SYSTEMS ENGINEERING
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An Artificial Environment for Exploring Systems Engineering Effectiveness.

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AUBURN UNIVERSITY

STEVENS INSTITUTE of TECHNOLOGY
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Agenda

- Overview and Status
- Observations from initial prototype
- Examples of Refined Definitions
- Walkthrough of example
- Next steps

Agile/Lean SE

- In 2011, the IC identified 4 critical problems to the SERC:
  1. Ineffectiveness of IMS/IMPs within large, evolving operational SoSs
  2. Scarce SE resources inadequate to support schedule-driven projects
  3. Decisions made late or at a level removed from the context
  4. Lack of visibility into the status of SoS-wide capability developments
- SERC postulated agile/lean approaches and adaptive governance mechanisms as possible solution
- Two year investigation developed proposed concepts
- Issues:
  - How to evaluate validity
  - How to transition knowledge/mechanisms

Capability Performance

Capability	% Value deployed	Demand/ Capacity	Est. Full Depl. Date
Network Refurbish NYC	64%	***115%***	7/14
HIPPA Changes	88%	83%	3/13
BYOD for MDs system-wide	15%	52%	11/15

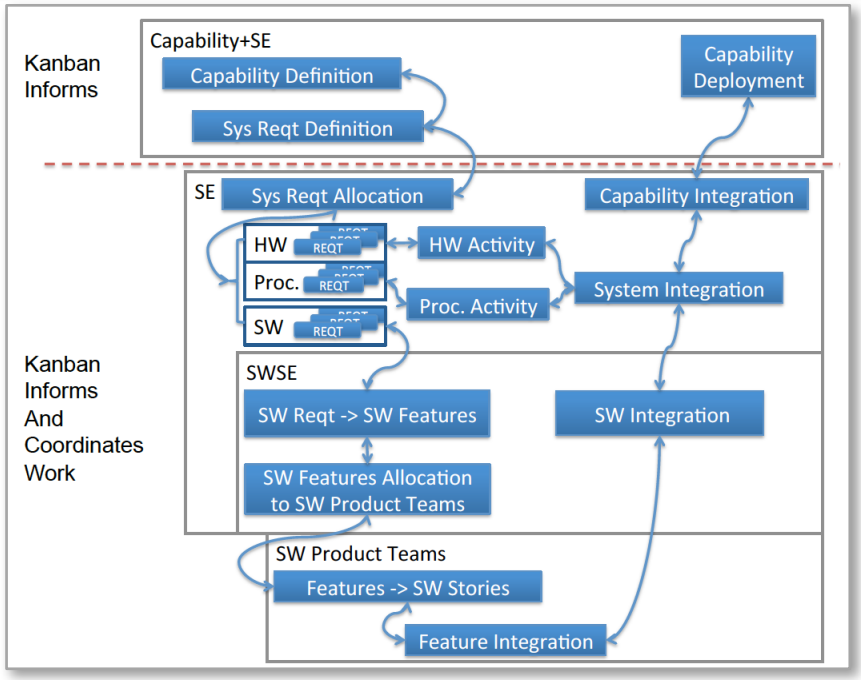
Capacity Allocation

New	52%
Sus	30%
Inf	18%

Flow Measures

	Capability	Requirement	Feature
Average Lead Time	13.3m	3.2m	.25m
Average Demand/ Capacity	101%	87%	***120%***
Average queue level	60%	74%	***135%***

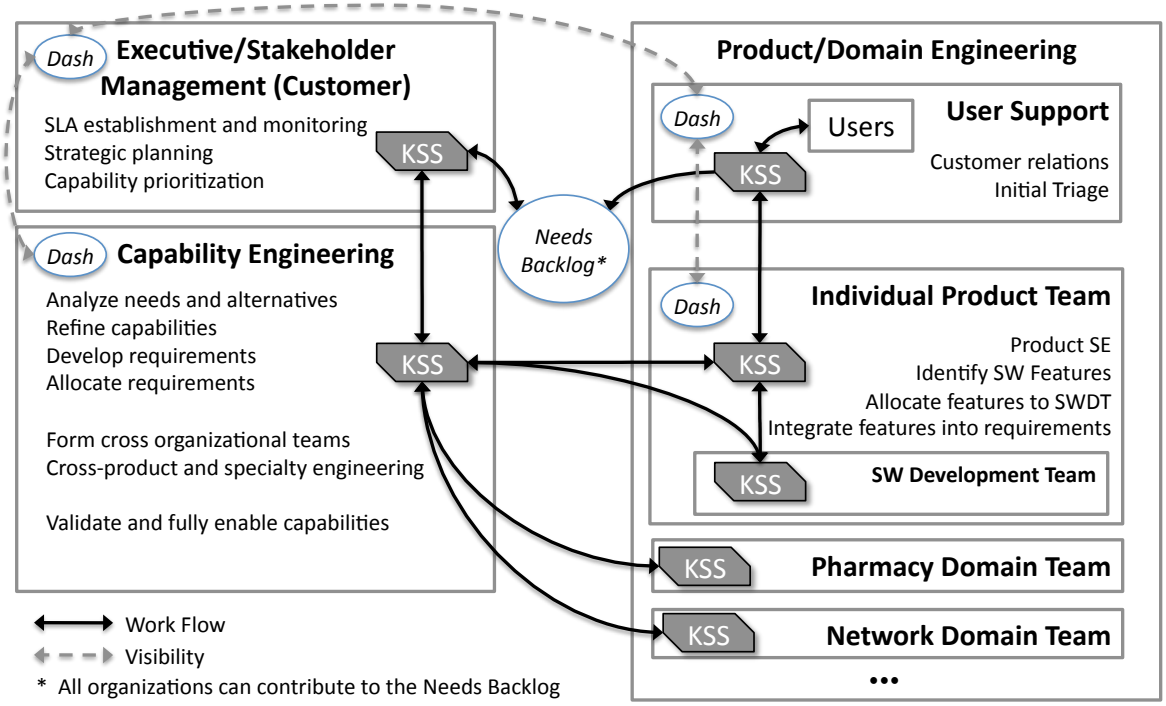
Age	Elevated Issues
New	SW SE Service request lead time 30% over upper control limit
2 weeks	Security engineering queue above capacity
3 weeks	Network engineering capacity reduced 30% (turnover)



Key Concepts

- Pull (kanban) scheduling
  - Value-based selection
  - Limited WIP
  - Classes of Service
- SE as a Service
  - Value negotiation
  - Scarce resource-driven
  - Collaborative/Negotiated
- Integrated work and data flow
- Information radiators at all levels
- Appropriate organizational structures

A Multi-level Network of Kanban-based Scheduling Systems



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Demonstration and Analysis Tool for Adaptive SE Management (DATASEM)

- Key enabler for both conduct and transition of the research
- A simulation-based research infrastructure to study, validate, and demonstrate to decision makers the costs, benefits, and risks of adaptive approaches

Objectives

Enable **realistic experiments** to understand how **governance model**s, organizational structures and work flows interact across a SoS

- Investigate new approaches in a wide variety of acquisition and development environments
- Understand the implications of organizations with mixed governance models across components
- A possible means of measuring the value of systems engineering

Provide a framework to **calibrate assumptions of performance**

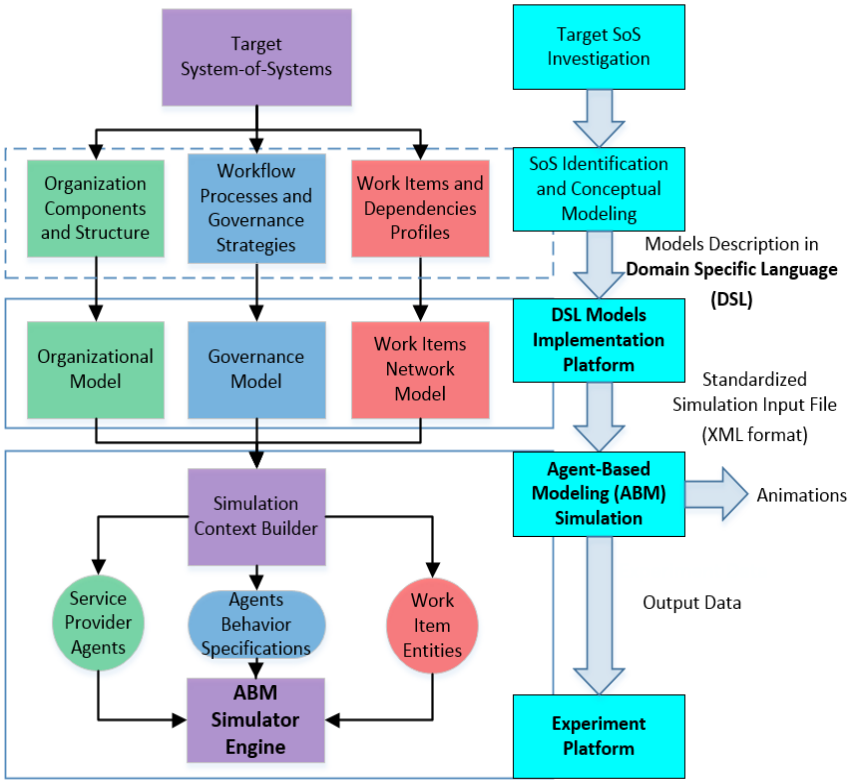
- Build data for increasingly sophisticated experiments
- Resource capabilities, team maturity, turnover
- Overhead costs, complexity of work, rate of environmental change

