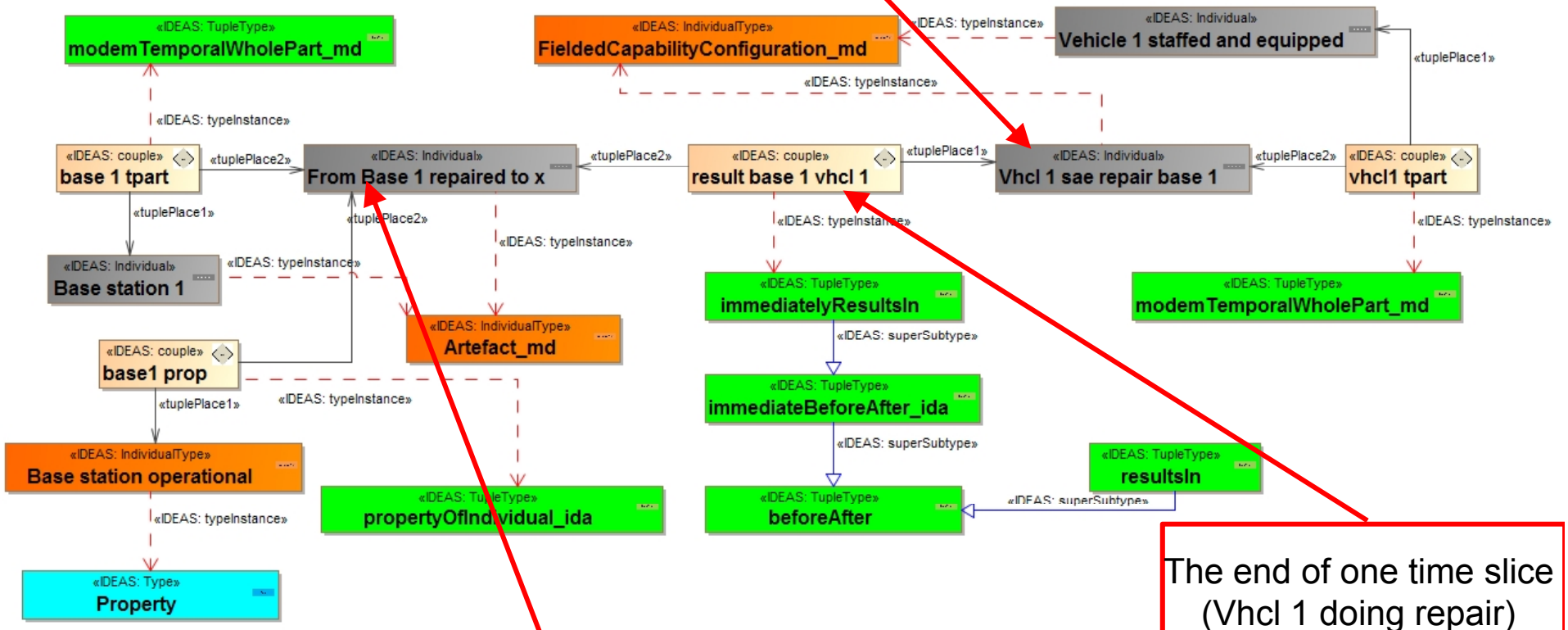
- The outcome of this turned out as follows:
  - Two base stations were repaired and brought back to full operational status.
  - One was repaired but did not seem to work properly and the team was not able to fix the problem.
  - One was not reached at all since the vehicle got stuck since parts of the road up to the base station was in very bad condition after the storm. Attempts to shift the vehicle caused parts of the road to collapse making access to the base station totally impossible without a major road repair effort and therefore the station remained completely off-line.
  - Due to the problems with two of the base stations the overall operational availability dipped below 98% until such a time that at least one of the base stations were fully operational.

Scenario from an cause, results and effect perspective

- *Capability:*
  - Repair ability for remotely located base stations
- *Effect that implementations of the capability are intended to achieve:*
  - Repaired and operational mobile base stations
- *Implemented capability:*
  - Rough terrain going vehicles staffed and equipped with a large set of technology
- *Desired effect by desirer:*
  - Operator wants to achieve an infrastructure with operational availability in excess of 99.5%
- *Actually achieved effects:*
  - Base station 1 fully repaired and fully operational,
  - Base station 2 fully repaired and fully operational,
  - Base station 3 repaired but not operational,
  - Base station 4 not repaired,
  - Access road to base station 4 rendered unusable,
  - Infrastructure availability at 96%.

Modeling cause and effect for base station repair

The temporal time slice of Vhcl 1 and staff performing and finishing repairs to base station 1



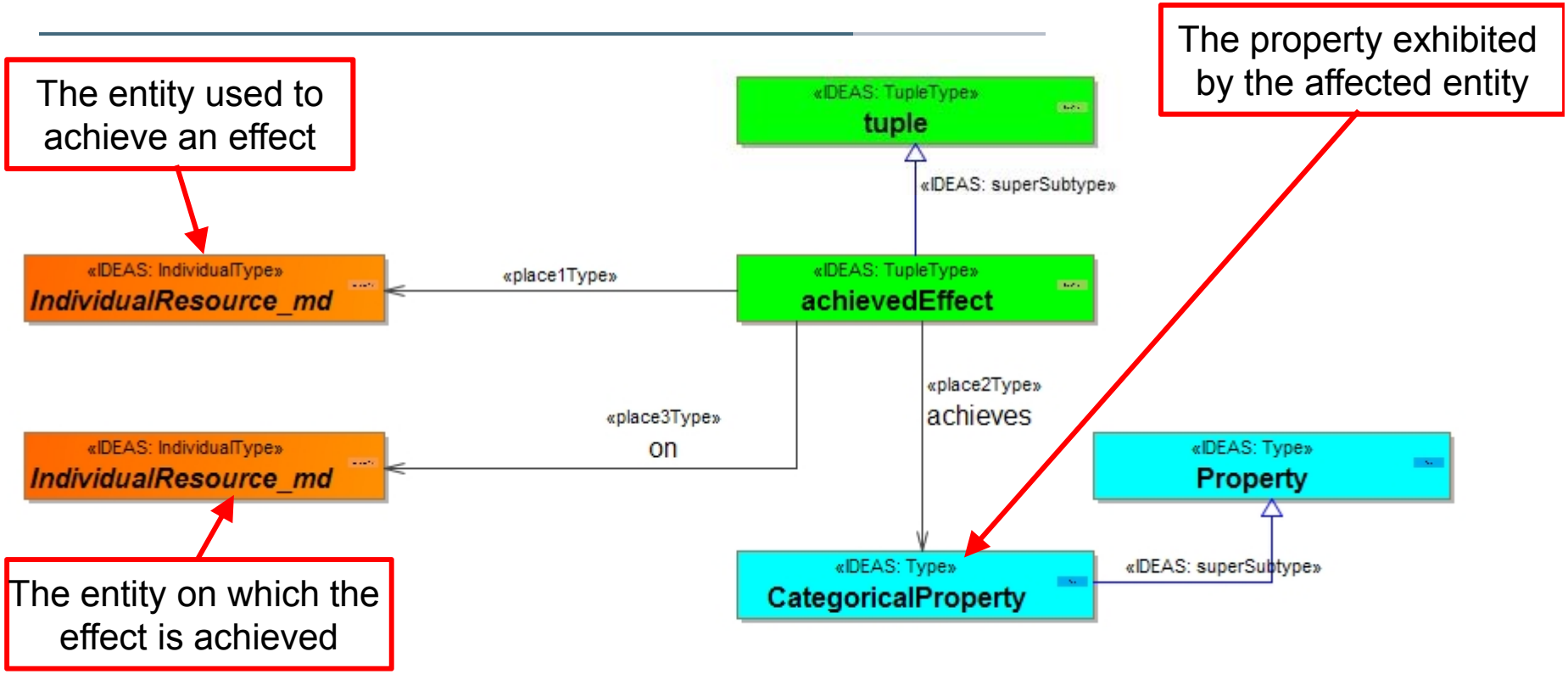
Base station 1 after successful repairs and prior to some future event x. This slice is a member of the base station operational property set

The end of one time slice (Vhcl 1 doing repair) prior to base station 1 operational time slice start.

What does this mean?

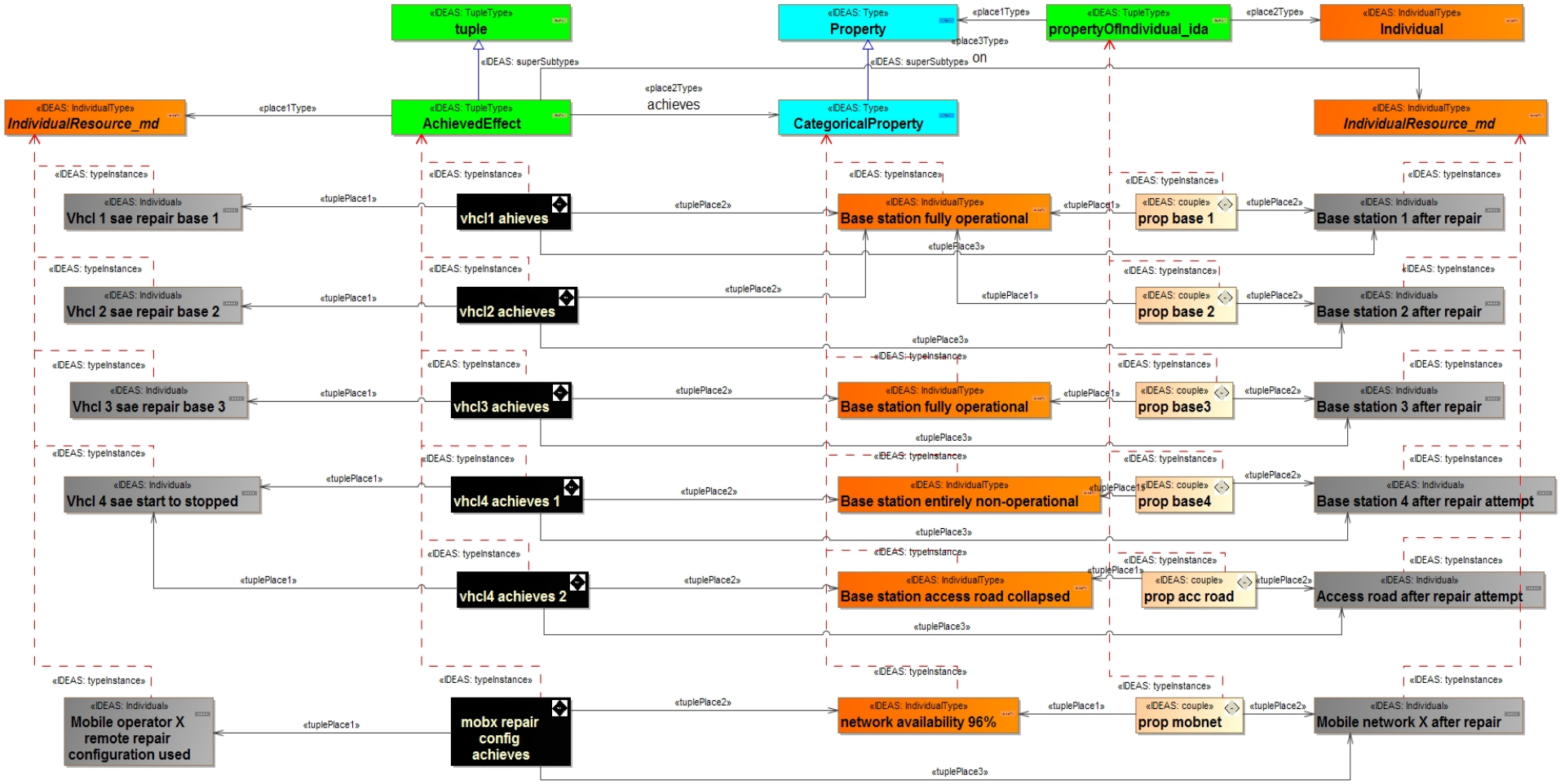
- A capability was implemented as a mobile repair configuration and there is an instance of that that for a part of its lifetime was used to repair base station 1.
- Base station 1 as a result of the repair ended up exhibiting a fully operational property and this lasted until a future event x.
- The temporal state of the mobile repair configuration where they repaired the base station ended as soon as the base station became operational, i.e. there is a beforeAfter and indeed in this case an immediateBeforeAfter relationship (both are IDEAS and MODEM concepts) between the temporal part of mobile repair and the temporal part of the fully operational base station.
- A subset of both beforeAfter as well as immediatelyBeforeAfter can be created in the form of **immediatelyResultsIn** and **resultsIn**. The difference between the two is simply that one happens immediately and for the other there may be a time lapse before the result (effect actually happens).