Integrated **experiment-generation tools** that provide the user with

- A broad selection of calibrated and experimental patterns for organizations and governance models
- Sophisticated stochastic support for generating large work item networks
- Comparison to other similar experiments
- Graphic demonstration of benefit/cost to convince risk-averse decision makers

Experiment Description Infrastructure

- **Domain Specific Language:** Define environmental and management characteristics
  - **Organizations:** Captures various organizational structures, including SoS
  - **Work flows:** Defines the technical work to be accomplished
  - **Governance:** Specifies how work is accomplished across and within organizations
- **Implementation infrastructure:** Software libraries that implement the DSL models for simulation
  - Enablers for executing the DSL syntax and semantics
- **Simulation engine(s):** Software that performs and controls the simulations
  - Initially using RePast an agent-based simulator
  - Research should generate sufficient data to add other simulation modes or specialized simulations such as systems dynamics models



R-126 delivered an initial prototype of DATASEM in a web-accessible and standalone edition in December 2015. However, ...

Status

- Initial prototype was completed and delivered to the sponsor in December 2015
- Start of 2016 work delayed until March

es

of the prototype by the team led to a number of observations and the decision to address some foundational issues

- Have revised the definitions of many of the modeling structures
  - Currently undergoing review
  - Revising the DSL to align with the changes
  - Beginning revision of the software

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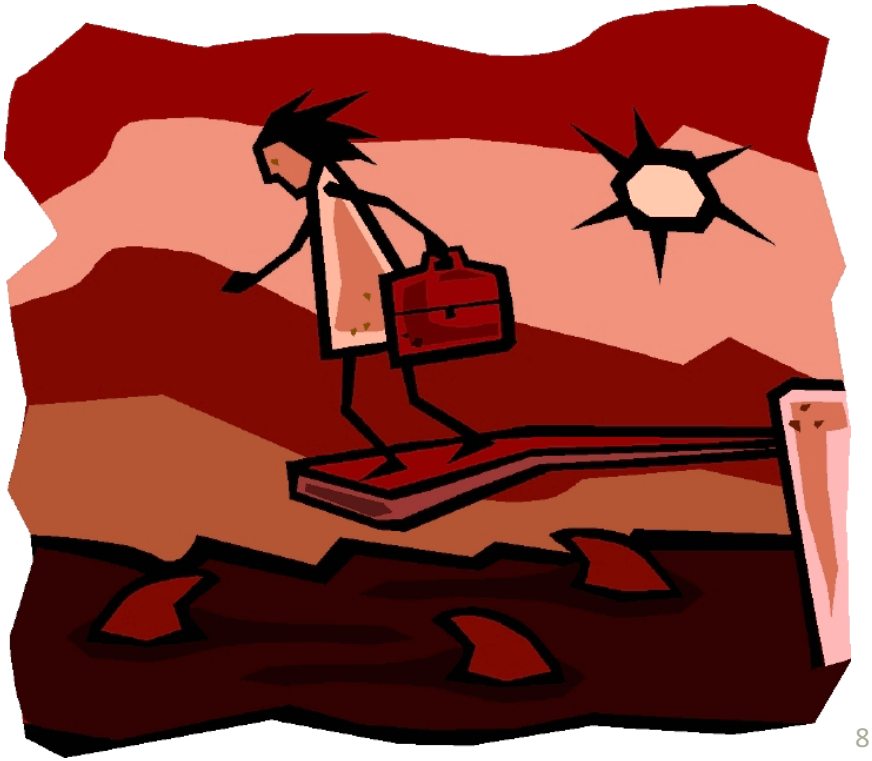
Observations from RT-126 (-) and Responses in RT-152 (+)

- Vague definitions of governance strategies and mechanisms
  - — The definitions were misunderstood and so implemented incorrectly
  - + Definitions have been updated and clarified
  - + New definitions being reviewed by industry and sponsors
  - + Building a set of real world scenarios showing how mechanisms work
- Interaction of organization, work and governance models and work flow definition
  - — Had assumed (incorrectly) that the models were independent
  - + New definitions and templates
  - + incorporate interaction
- DSL
  - — Tension between elegance, extensibility, and practicality
  - + DSL being revised based on the new definitions



Refined Definitions

Organizational Components (OCs)

OCs are companies, organizations, teams, individuals, resources – are defined according to their capabilities, governance models and relationships in a data-rich graph.

Each OC has a requested work queue and an accepted work queue

Each OC has 4 key functions:
***A**ccept work*
*allocate **R**esources*
***E**xecute work items,*
***M**onitor and report status*.

Each OC has a *Governance Model*, defines the scope, concurrence and activity of the technical process and management mechanisms.

Two types of OCs

Basic. Basic OCs have only internal resources. Can represent tools or special equipment (for example a test suite configuration), or individual staff resources.
Delegating. Delegating OCs perform work using internal resources or by arranging to delegate work with external OCs of any type

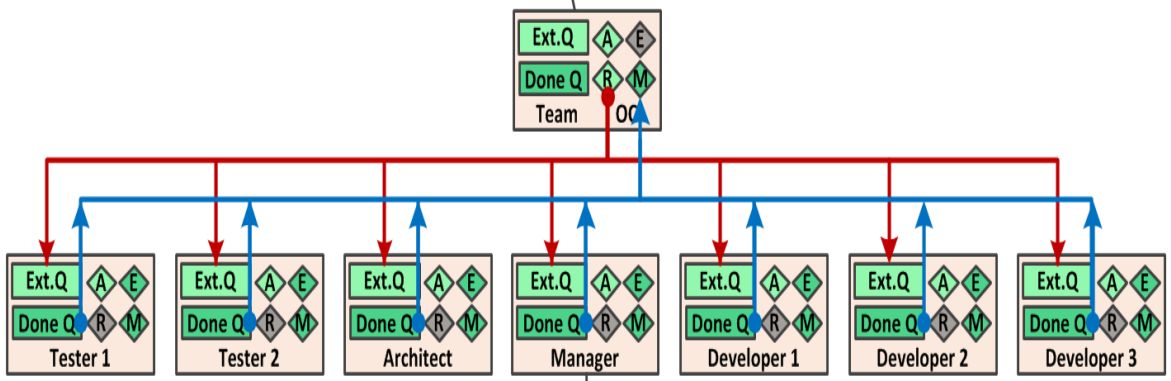
Two types of relationships in the OCs graph:

Workflow relationship. A relationship that defines how requests for work can flow between organizational components. The directionality and parameters of the relationship are defined in the individual OC's governance model.
Management hierarchy. Identifies where there are hierarchical or management relations. Every OC operates according to a governance model. Unless a governance model component is specifically defined for an OC, the OC inherits the component from its parent in the hierarchy.

Definitions

Example Organization Graphs

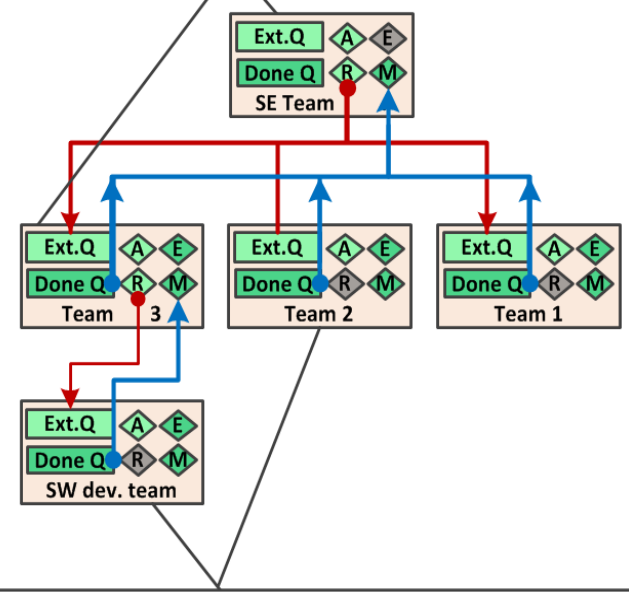
No internal work execution.
All work is delegated to lower level OCs. Team SP can receive work from lower level OCs (work placed to the external queue, and then accepted)



These are basic OCs. They accept work and execute it internally and do not delegate accepted work to other OCs.
Red arrows show work delegation (downstream) and blue arrows show status monitoring or WI status updates (upstream).
Basic OCs can delegate work back to upstream OC for redistribution only if it is a new WI that was triggered by the current WI under execution (e.g. request for additional analysis, unforeseen work, etc.).

Single-team Organization

These two teams can either delegate work to lower level (downstream flow) or execute it internally.



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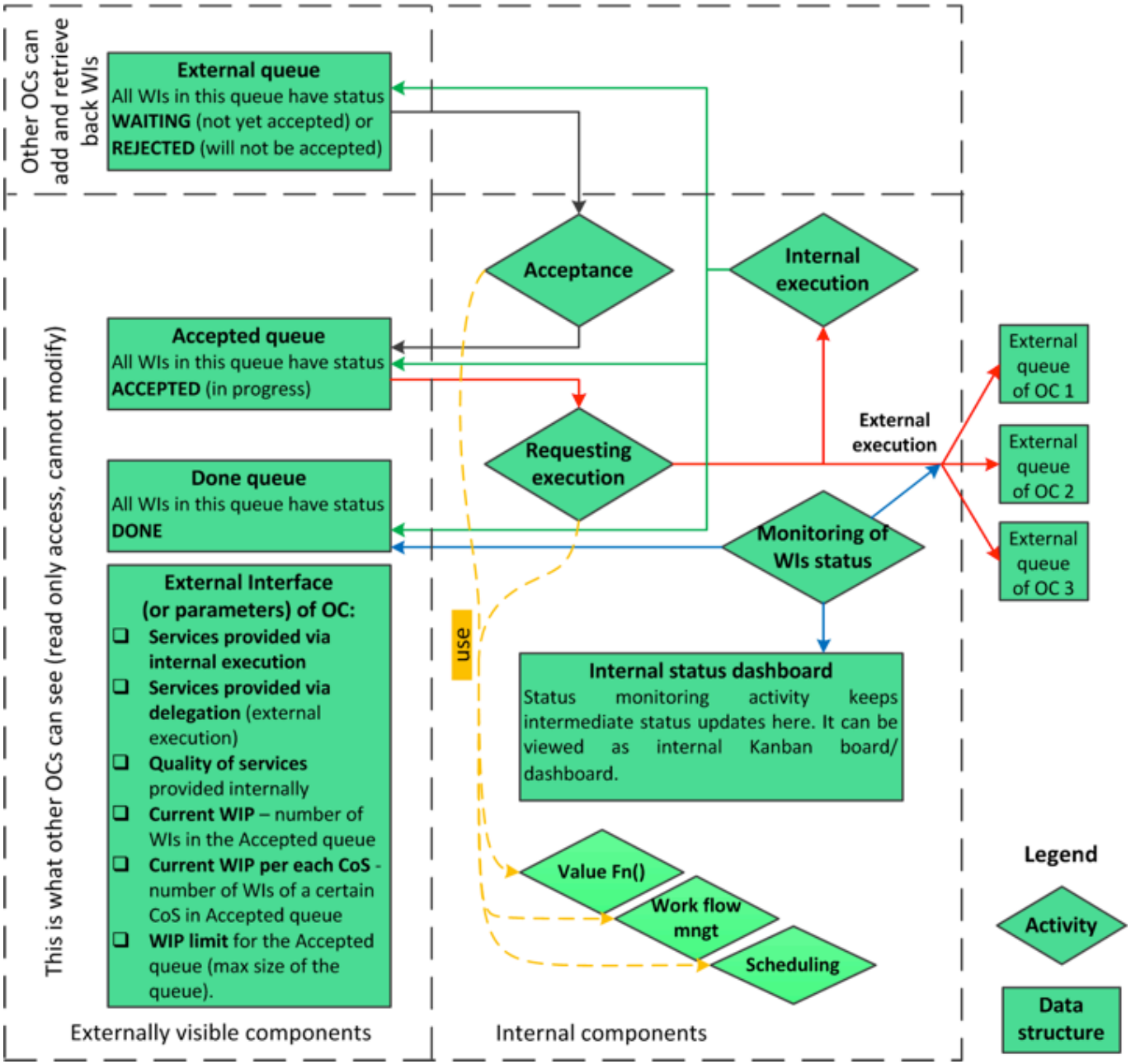
Multi-team Organization

Refined Definition
OC Operation

- Square boxes show artifacts or data structures
- Diamonds show agents' governance mechanisms components or activities/functions



Refined Definitions:
OC Scheduling Approach

- Because there is a relationship between the technical work decomposition and scheduling mechanisms, two types of scheduling approaches were defined
- This simple binary choice is an initial representation of an extended spectrum
- Using the PMI definitions, we have described the approaches as
  - Predictive. Work is scheduled far ahead of time, batch size of tasks is usually large, progress is based on that schedule, and the schedule is adjusted rarely.
  - Adaptive. Work is scheduled continually or in short iterations, batch sizes are usually smaller, value may be used to prioritize work, and flow controls may be used.

Refined Definition

Organizational Component Acceptance Activity

Acceptance chooses what and how many WIs to take from the external queue into the accepted queue. Acceptance can either be triggered by an event or by cadence.

The acceptance process has the following set of parameters for adaptive OCs:

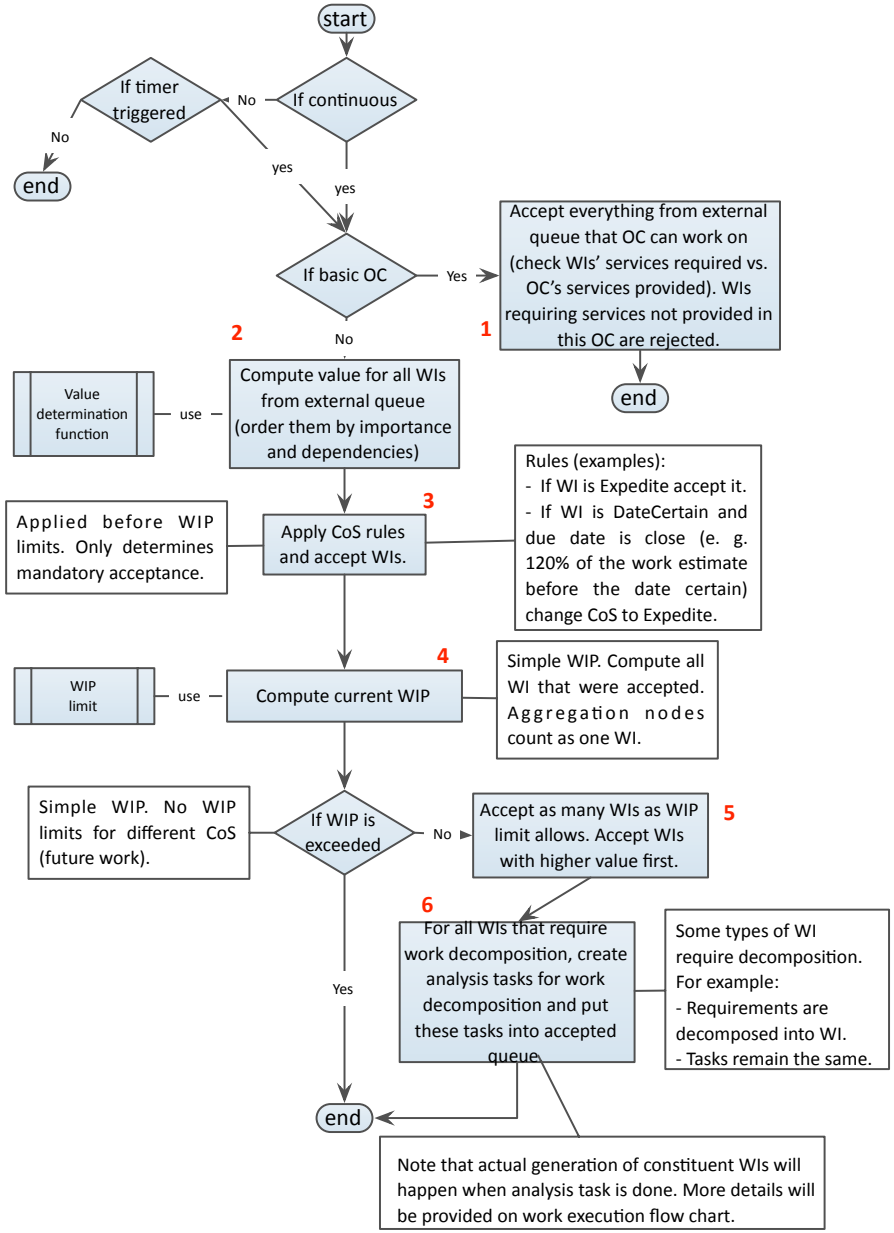
Cadence - how often acceptance is performed

Scheduling Mechanism- an instance of a scheduling mechanism (e.g. schedule, sprint, kanban-pull, ...)