Achieved result/ effect summary model



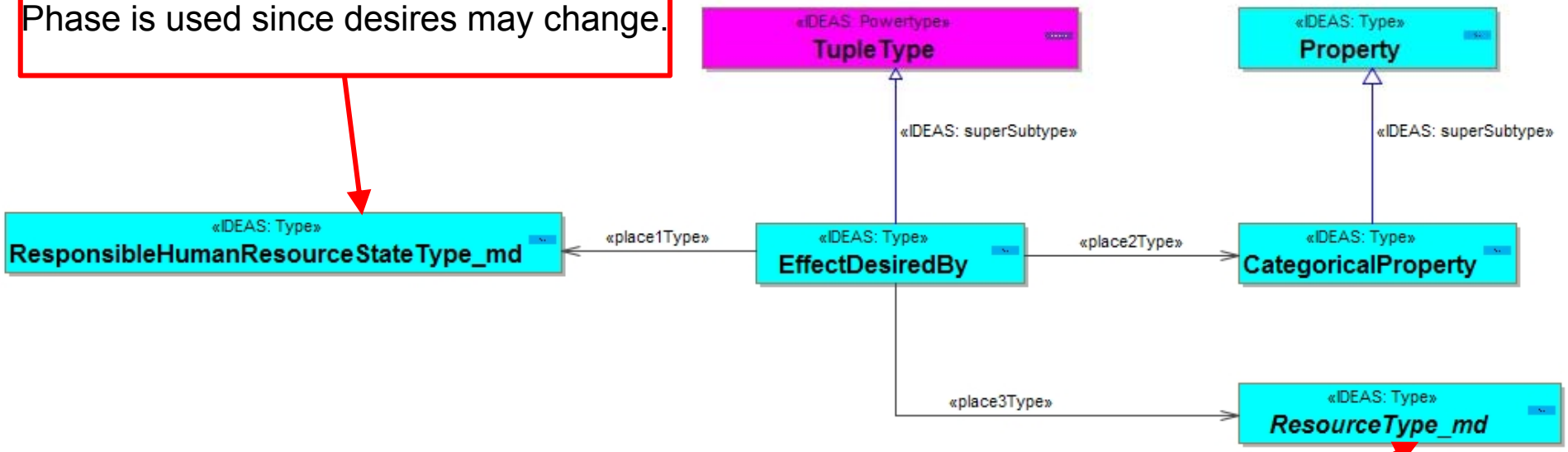
- This can be summarized as described above by stating that the use of some configuration of resources on some other configuration of resources causes the latter to exhibit a specific property.
- Property can be subdivided into dispositional property as well as categorical property, the former implying that the configuration is able to exhibit this property but is not actually doing this at this point. The latter implies that the time slice of the configuration where it actually achieves this property is implied.

Achieved effect: scenario



Desired effect/ result summary

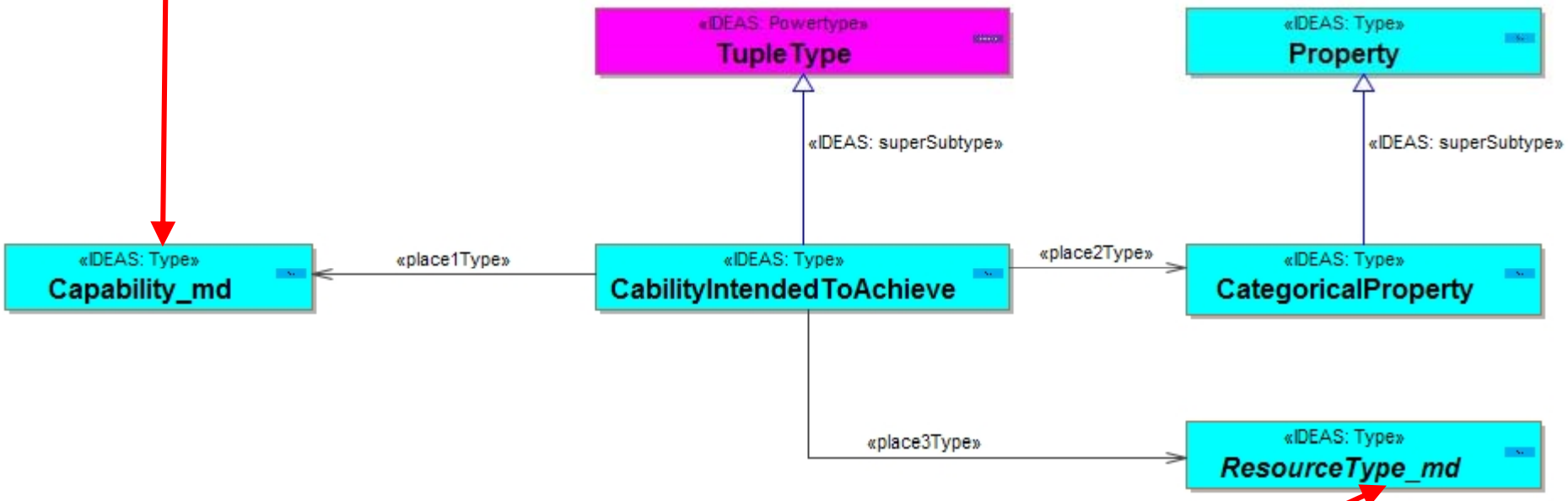
The phase of some responsible human resource that desires to have an effect on a given resource. A temporal Phase is used since desires may change.



A combination of resources where there is a desire to have it exhibit a certain categorical property

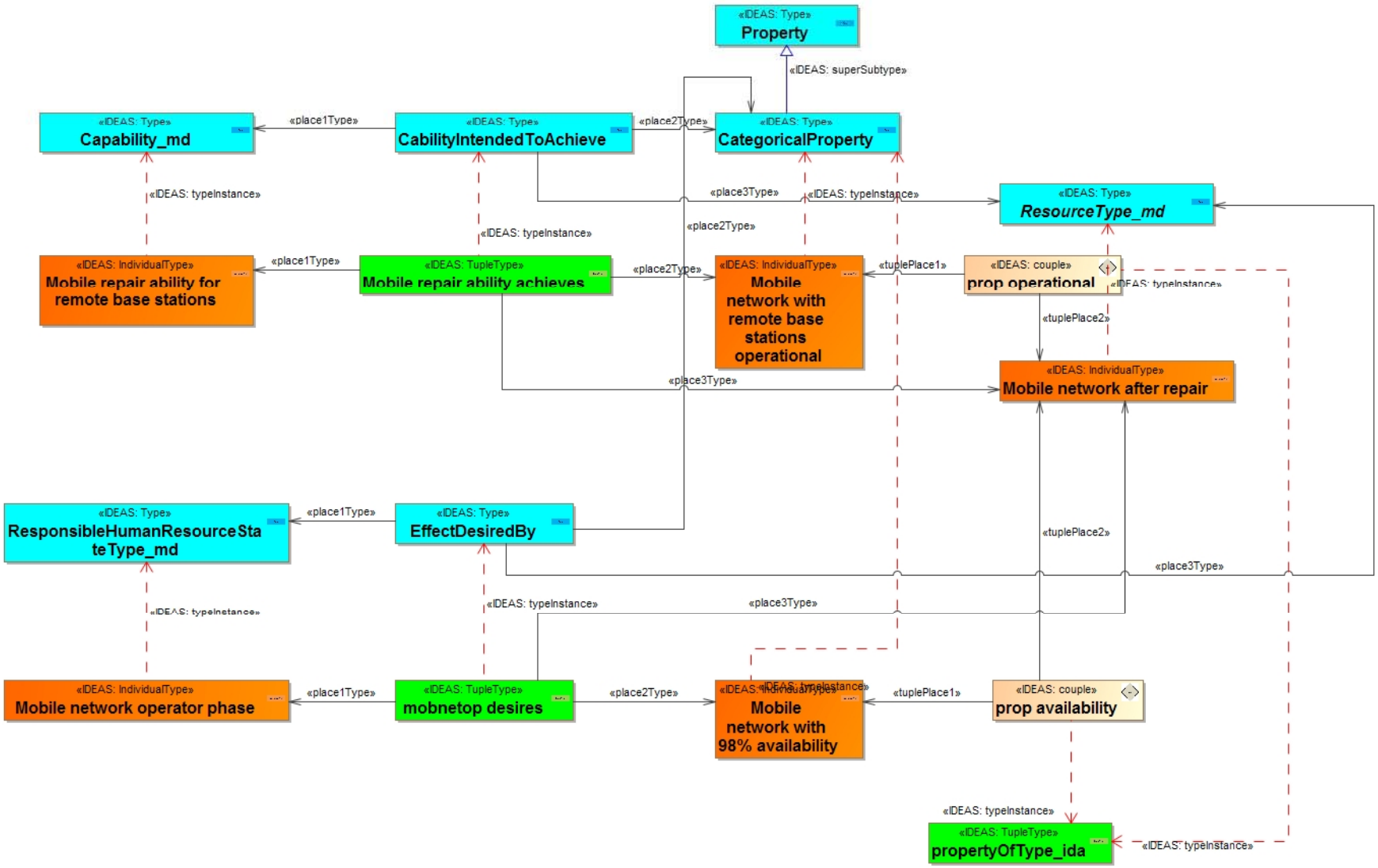
Intended effect/ result

A high level specification of the enterprise's ability.
Note: A capability is specified independently of how it is implemented.
Note: Capabilities are dispositional. A given system or organization that has a capability (i.e. it is disposed to do something) may never actually have manifested it.



A combination of resources where use of something that implements a given capability should result in the resource configuration exhibiting a certain categorical property.

Desired and intended effect: Scenario



Explanation

- The first of the two previous slides enables effect to be summarized as something that a capability is intended to achieve.
- It also shows how the desired result/ effect can be summarized.
- This is then shown exemplified for a Mobile repair ability for remote base stations as well as for a mobile network operator.

The Unified Profile for DoDAF and MODAF (UPDM)

- UPDM is a standardized way of expressing DoDAF and MODAF artefacts using UML and SysML
  - UPDM is *NOT* a new Architectural Framework
  - UPDM is not a methodology or a process
  - UPDM implements DoDAF 2.0, MODAF & NAF
- UPDM was developed by members of the OMG with help from industry and government domain experts.
- UPDM is a DoD mandated standard and has been implemented by multiple tool vendors.

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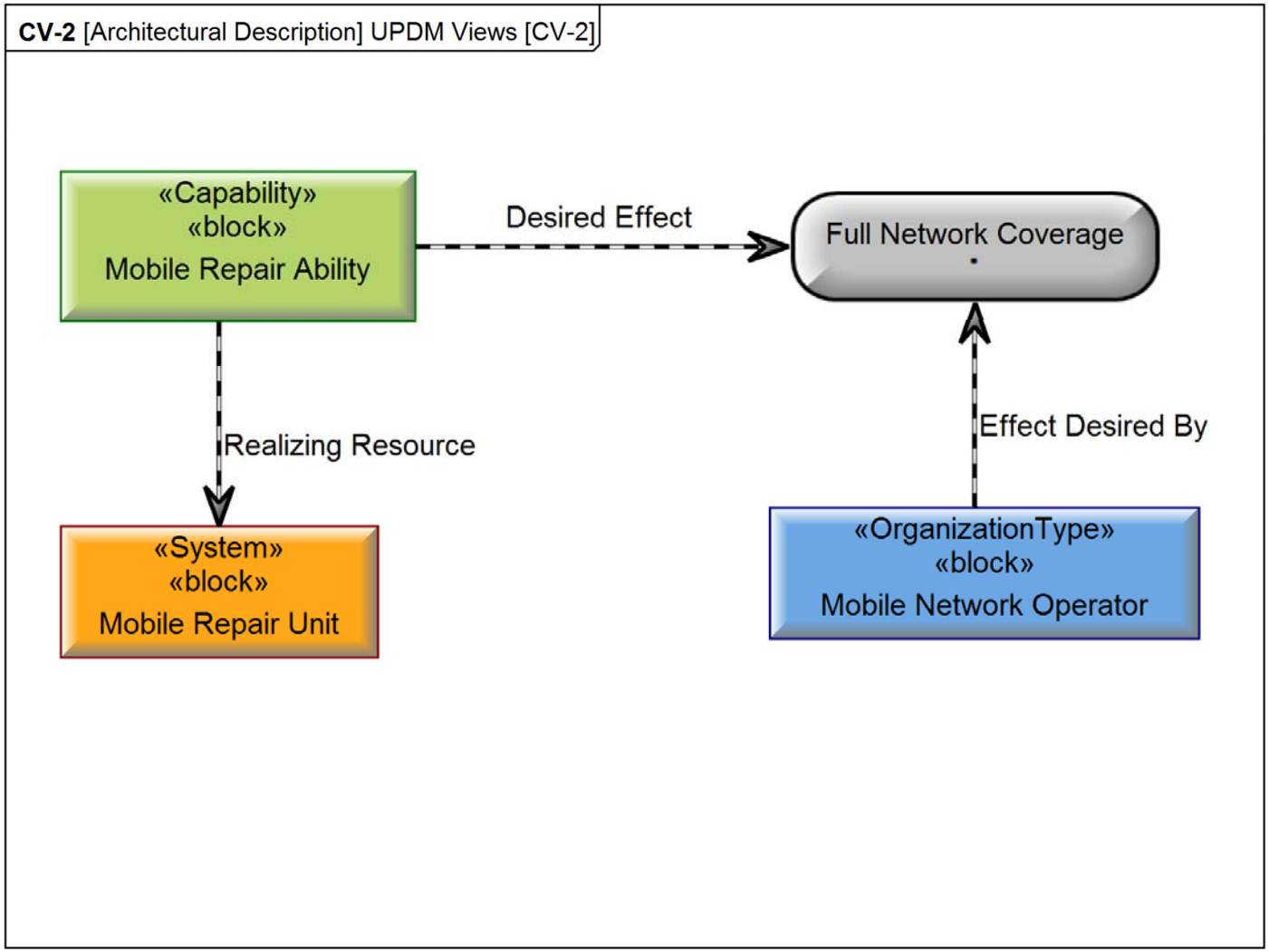
Representation in UPDM / SysML

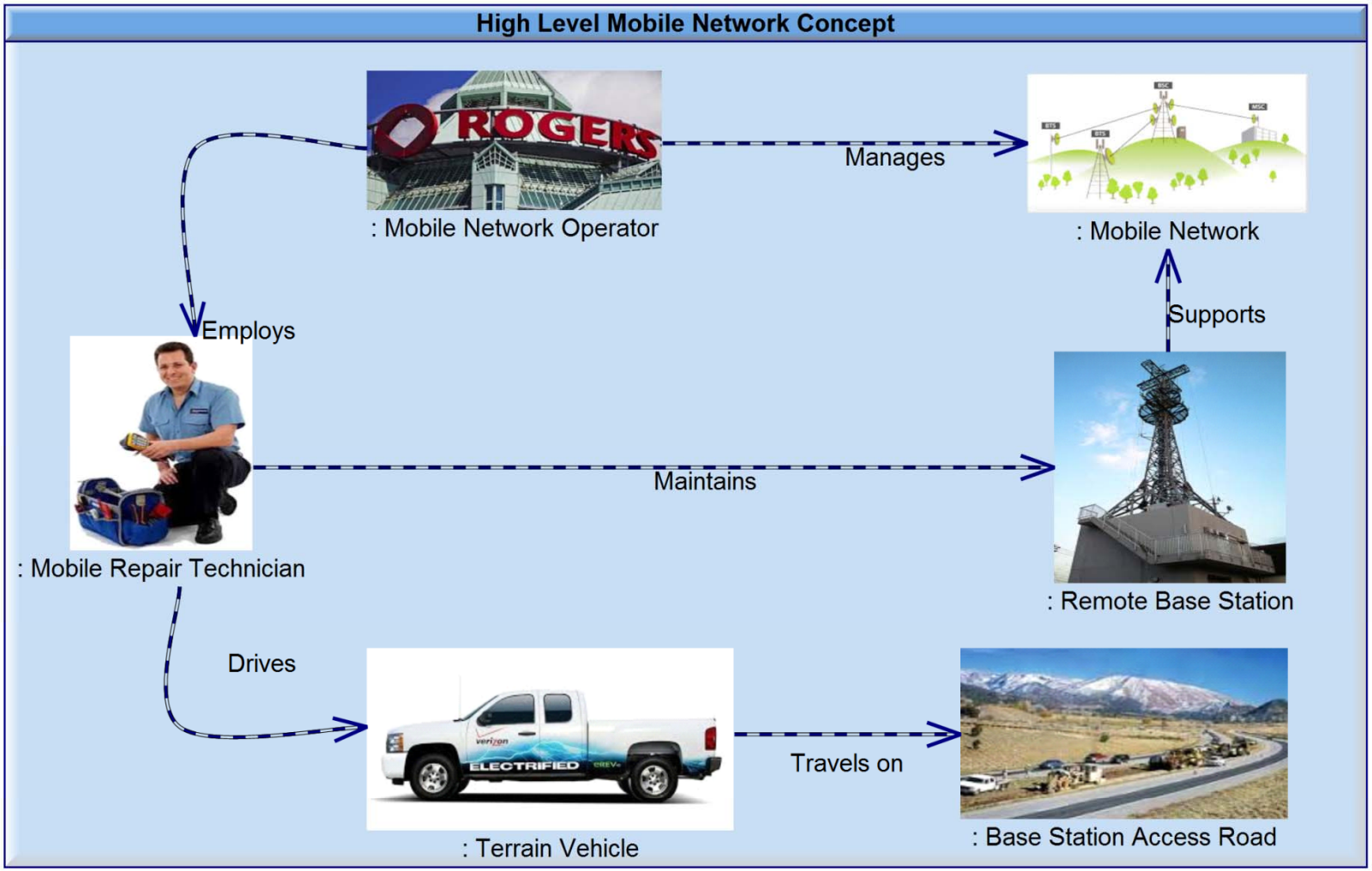
- MODEM/DoDAF does not prescribe a graphical representation
  - Implementations such as UPDM are required for visualization
- State Diagrams
  - Models the state-based behavior of structural elements
  - Useful for capturing event/effect sequences
- Activity Diagrams
  - Used to model behavioral sequences using activities
  - Shows the flow of control and information
  - Can include structural elements
- Sequence Diagrams
  - Captures a series of interactions between structural elements
  - Can include timing information, parallel and optional sequences,
- SysML Parametric Diagrams
  - Captures the relationship between quantitative structural aspects

Capability



OV-1 High Level Concept

OV-1a [High Level Operational Concept] High Level Mobile Network Concept [Graphic]



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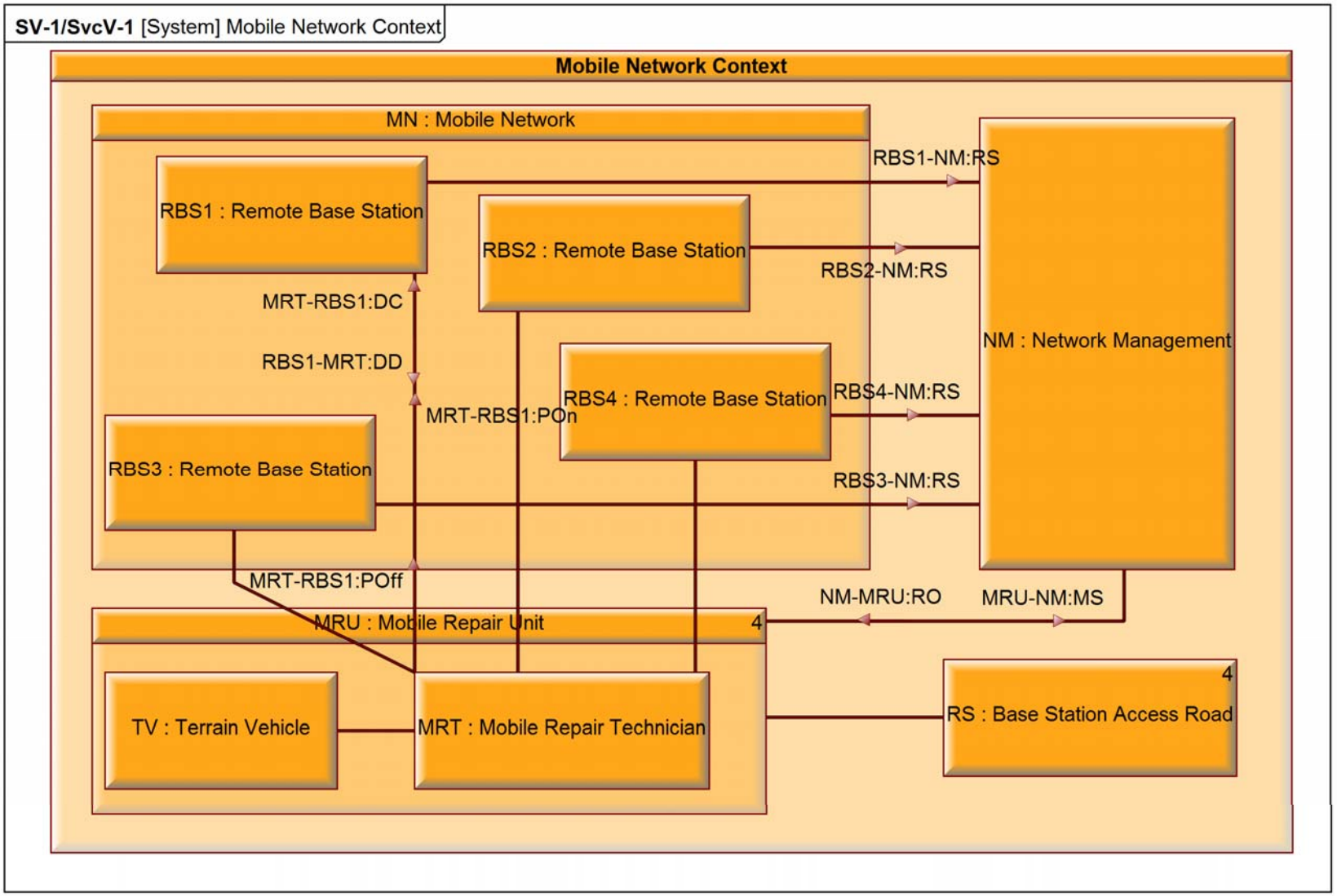
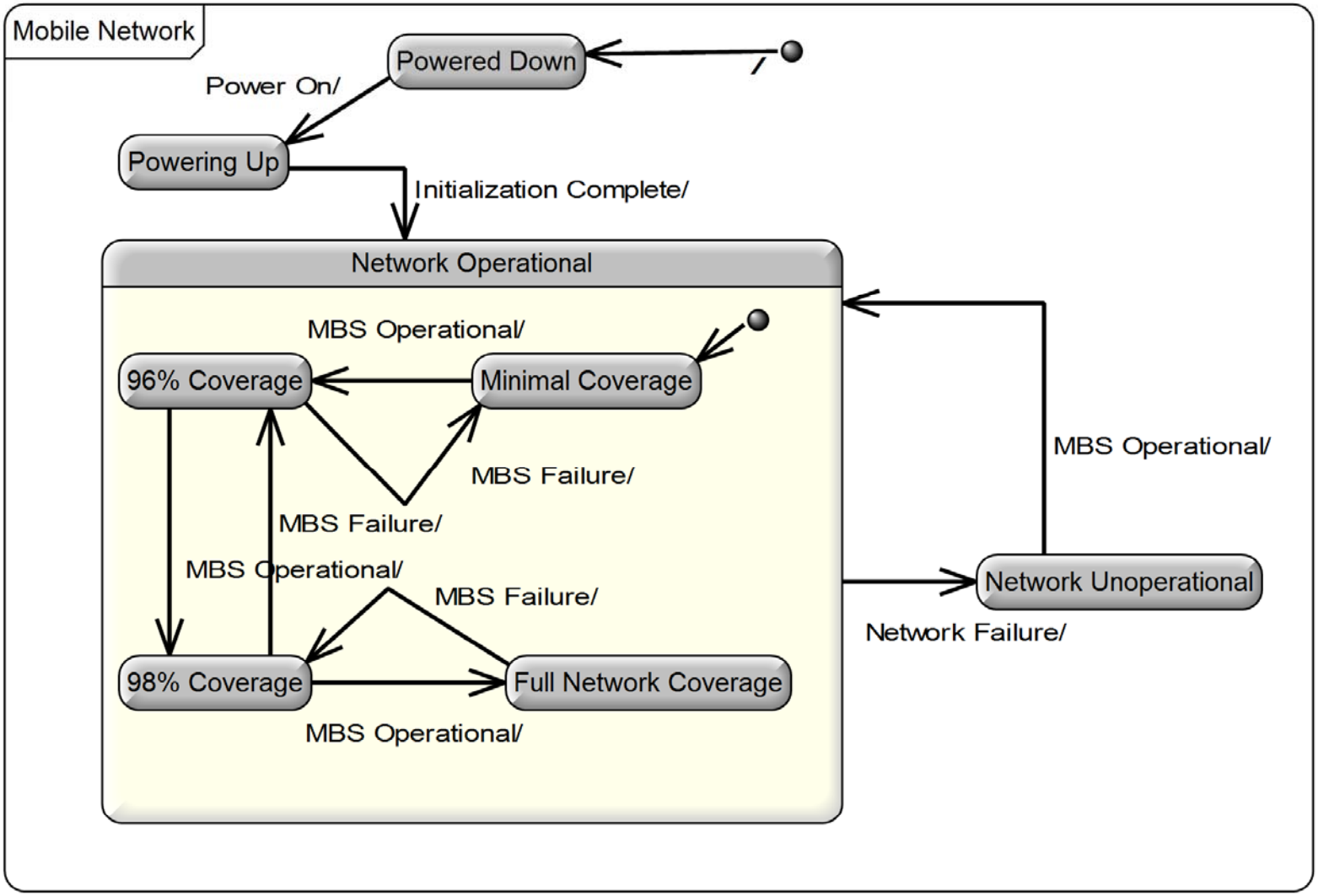
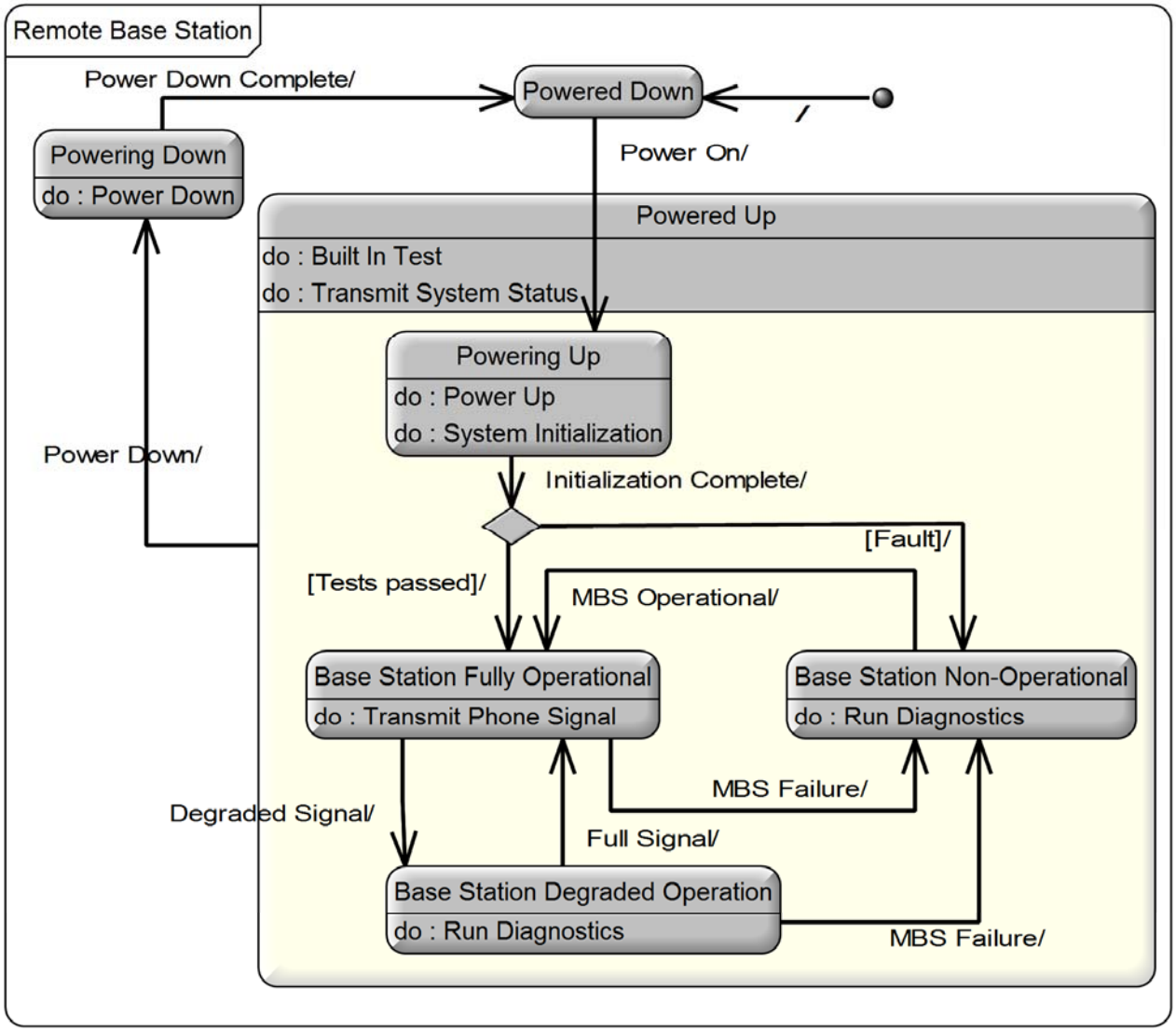
System Structure (Simplified)