Value Determination - this mechanism uses user-specified parameters (e.g. weights of different criteria, method of aggregation of different criteria, etc.) to determine the value of work items in the queue

Work Flow Mechanisms – CoSs, WIP limits.

Acceptance for adaptive technical processes



Refined Definition

Organizational Component Acceptance Activity

The acceptance process has the following set of parameters for **predictive** OCs:

- **Cadence**
- **Acceptance policy** towards new work in the external queue.

Currently there are three policies for acceptance:

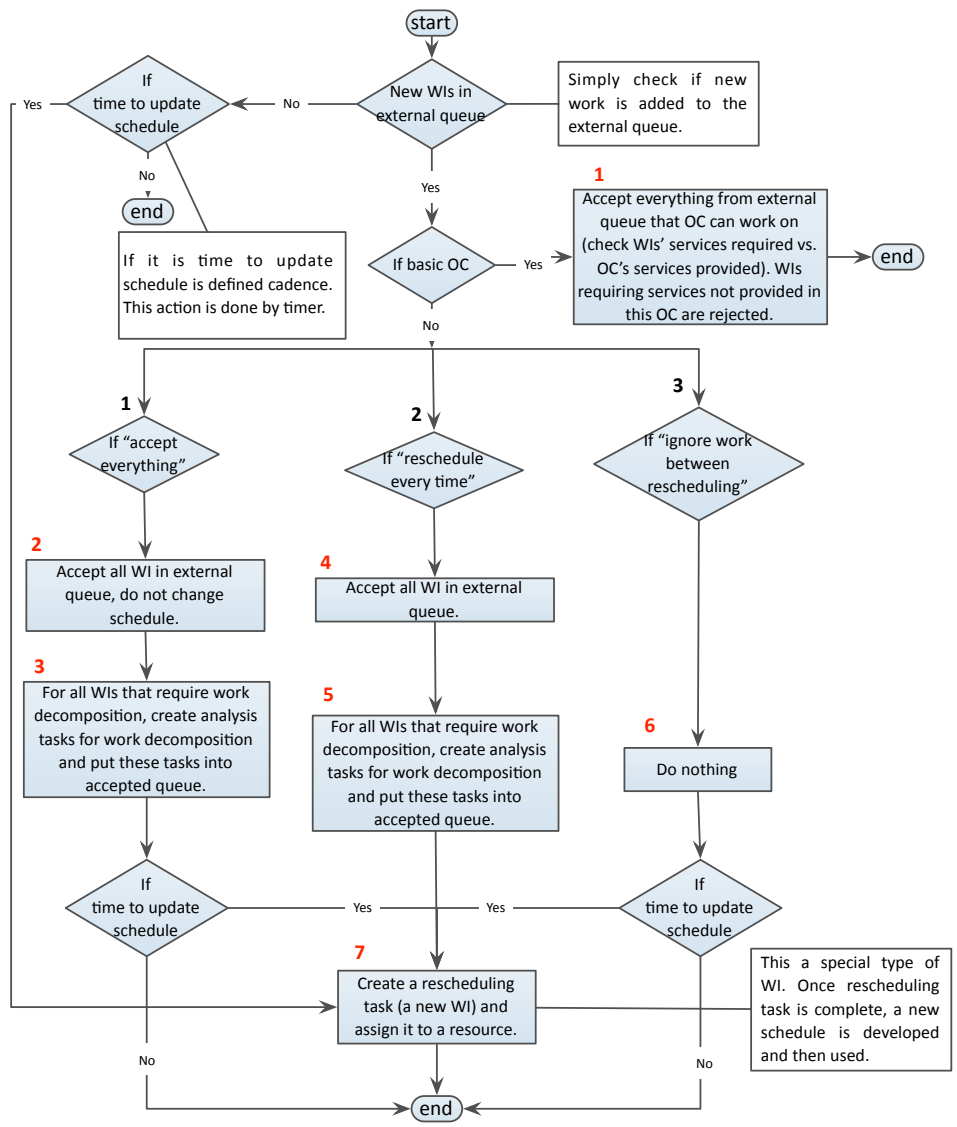
1. Accept everything from external queue and assign to resources in parallel to already existing plan. First try to utilize available resources, and only then multitask busy resources.

2. Reschedule everything every time something new appears in the external queue.

3. Ignore external queue between rescheduling.

No matter what acceptance policy is used, rescheduling is also done with a certain cadence (every month, year, etc.). Rescheduling cadence is a user-defined parameter.

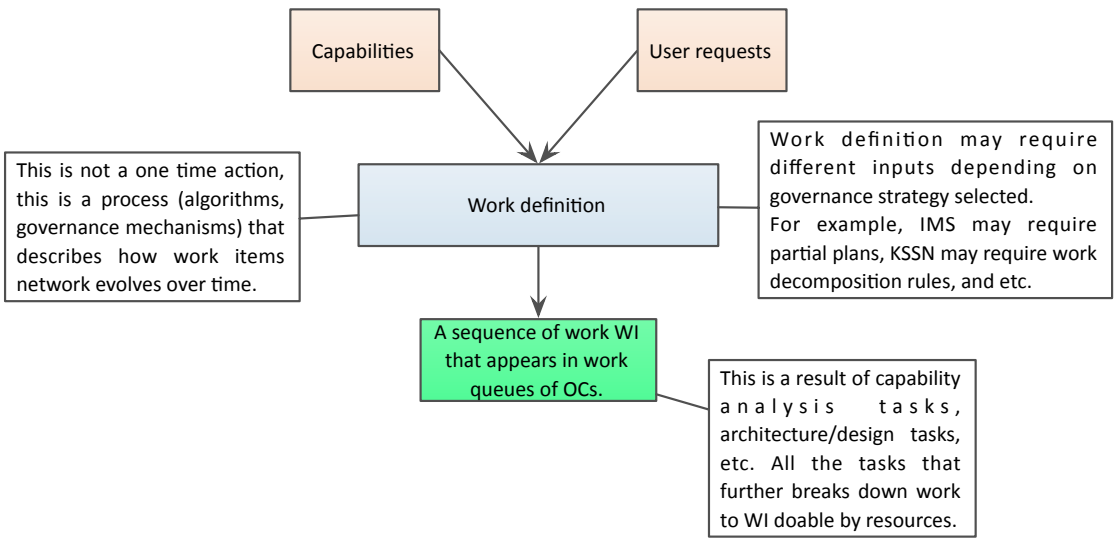
Acceptance for predictive processes



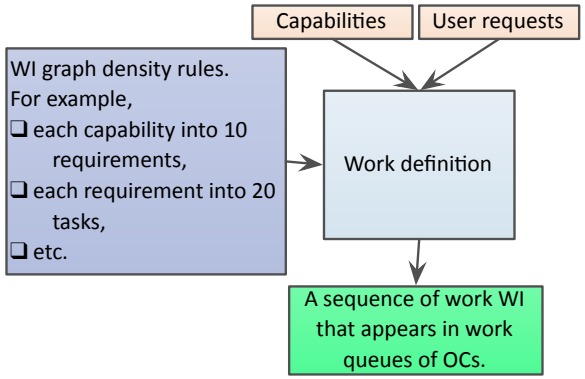
Refined Definitions

Work definition and work flow

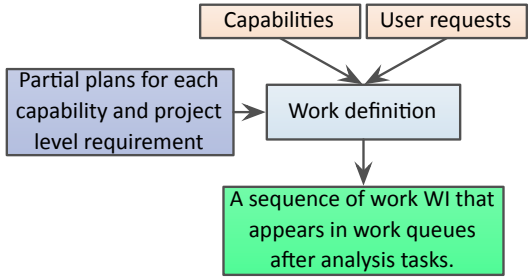
- Described by Work Items (WIs) in a WI Network (WIN) with multiple levels resembling a traditional work breakdown structure (WBS).
- Users specify information for the first few levels of work (e.g. capabilities, requirements, work packages); the rest of the network is stochastically generated using parameters OC technical approach and governance models