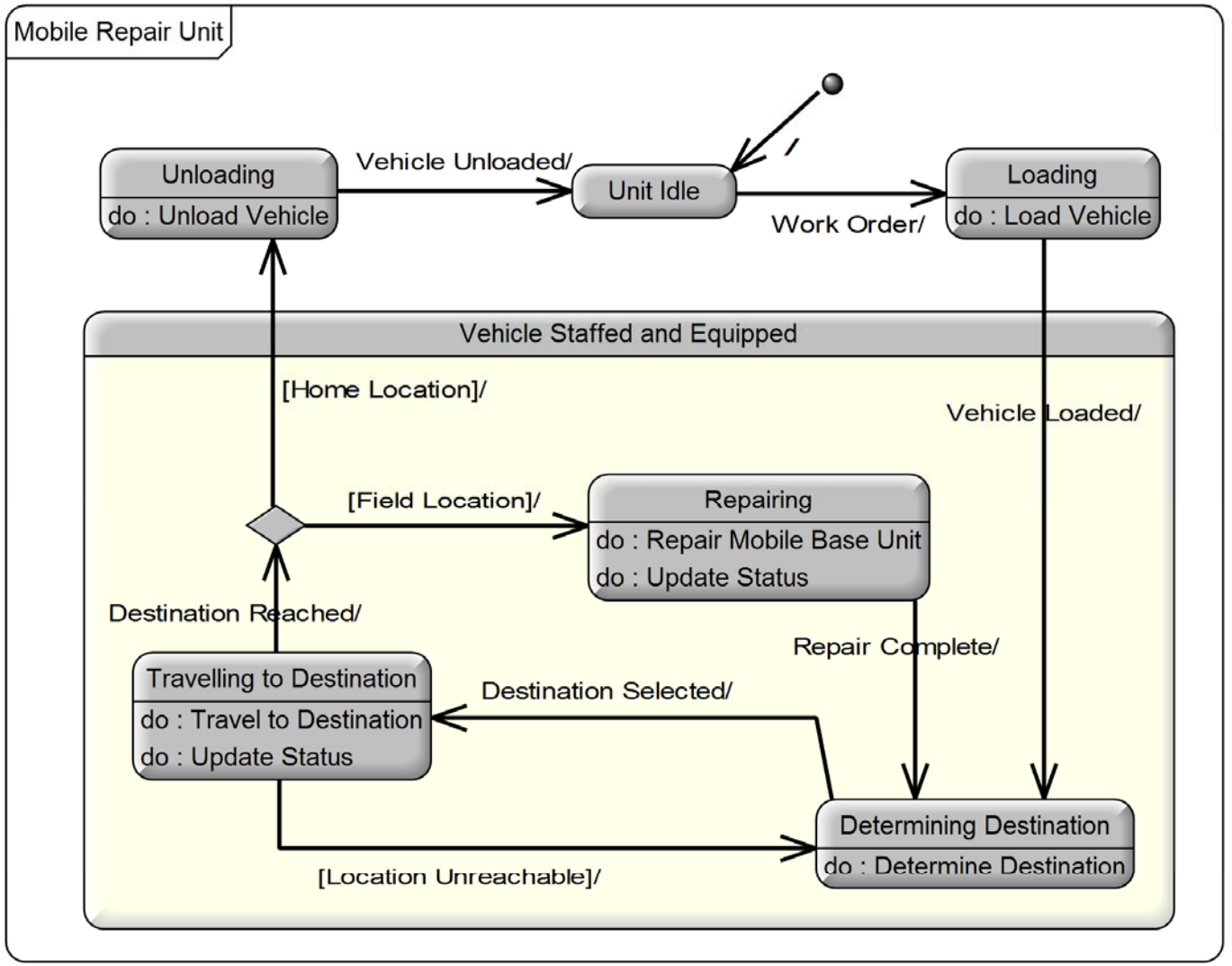
Mobile Network System States



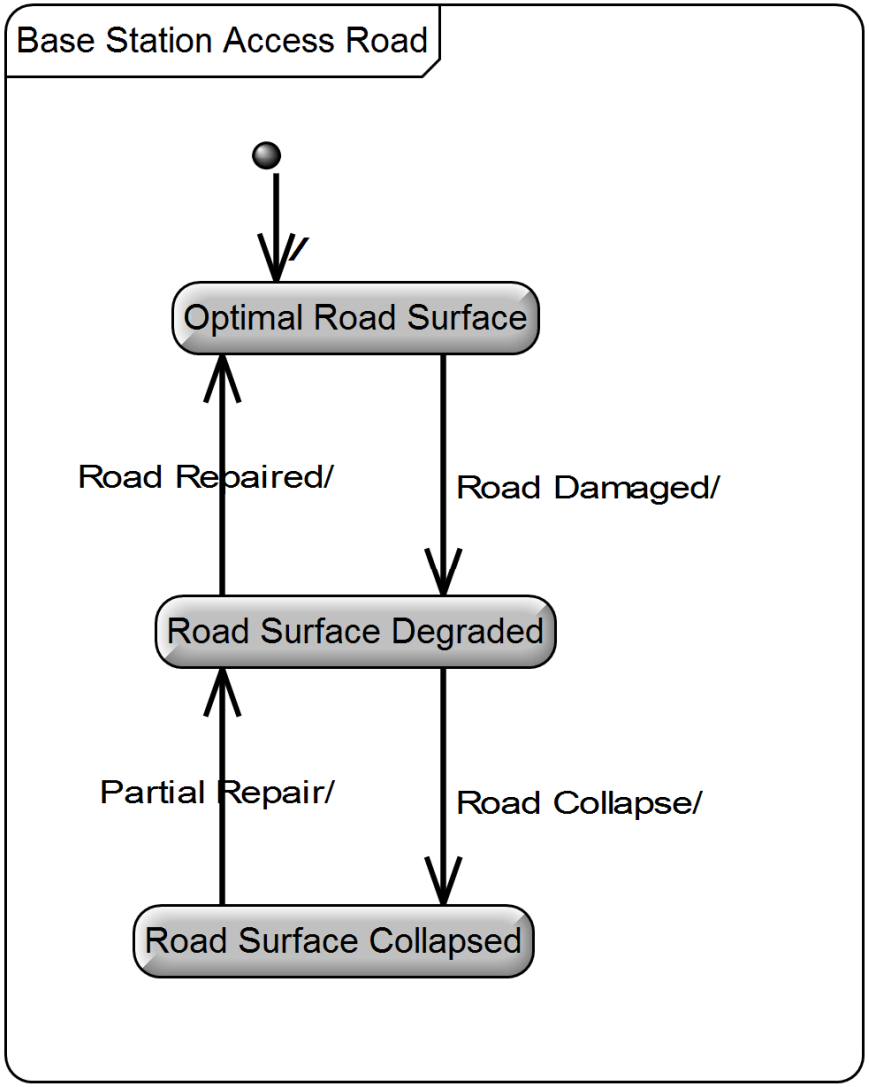
Remote Base Station System States



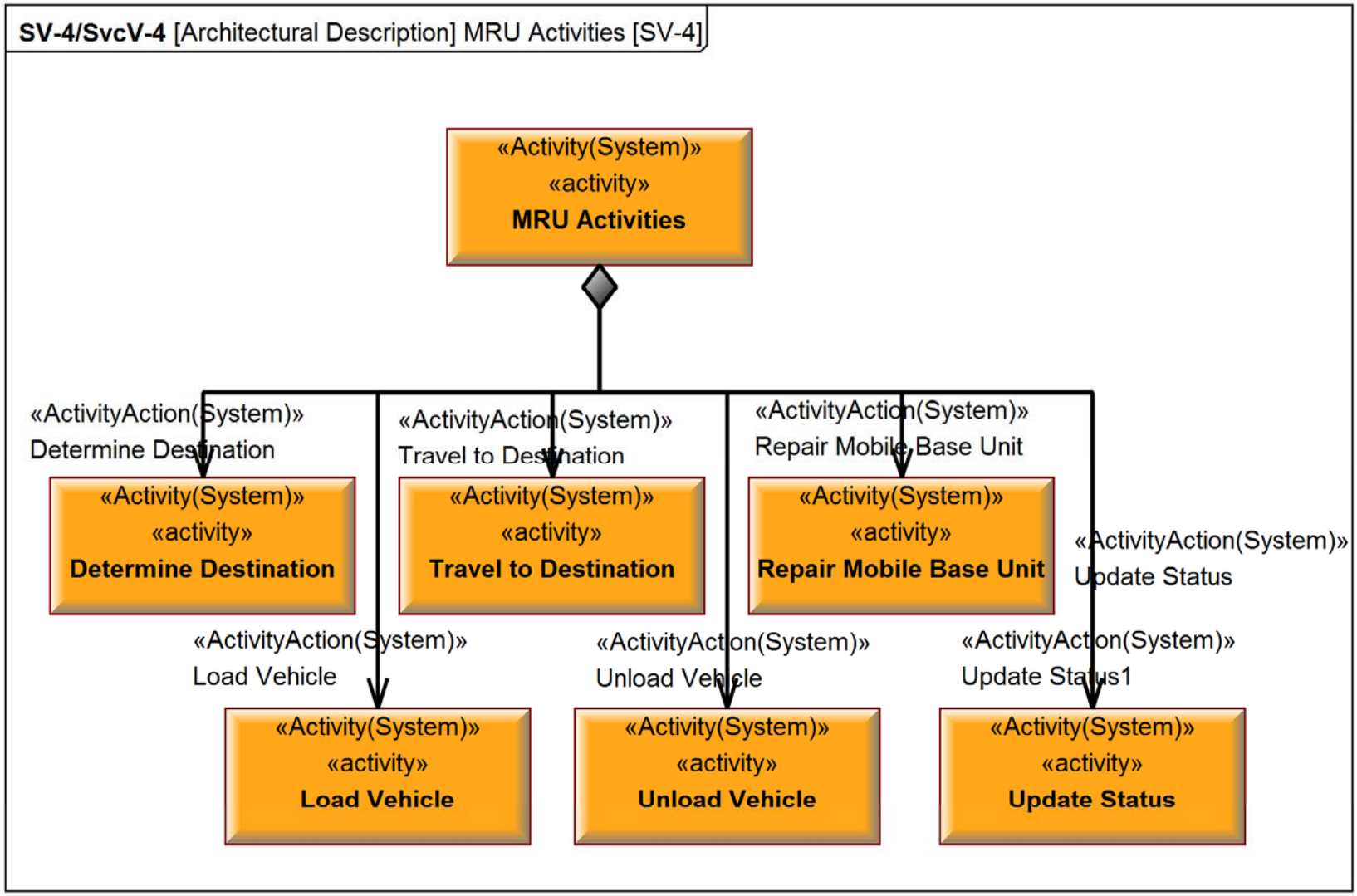
Mobile Repair Unit System States



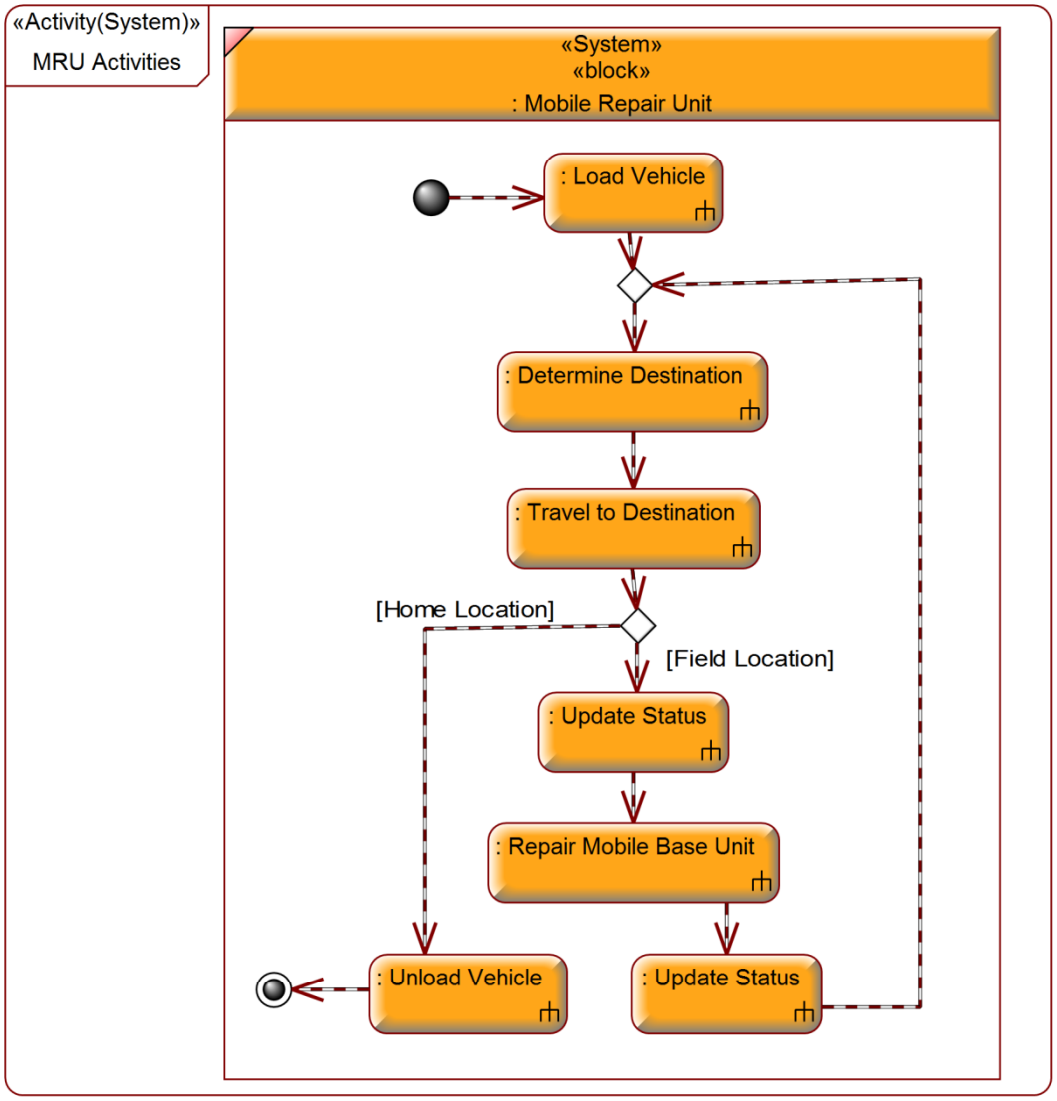
Base Station Access Road System States



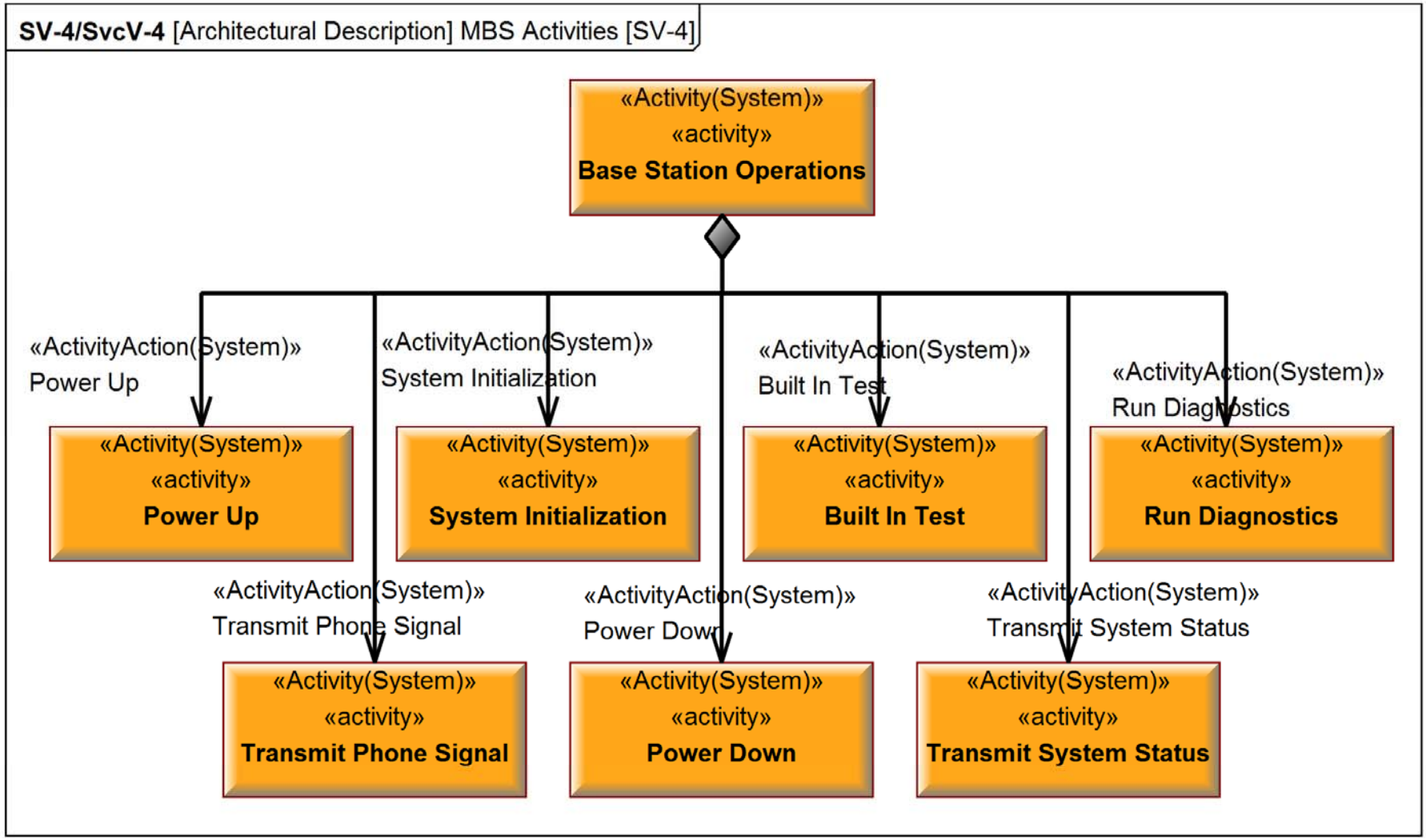
Mobile Repair Unit Activity Diagram



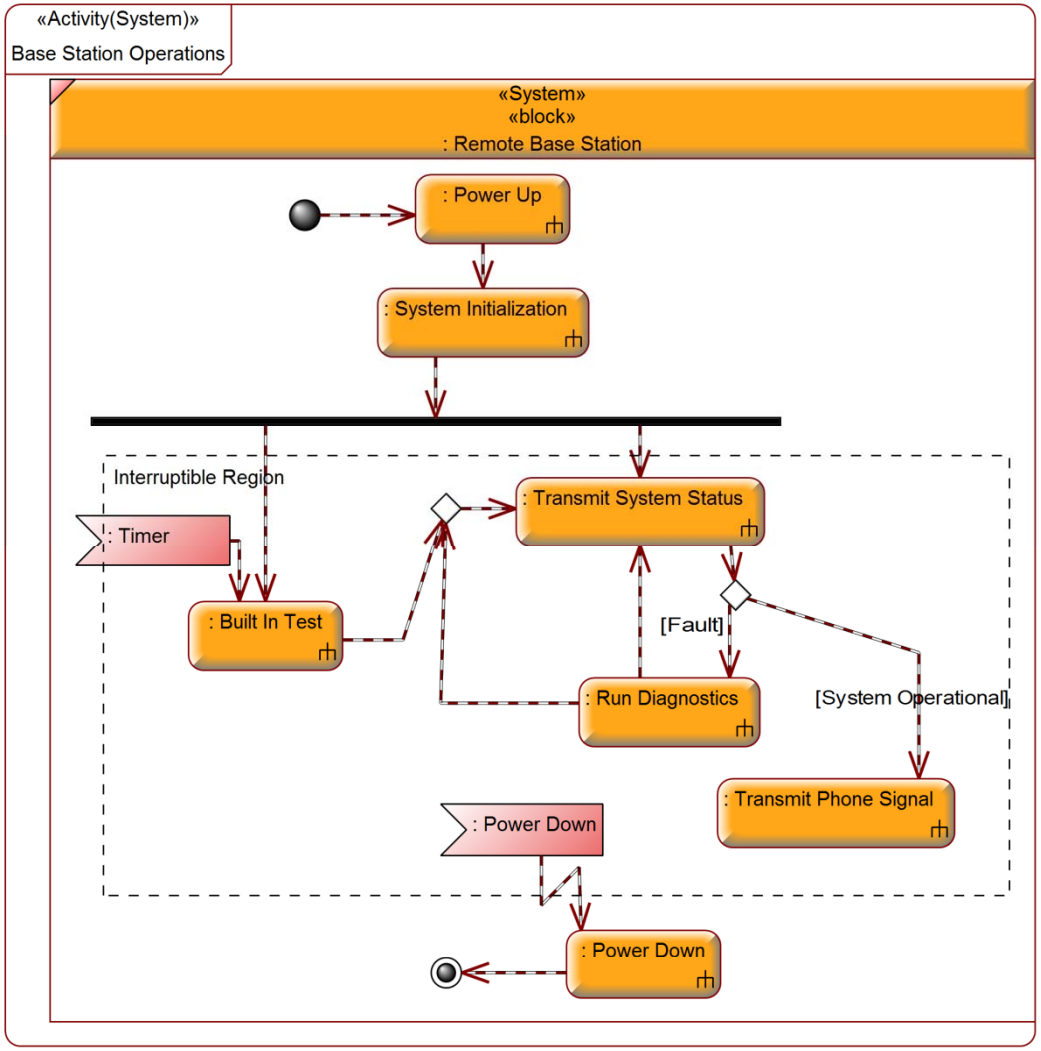
Mobile Repair Unit Activity Diagram



Remote Base Station Activity Diagram



Remote Base Station Activity Diagram

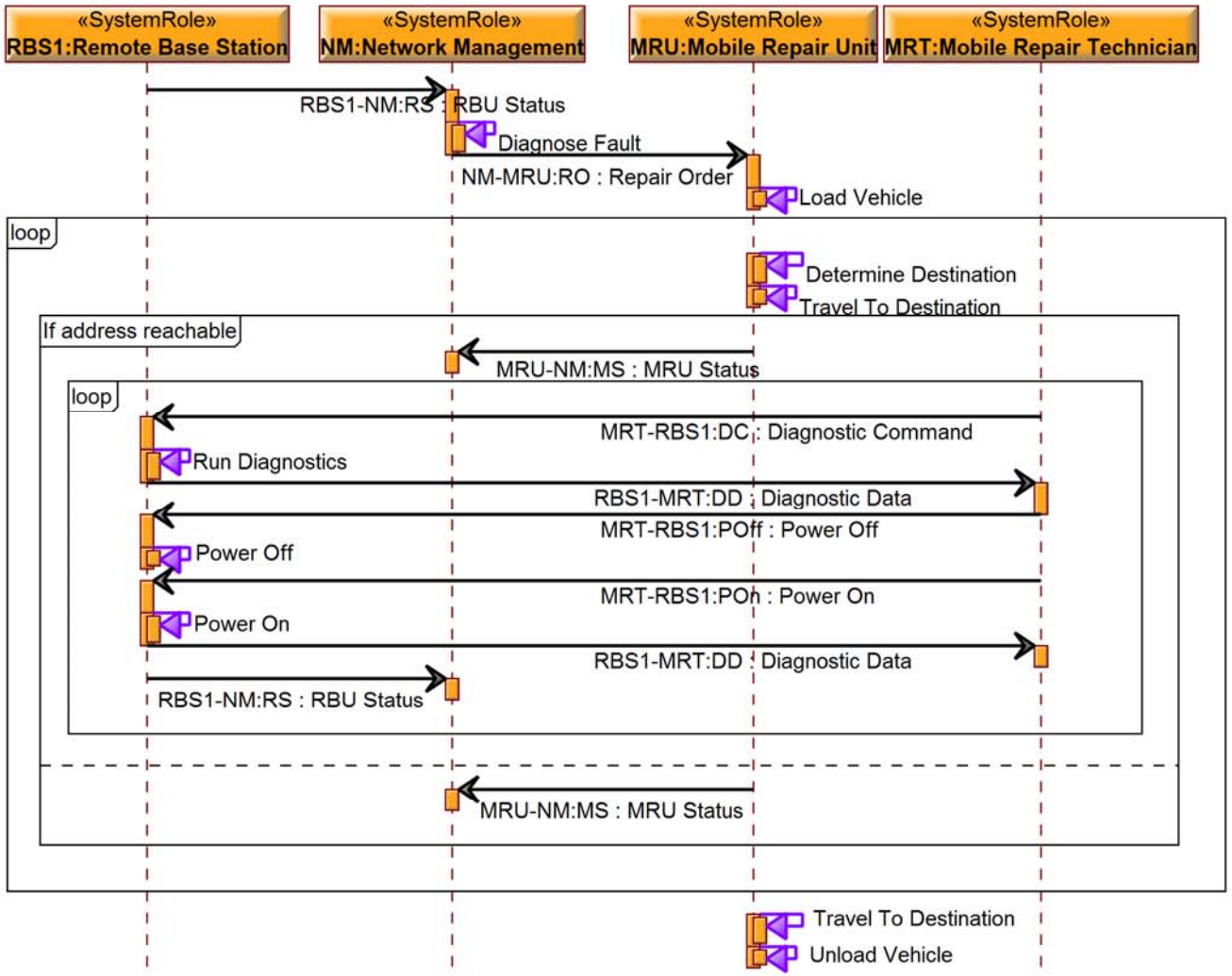


Sequence Diagram – Base Station Repair

Mobile Network Context

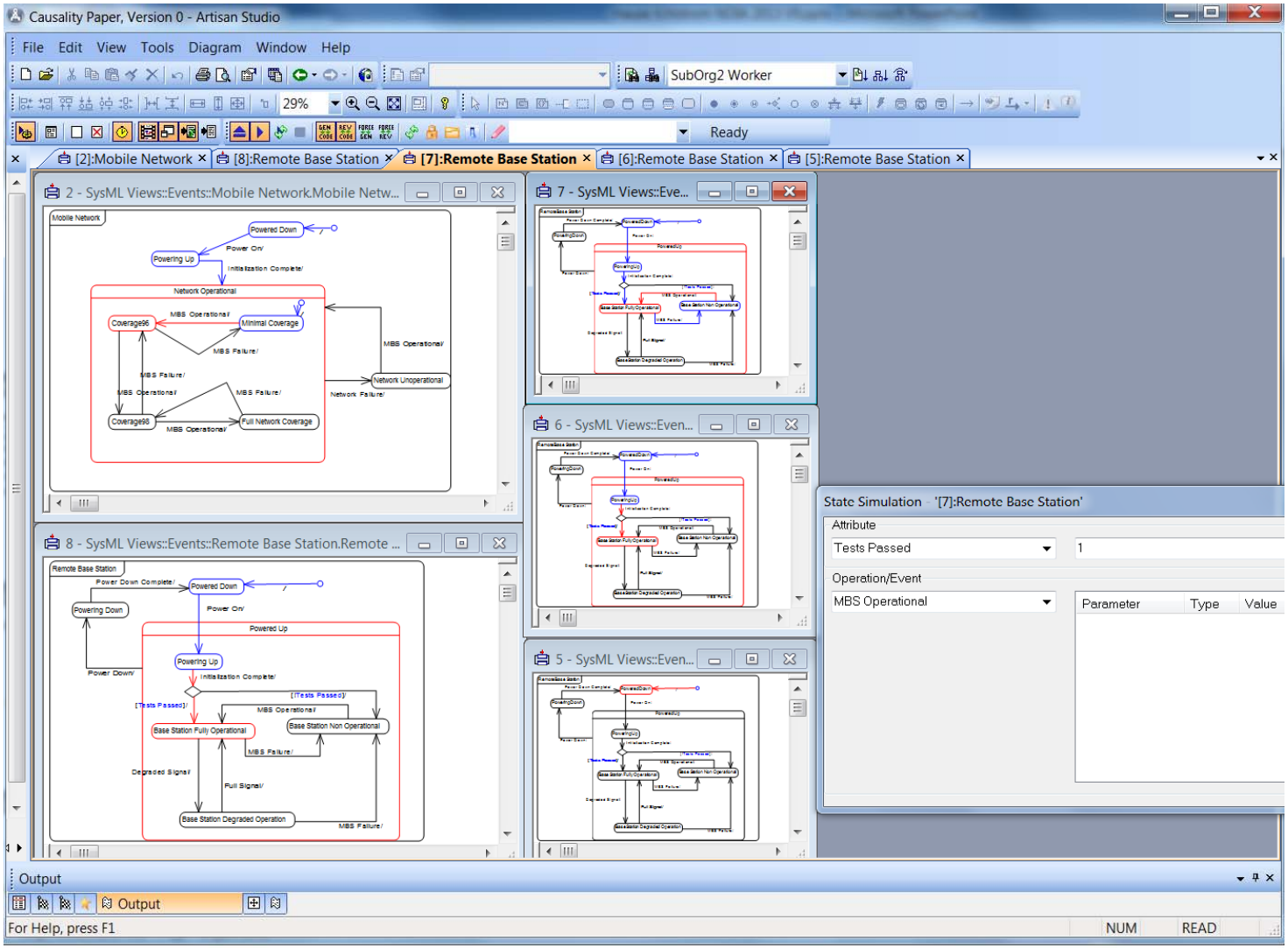