Adaptive Example



Predictive Example

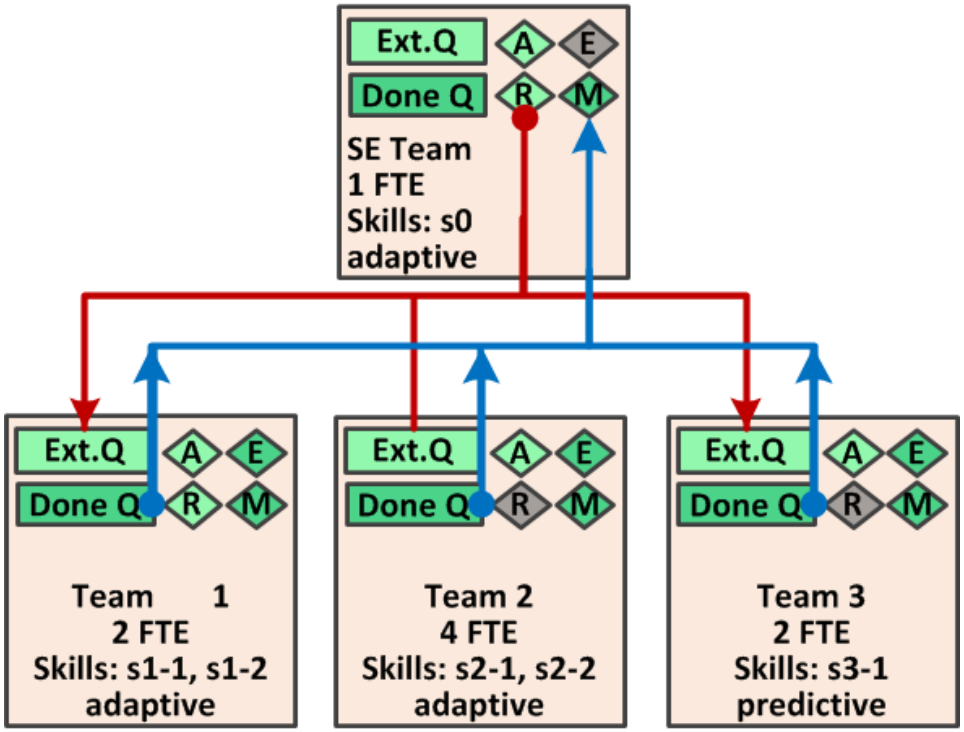


- Stochastic work item decomposition is performed when the WI is accepted by an OC. A Work Decomposition task is created. Once that task is complete, a WIN-generation algorithm creates a new set of nodes using parameters defined in the WI and the OC's governance specification.

Example (using the new definitions)

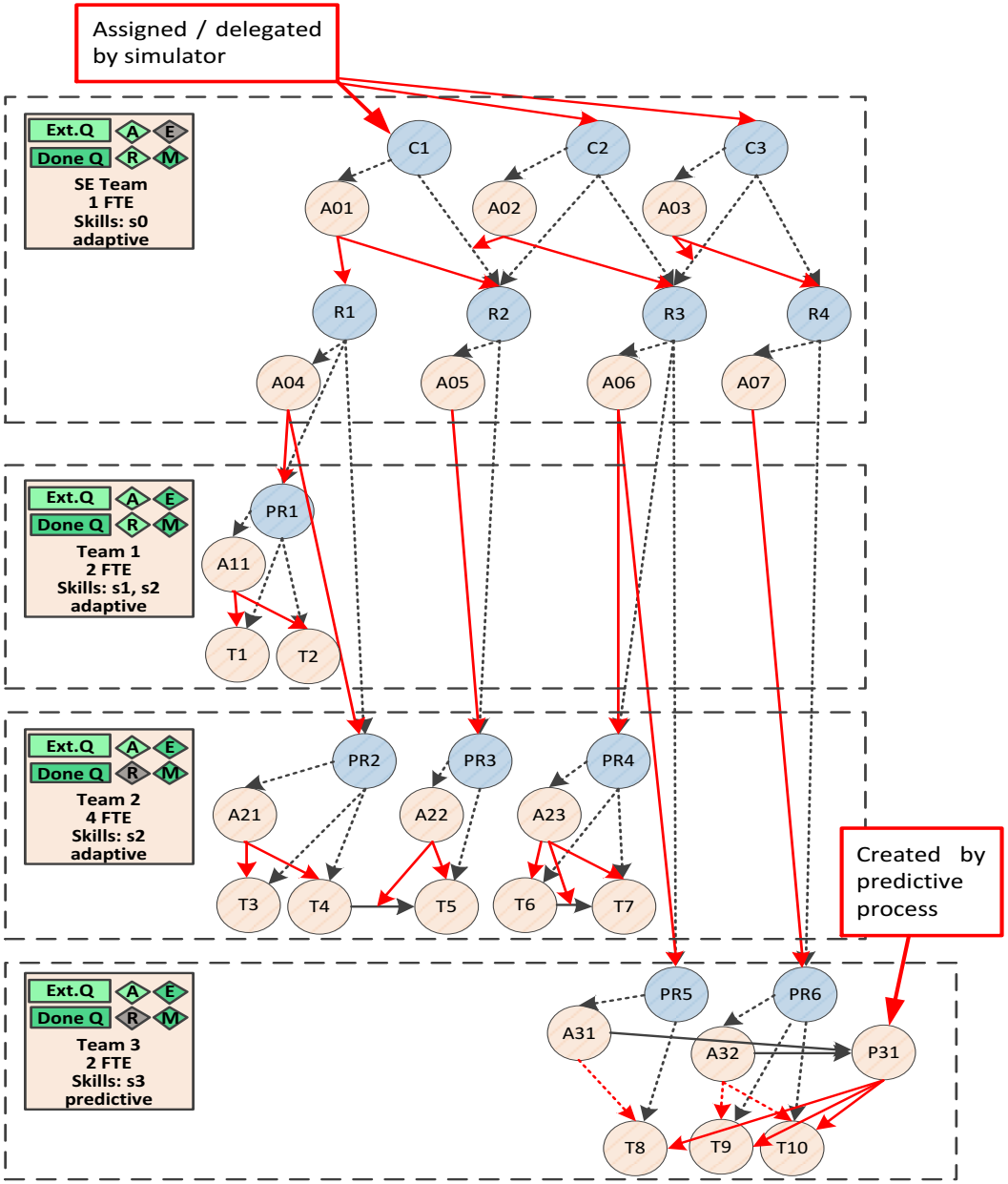
- Organizational structure

Org. structure

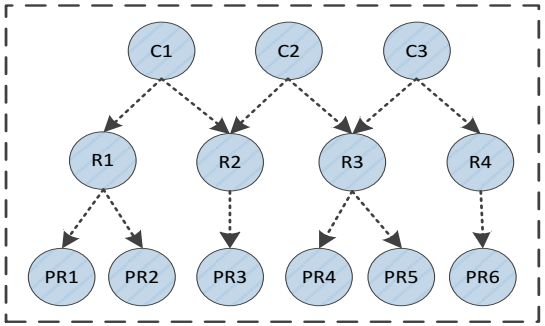


*FTE – full time equivalent

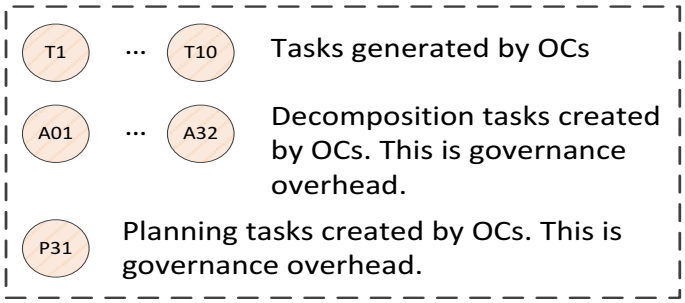
Example of using the new definitions (cont-d)



Process independent WIs
(input from user, from DSL)



WIs introduced by simulation



Generated by (source task creates destination tasks and/or relationships). A source tasks is a decomposition task.

Generated by (source task creates destination tasks, but not schedules them). Only for predictive processes.

Inheritance – decomposition hierarchy

Precedence (source precedes/causes destination).

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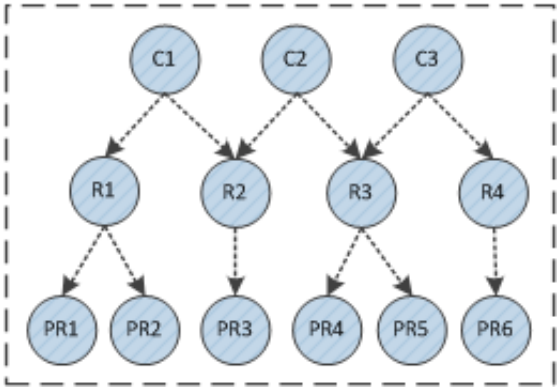
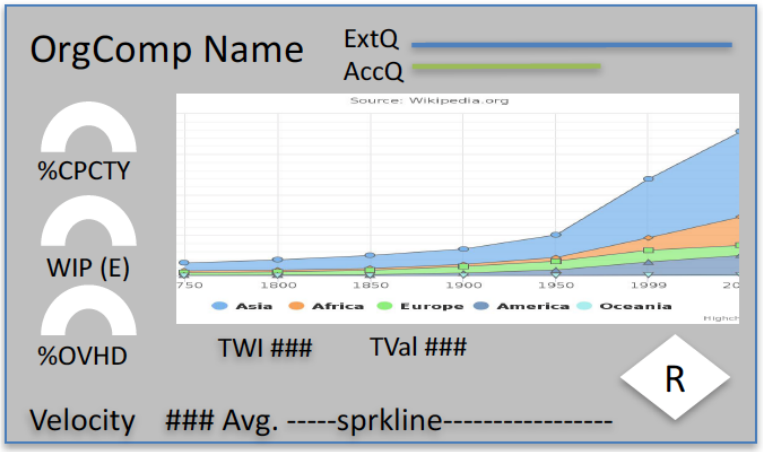
Example Process-independent work definition

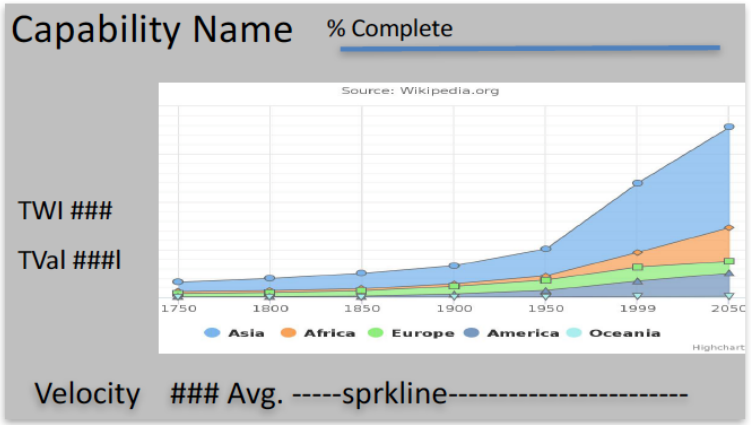
Process independent WIs
(input from user, from DSL)

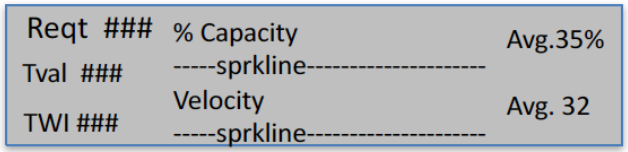


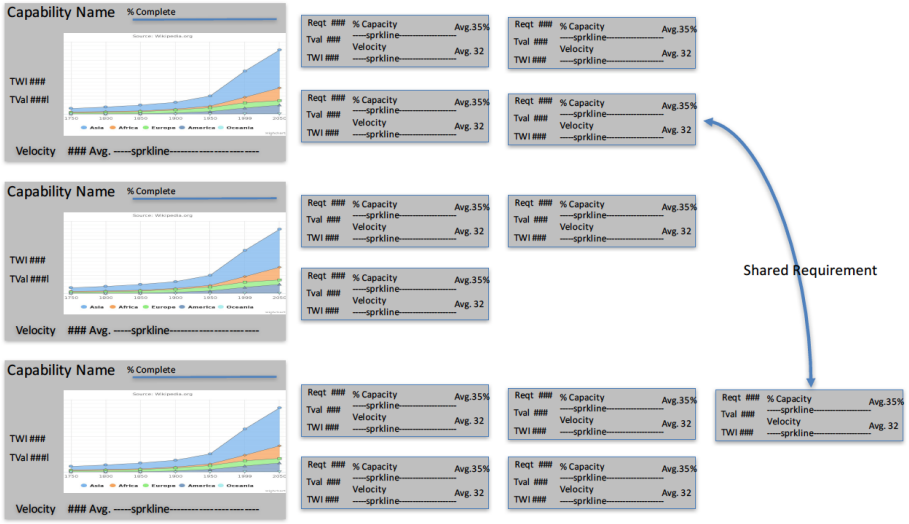
	C1	C2	C3	R1	R2	R3	R4	PR1	PR2	PR3	PR4	PR5	PR6
Value	40	30	30	20	35	30	15	10	10	35	15	15	15
Value distribution for constituent WIs.	-	-	-	-	-	-		Distribute value proportionally (divide parent's value proportionally).					
Estimated size	10	10	10	5	5	5	5	2	3	5	2	3	5
Estimated error	0	0	0	0	0	0	0	0	0	0	0	0	0
Required skills	S0 S1 S2	S0 S2 S3	S0S 2 S3	S0 S1 S2	S0 S2	S0 S2 S3	S0 S3	S1	S2	S2	S2	S3	S3
Distribution of skills for constituent WIs	-	-	-	-	-	-	-	S1-100 %	S2-100 %	S2-100 %	S2-100 %	S3-100 %	S3-100 %
Probability of change	0	0	0	0	0	0	0	0	0	0	0	0	0
Constituent WIs internal relationships complexity	-	-	-	-	-	-	-	0-90% 1-10%	0-90% 1-10%	0-90% 1-10%	0-90% 1-10%	0-90% 1-10%	0-90% 1-10%
Constituent WIs external relationships complexity	-	-	-	-	-	-	-	0-100 %	0-100 %	0-90% 1-10%	0-10%	0-100 %	0-100 %
Deadline (days)	8	12	20	8	8	12	20	8	8	8	12	12	20

Illustration Components

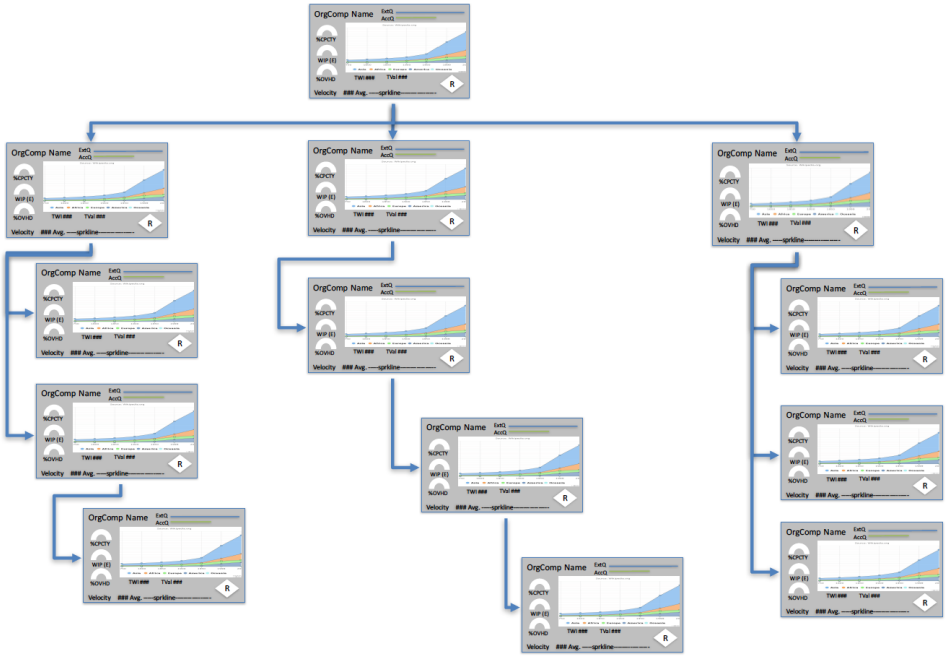








OC Tracking



Future work

- **Calibration and validation.** DATASEM needs to be validated through rigorous experimentation for sensitivity, and through the use of real data from development organizations for improved accuracy and realism. An experimental validation framework was created by Forrest Shull from the SEI.
  - Validation of tool in development and acquisition environments (ongoing)

- **Concepts still to be implemented or further studied**
  - Value determination and agreement (ongoing)
  - Interface of predictive and adaptive governance mechanisms (beginning)
  - Extend DATASEM to address acquisition (ongoing)
  - Model human behavior in decision making and negotiation among components of a system of systems (Not yet begin)
  - Conflicts between SoSE and constituent systems (not yet begun)
  - Negotiation of services and contracts (not yet begun)
  - Incorporate DATASEM into the SEEA (not yet begun)
- **Develop user interface for non-developers.** DATASEM's UI enhanced so a typical systems engineering or engineering manager can create products readily understandable by decision makers and executives.
  - Simplified graphic design and display interface (beginning)

How you can help

- Survey-based review version of the new mechanisms definitions is available
- Link: https://www.surveymonkey.com/r/DATASEM
- Please complete the review and share the link with colleagues with interest in this work
- Understanding the community's preferences will help us in refining and implementing the definitions

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Questions?

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Backups

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Use Scenario Example (still being defined)

- Title: Systems of Systems
- Description: A Systems of Systems project provides opportunities for a good mix of work to be completed in house and work to be contracted out, which is often not an easy decision for a company to make.
- Potential Considerations: Work item value can potentially serve a dual purpose, the first being the traditional sense of value delivered to customer, but the work items may have intrinsic value to the OC performing the work if it helps develop/maintain domain knowledge related to a core value stream. It may not be in the company's long term interest to delegate WI's related to a value stream even if it enhances value delivered in the short term.