Description

Send Status
Determine Fault
Send Repair Order
Load Vehicle
loop
    Determine Destination
    Travel To Destination
    If address reachable
        Send MRU Update
        loop
            Request Diagnostics
            Run
            Send Data
            Power Off
            Powering Off
            Power On
            Powering On
            Send Data
            Send RBS Status
        Until Repaired
    else alt
        Send Update
    end alt
Until Orders Performed
Travel
Unload Vehicle



Using Simulation to Test Behavior

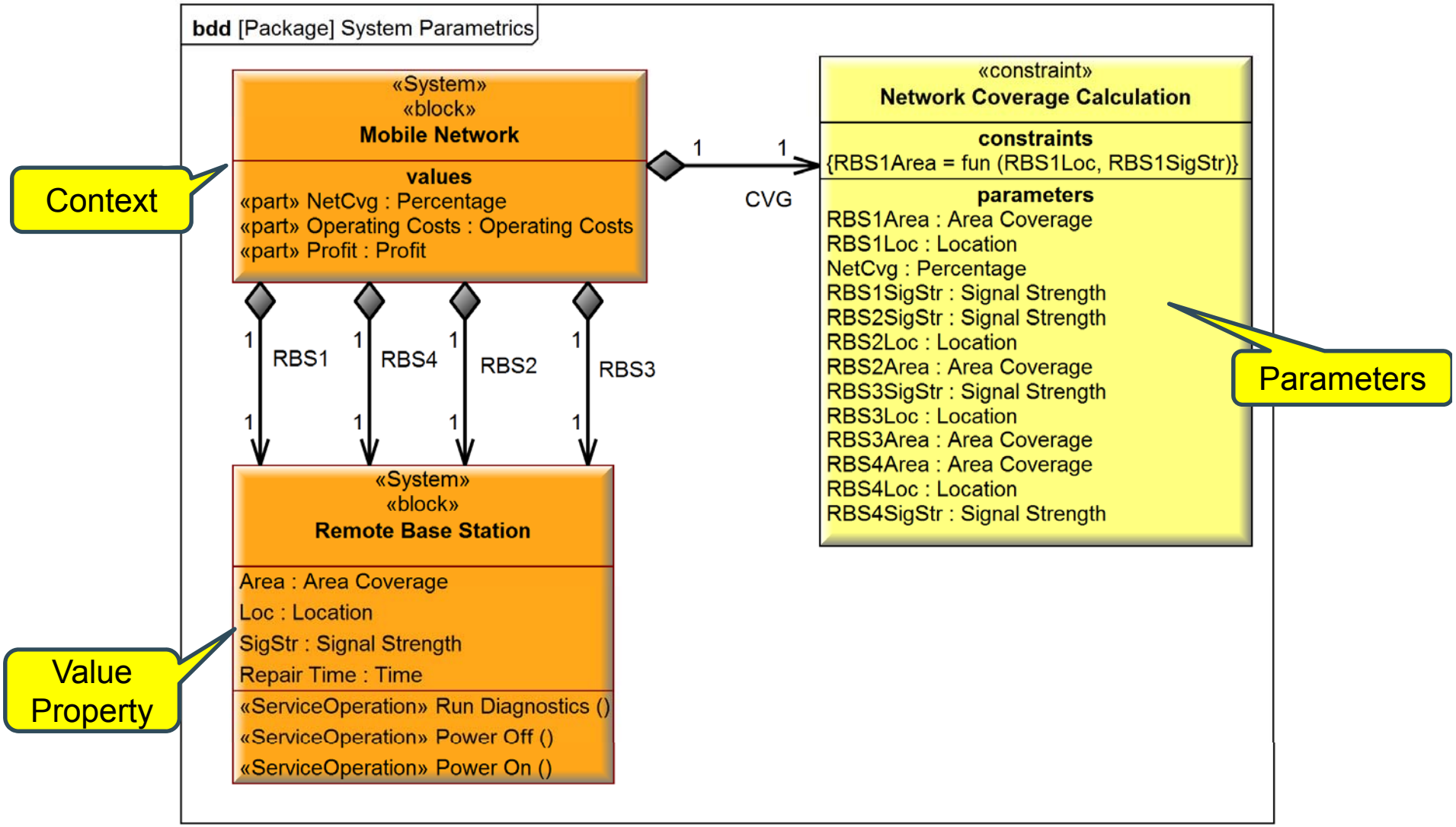
- Snapshot of a simulation of the state behavior of the base units and network.
- Network is at 96% coverage with two failed Base units.



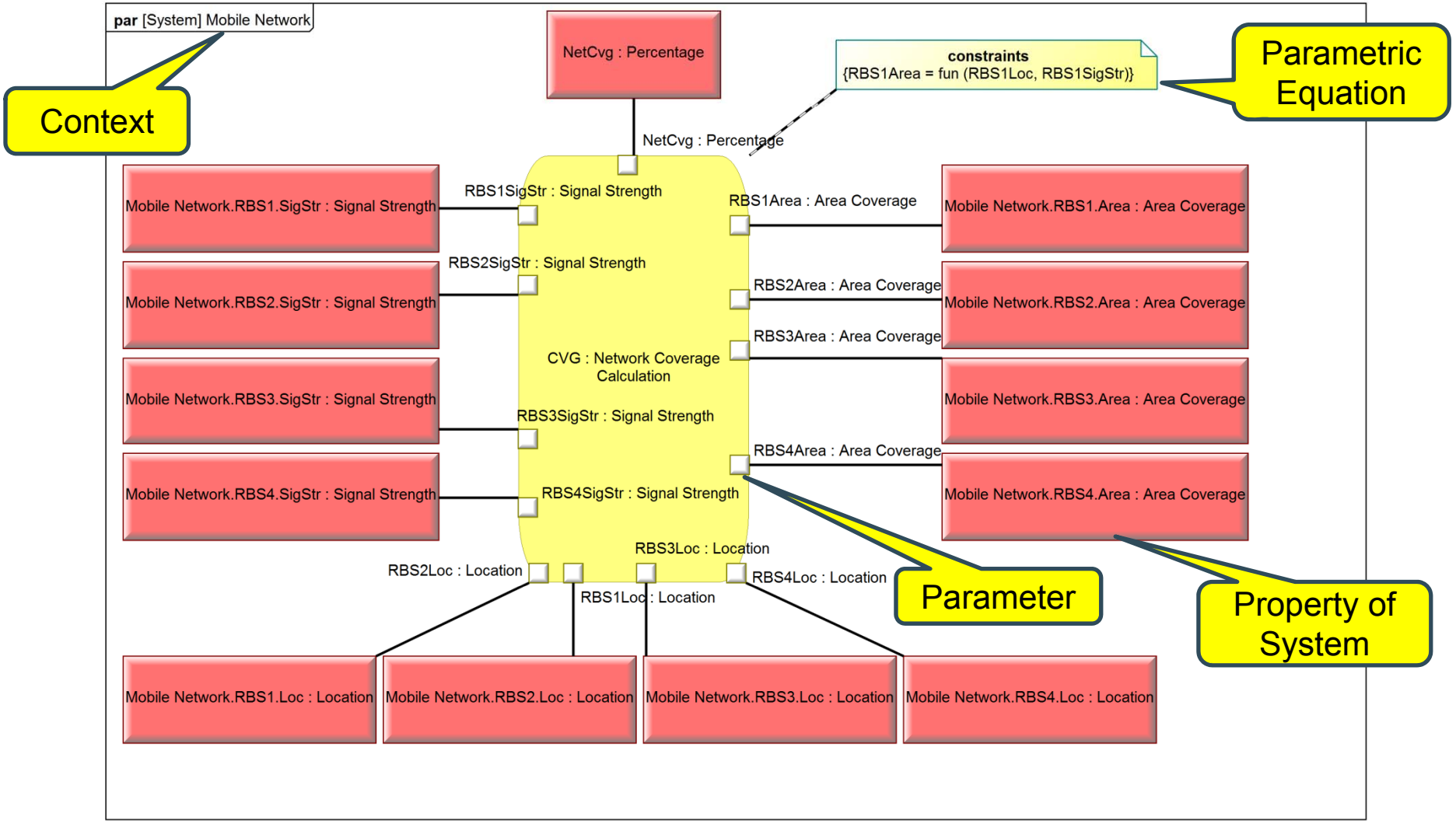
SysML Parametrics – Trade-Off Analysis

- Used to express constraints (equations) between value properties
  - Provides support to engineering analysis
    - e.g. performance, reliability, etc
- Constraint block captures equations
  - Expression language can be formal
    - e.g. MathML, OCL …
  - or informal
  - Computational engine is defined by applicable analysis tool
    - and not by SysML
- Parametric diagram represents the usage of the constraints in an analysis context
  - Binding of constraint usage to value properties of blocks
    - e.g. vehicle mass bound to **F= m * a**