Rick Scarpetti's ongoing work…

Example of using the new definitions (cont-d)

Process-independent work definition (blue WIs on the next chart) includes three capabilities, their decomposition into requirements and project level requirements. The SE team delegates project level requirements to OCs that decompose them into task level WIs (red WIs on the next chart). The work decomposition steps:

- Capabilities are allocated to SE team. Simulation engine allocates capabilities (roots of the WIs graph) based on required skills.
- Capabilities are decomposed into requirements by SE team.
- Requirements are decomposed into project level requirements by SE team.
- SE team delegates PRs to other team, other teams decompose PRs into tasks using their governance settings

Agile (Adaptive) SE goals

- Identify agile, lean, and other adaptive processes and governance mechanisms to help systems engineers
  - Identify, analyze and quickly **react** to issues in an environment of accelerating change
  - Keep pace with **evolving** requirements, risks and opportunities **throughout** the extended development lifecycle
  - Understand and manage the changing **economic and political factors** that undergird and enable system development
  - Broaden SE influence and **holistically** approach
    - Creation and evolution of systems of systems
    - Interoperability between legacy and new capabilities
    - Reductionism resulting in point solutions or locally optimized decisions
- A modeling environment to validate and experiment with
  - Adaptive mechanism performance
  - Their interactions with more traditional SE
  - How they can balance adaptability with discipline in a broad variety of environments.
- Inform organizations contemplating changes to their system development processes in complex system or SoS environments where different development approaches are applied concurrently.

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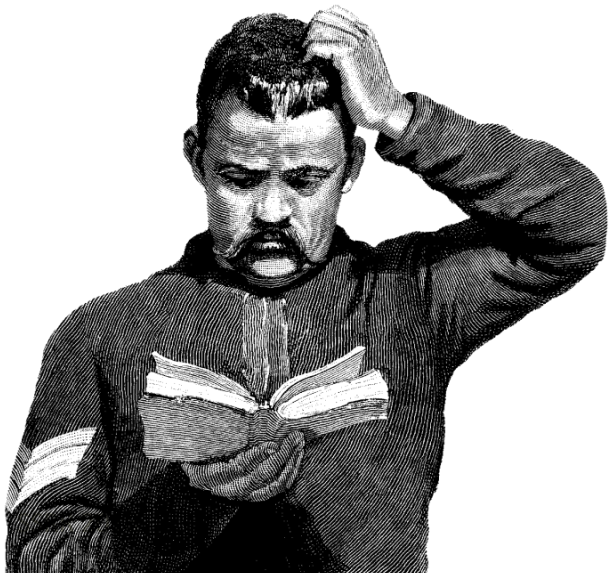
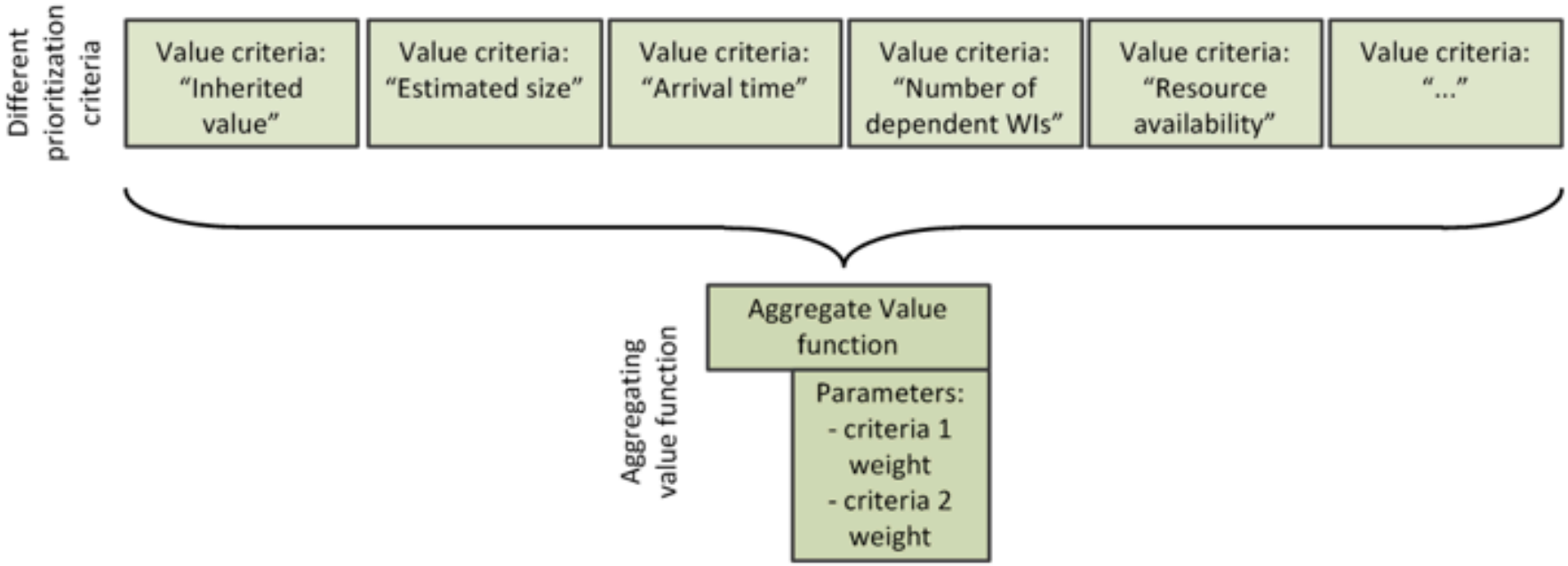
Management approaches considered

- **Adaptive, value-based** governance mechanisms that have been successful in some software, product development, and manufacturing environments
  - **Value-based** pull scheduling at multiple levels throughout the organization
  - **Value-driven collaboration** among developers, systems engineers, and stakeholders
  - **Visibility** of current value of work items and status throughout the SoS
  - **Improved flow** and more rapid delivery of stakeholder-influenced value through other agile/lean mechanisms (e.g., limited work in progress, queuing disciplines)



- Providing **SE** resources as coordinated and negotiated **services**
  - **Value-based** negotiated scheduling of SE services like all other work services
  - More **effective utilization** of scarce SE resources and fewer delays due to SE responses

Refined Definition
Value Function Mechanism (Example)



Example of aggregating value function:
Weighted sum of all components (by order) – each WI is ordered by all criteria and then weighted sum of orders is computed.

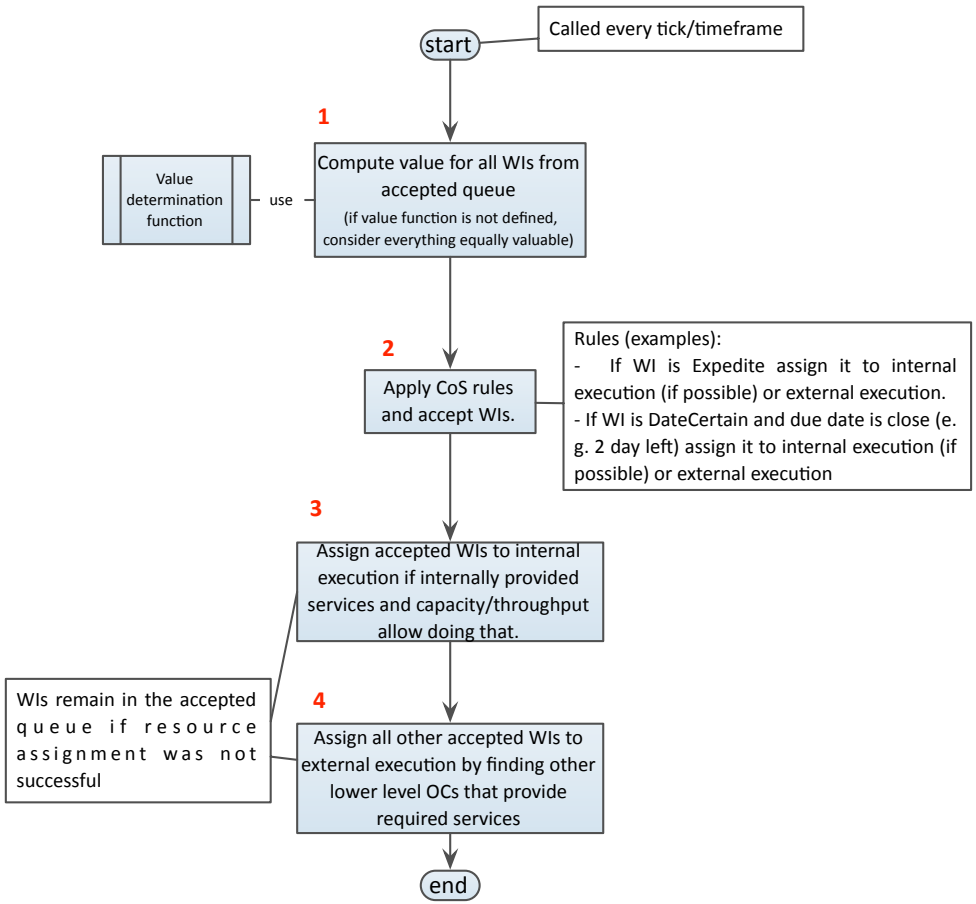
WI id	Prioritization component algorithm "Inherited value"	Prioritization component algorithm "Estimated size"	Prioritization component algorithm "Arrival time"	Prioritization component algorithm "Number of dependent WIs"	Prioritization component algorithm "Resource availability"	Aggregated
1	2	9	5	1	10	7
2	1	10	2	3	3	8
3	...	...	...	...	...	...