SysML Parametrics: Definition



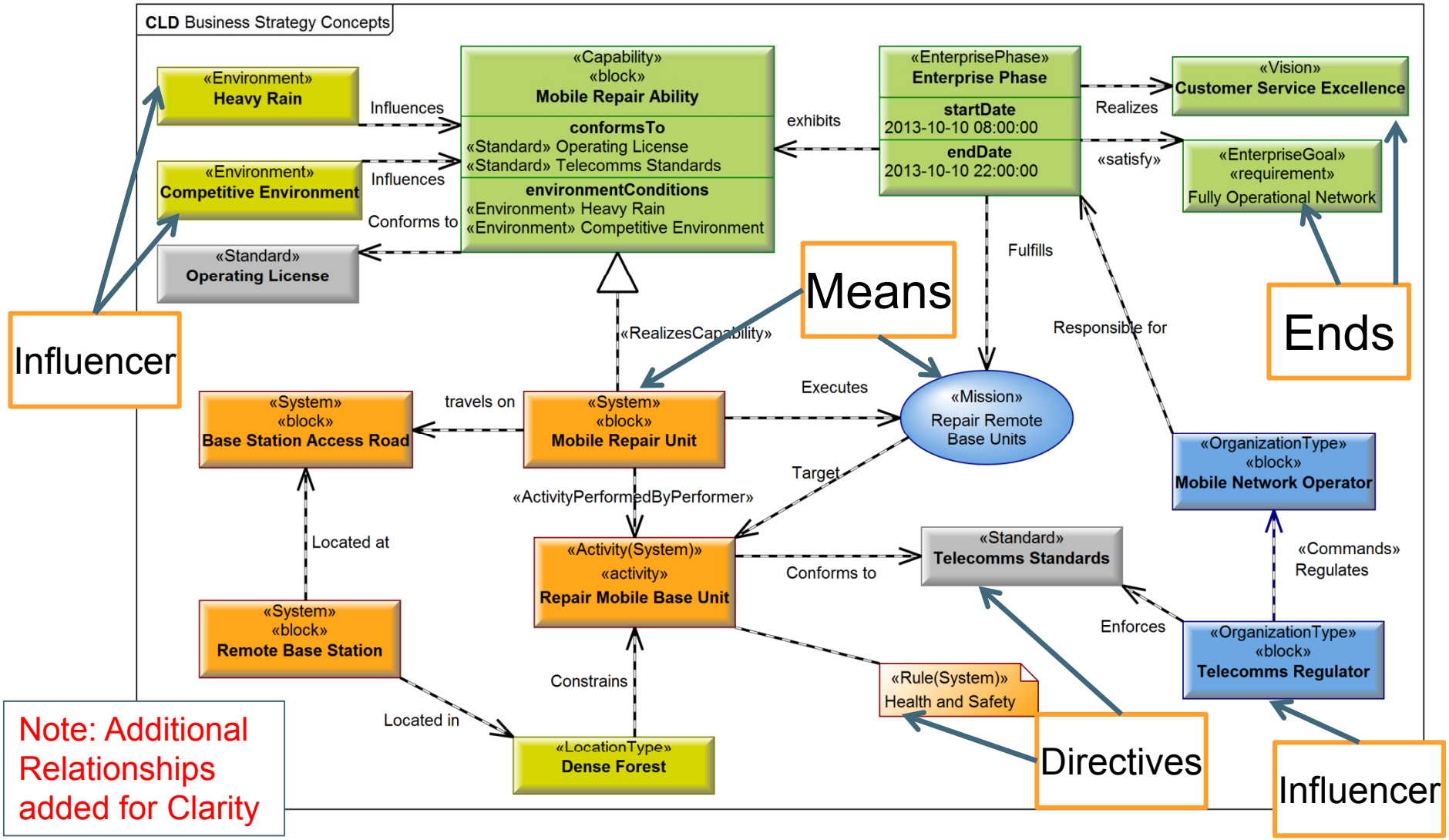
SysML Parametrics: Usage



Business Motivational Modeling (BMM)

- The OMG Business Motivation Model (BMM)
  - "BMM captures business requirements across different dimensions to rigorously capture and justify why the business wants to do something, what it is aiming to achieve, how it plans to get there, and how it assesses the result." [OMG, 2010]
- The main elements of BMM are:
  - Ends: What (as oppose to how) the business wants to accomplish
  - Means: How the business intends to accomplish its ends
  - Directives: The rules and policies that constrain or govern the available means
  - Influencers: Can cause changes that affect the organization in its employment of its Means or achievement of its Ends. Influencers are neutral by definition.
  - Assessment: A judgment of an Influencer that affects the organization's ability to achieve its Ends or use its Means.

BMM Concepts in DoDAF

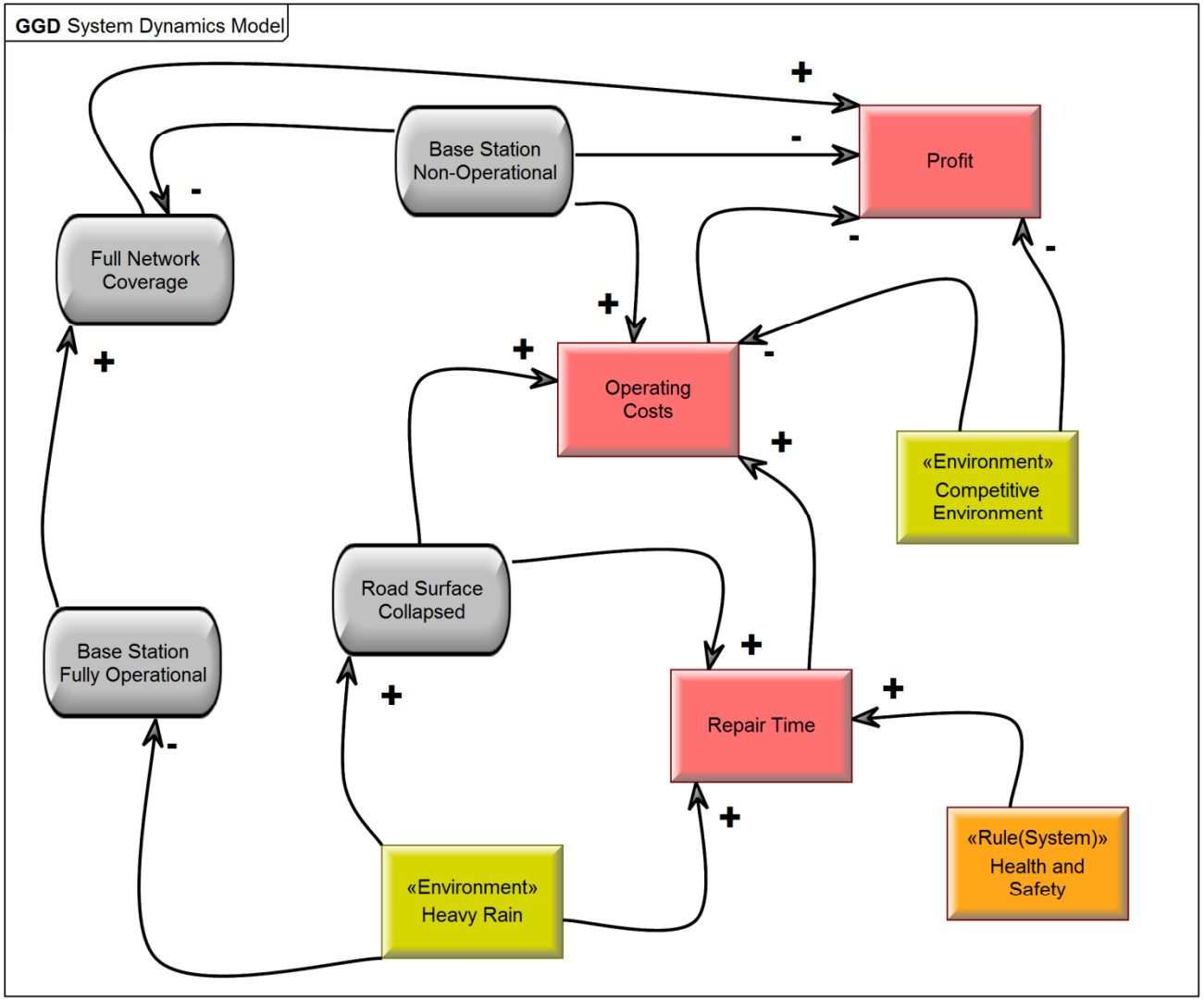


System Dynamics

- System dynamics is an approach to understanding the behavior of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system
- They are a potent tool to:
  - Teach system thinking concepts
  - Analyze and compare assumptions about the way things work
  - Gain qualitative insight into the workings of a system or the consequences of a decision
  - Recognize dysfunctional systems
  - Analyze system interactions and influences
- Normally simulation is used to assist in the analysis

System Dynamics

- Models the relationships between the system elements
- Example diagram uses states, value properties, rules and environment
- Many more objects and relationships are possible



Conclusion and Summary

- Understanding causal sequences is critical to systems engineering and architecture
- These sequences can be modeled in DoDAF/MODEM
- Simulating the sequences aids in understanding
- Different representations are required for different audiences

Questions, Comments, Discussion

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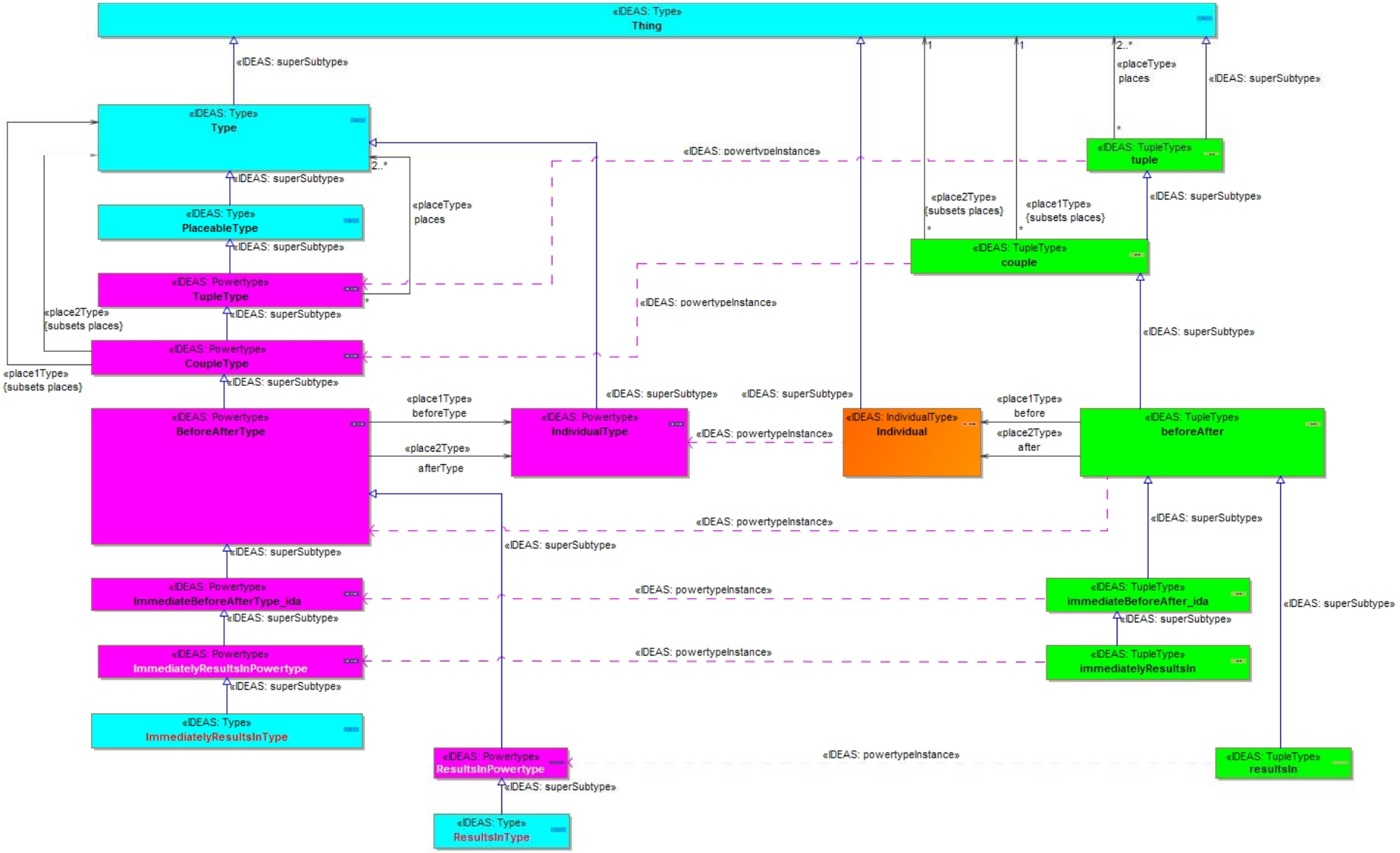
Motivating argument for the effect connections



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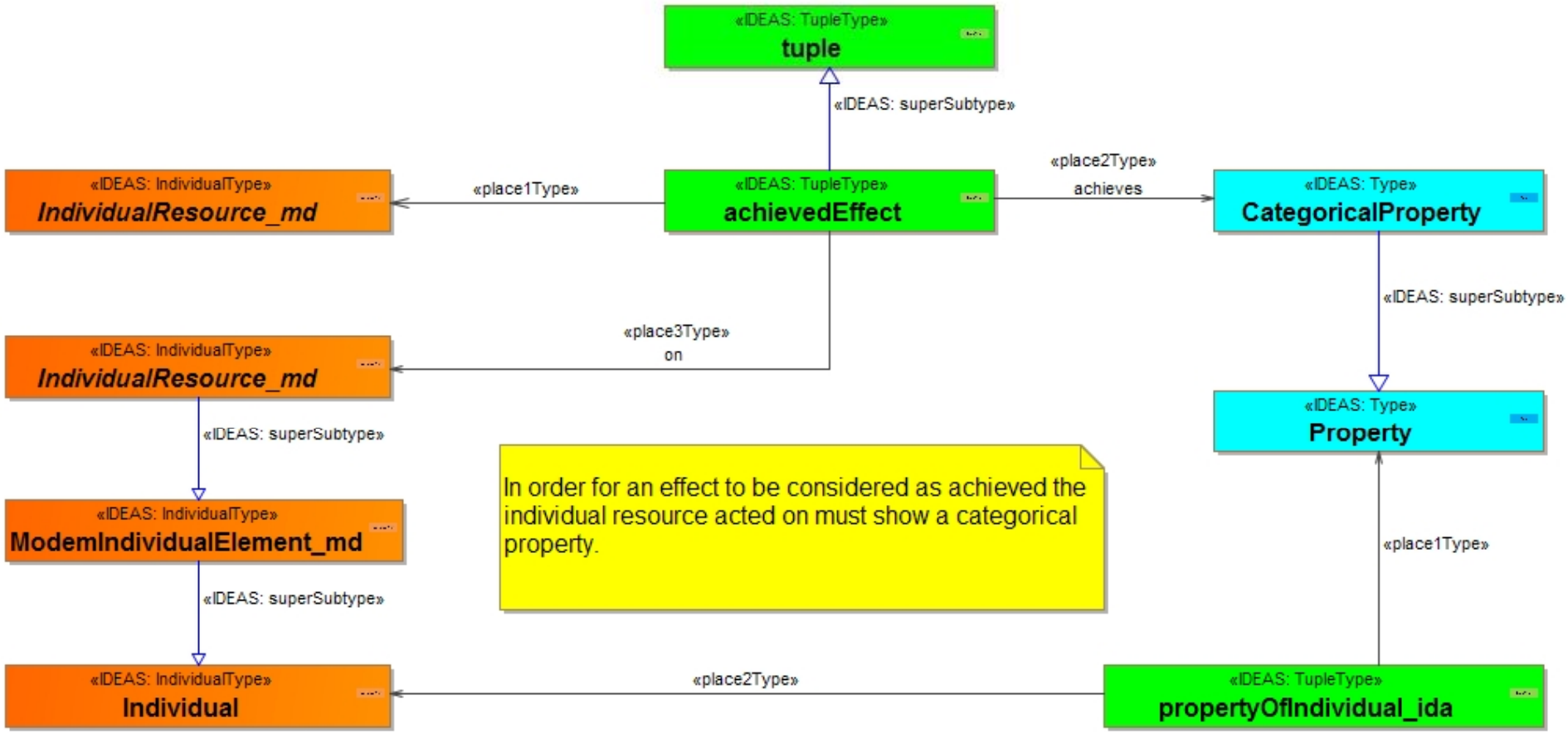
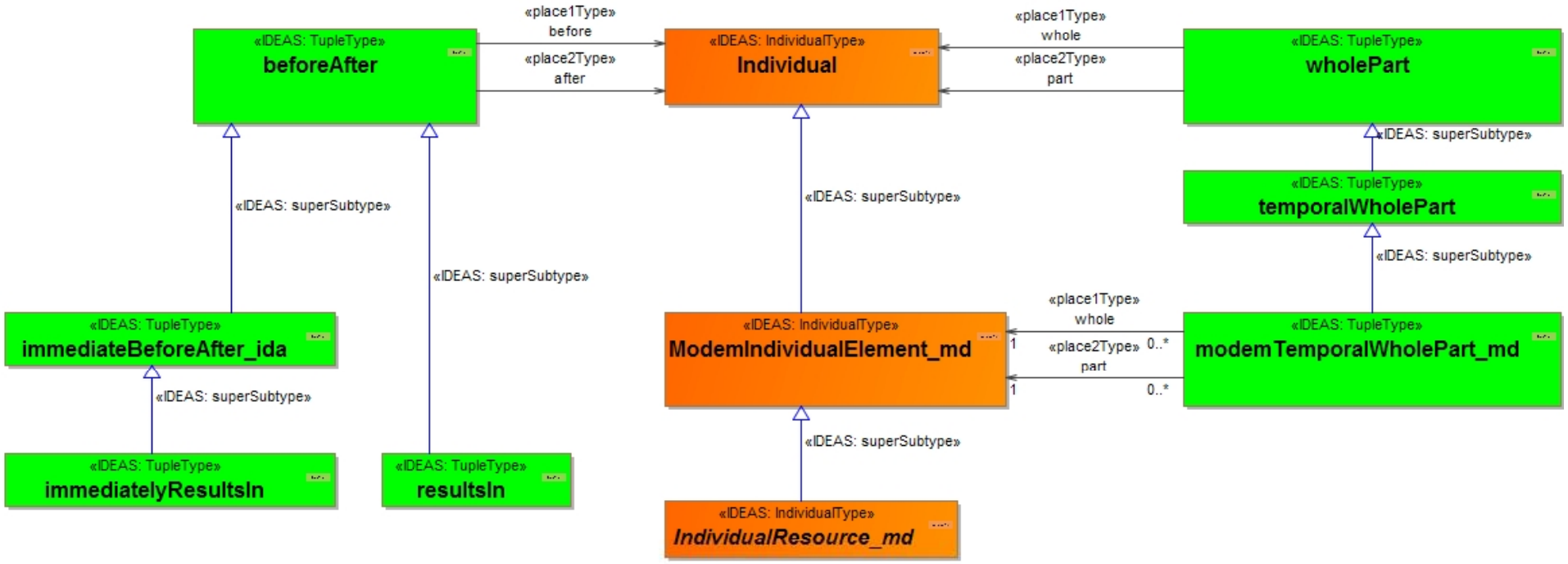
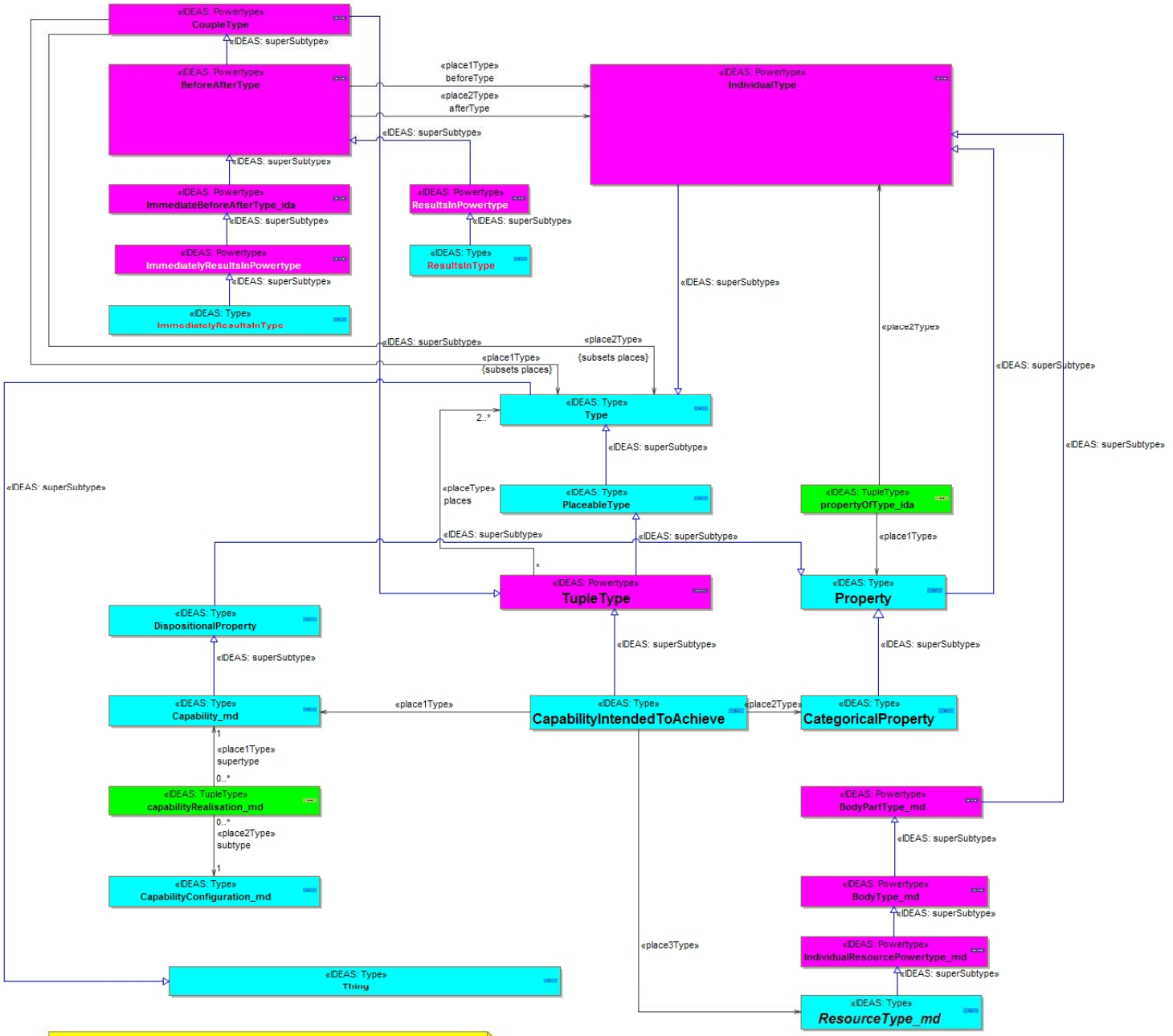
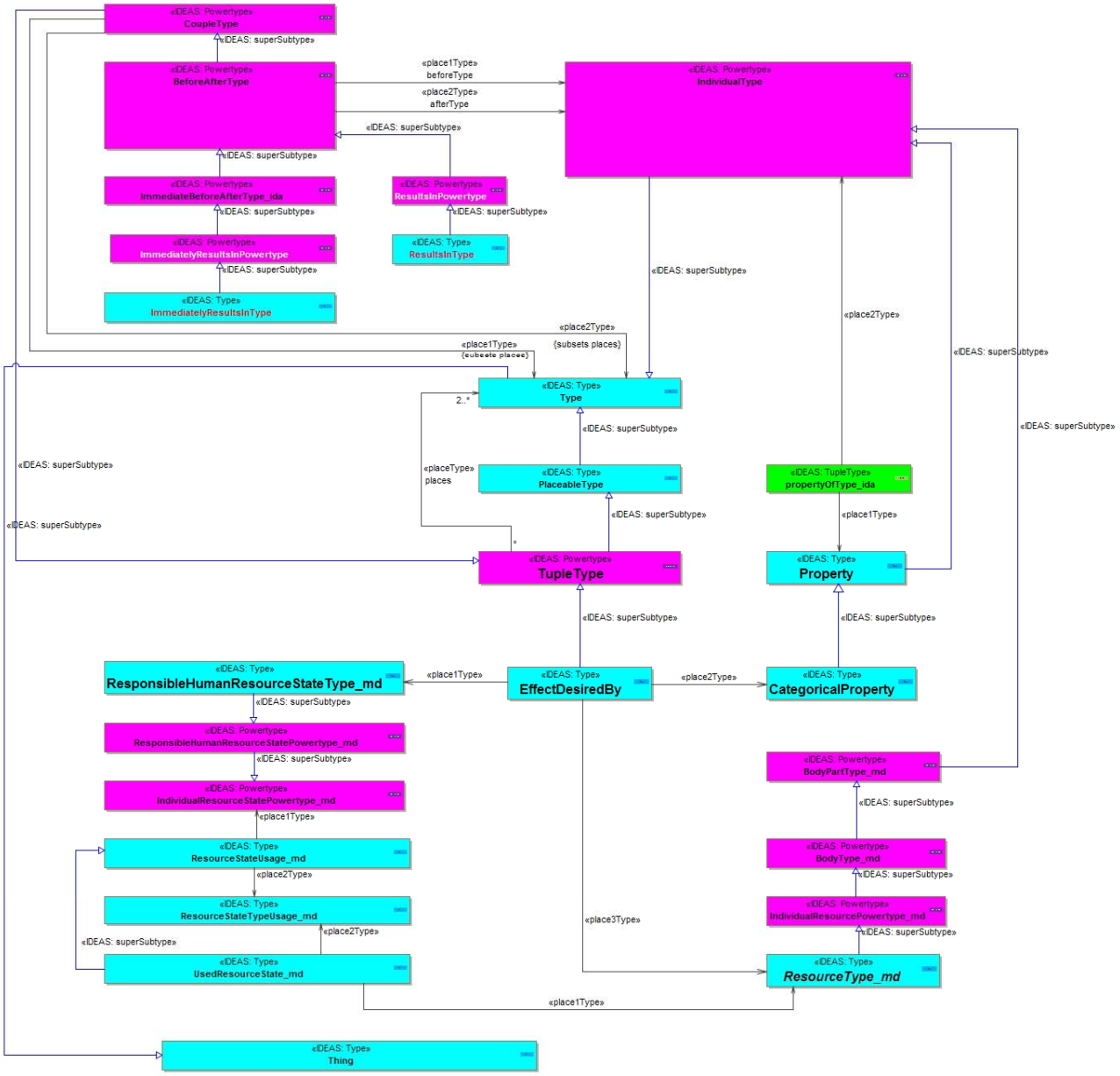




There are temporal parts of at most two individual resources where it can be stated that one temporal part of one resource ends before the other starts and where it is determined that the temporal part of one immediately results in the other temporal part or just results in the other.



This rather complex diagram traces the connections between al the elements involved in this representation and it shows that a property of type need to tie the affected resource type to the categorical property and that a ResultsInType or an ImmediatelyResultsInType relationship should exist between the resource types that exhibits the categorical property and the CapabilityConfiguration (a subset indirectly of ResourceType).



This rather complex diagram traces the connections between al the elements involved in this representation and it shows that a property of type need to tie the affected resource type to the categorical property and that a ResultsInType or an ImmediatelyResultsInType relationship should exist between the resource type affected and the ResourceType that after a somewhat elaborate connection can be found as being used by the phase of the responsible human resource.