Refined Definition

Organizational Component Requesting Activity

Adaptive technical processes often use multiple iterations or increments with constant or changing cadences to provide continuous value and validation. They may order WIs according to some value formulation, or handle resource constraints due to the changing environment of the project. They may enforce broad Classes of Service that are used by other OCs, internal Work In Process limits, or other methods to support better flow.

Requesting execution ('resourcing', ordering and resource allocation) for adaptive processes

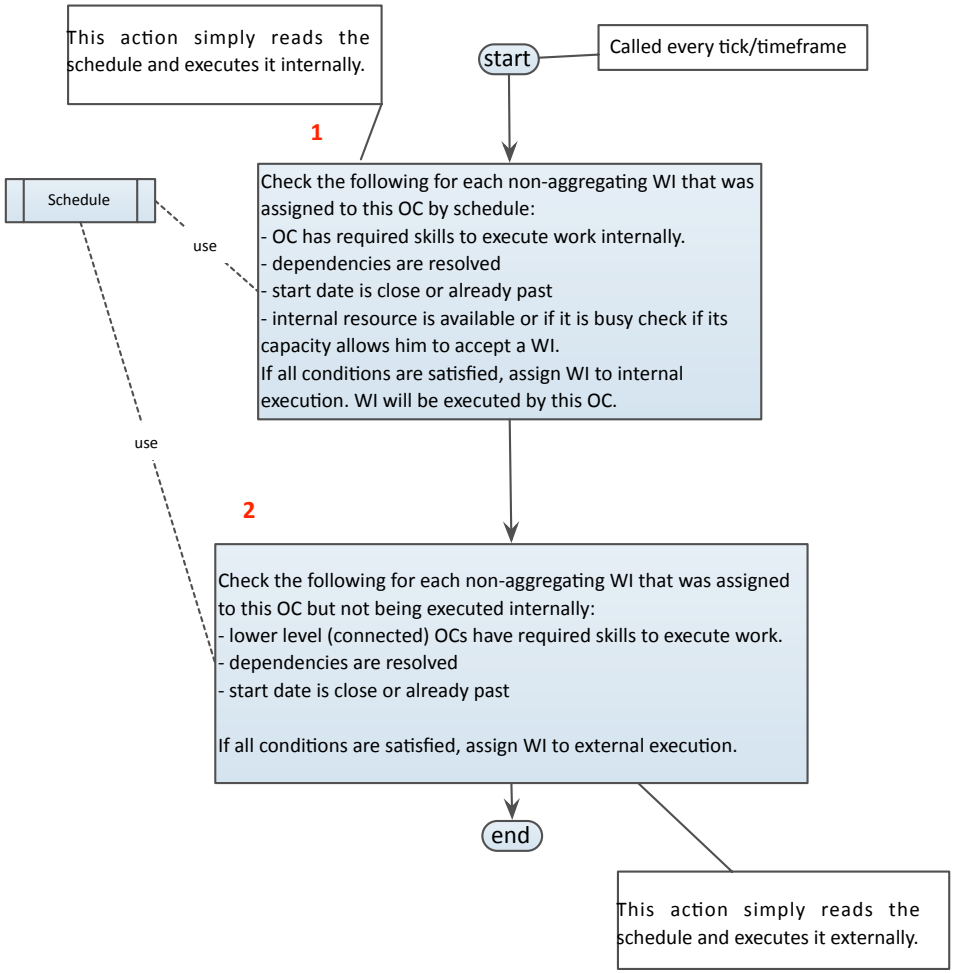


Refined Definition

Organizational Component Requesting Activity

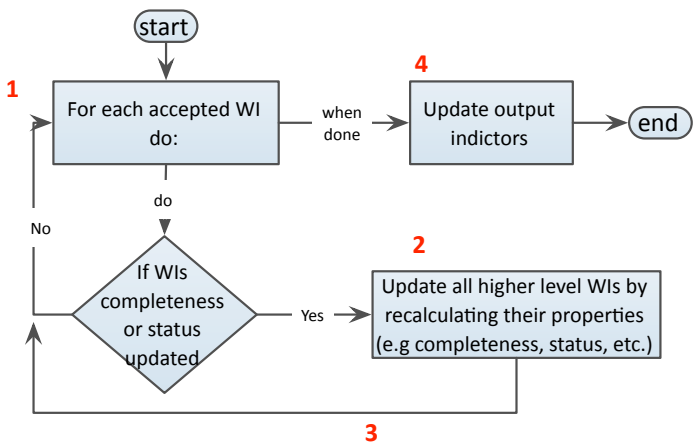
Predictive technical approaches usually generate (or obtain) a schedule and then execute it as closely as possible, redeveloping schedules when they reach some defined level of incongruence to provide insight and make management adjustments.

Requesting execution ('resourcing', ordering and resource allocation) for predictive processes

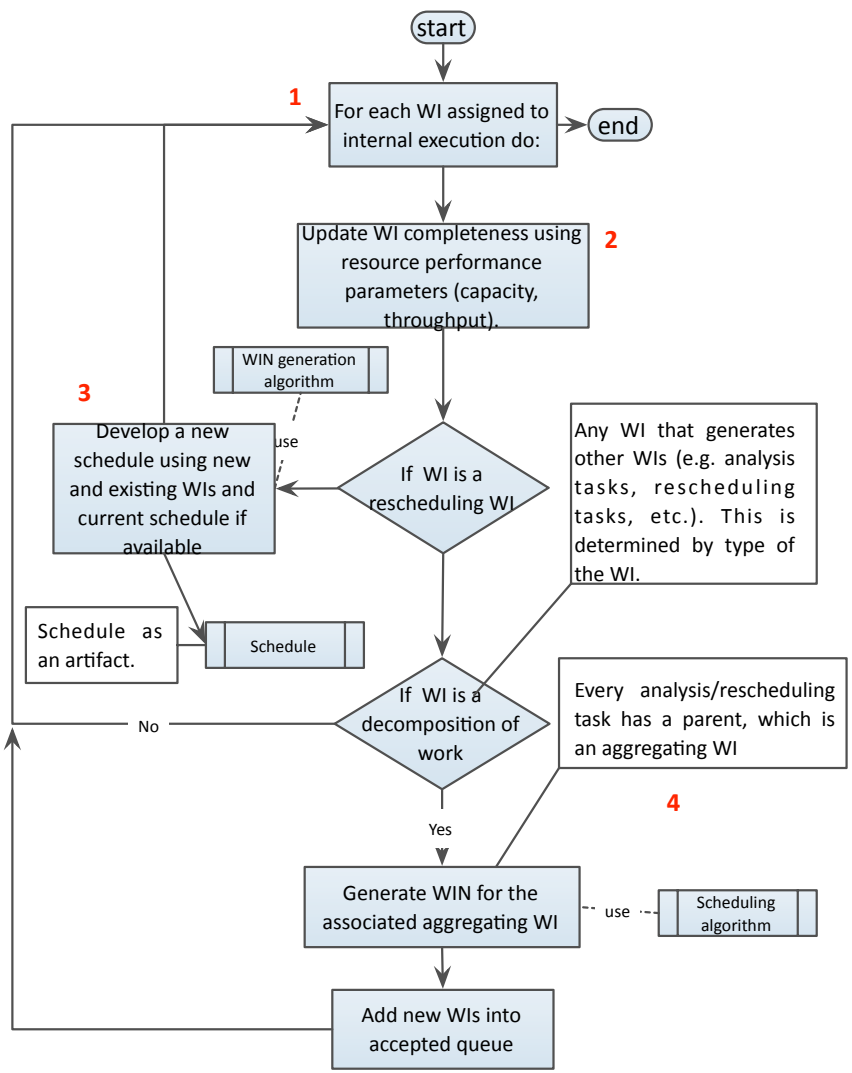


More Definitions…

Monitoring



Internal work execution



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