Measures to Reduce the Development Time of Large Systems

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Metrics of Interest

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- Want to reduce development time of large cyber-physical systems
  - Move experimental analysis into design phase.
  - Metrics-based approach

- Contention Complexity
  - Specific to scenarios where processes/tasks/entities share resources.
- Process Complexity
  - Works at two levels - specific to (re)design processes and processes performed by designs.
- Others
  - Ask me offline!

Demonstration Examples

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- It is necessary to use demonstration examples that:
  - Are available in the early phase of this research
  - Provide inputs and outputs needed to compute a given metric
  - Are as realistic and relevant to problem domain as possible given the first two constraints
- Because of the broad span of our metrics, we have adopted a tiered approach to demonstrating and testing metrics
  - Theoretical justification
  - Demonstration using simplistic mathematical models
  - Conceptual testing on small models created for this purpose (qualitative models of hybrid power trains)
  - Computational testing on suitable real models
- All of this work is ongoing

Contention Complexity

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- Underlying Theory
  - Contention Complexity represents propensity for resource contention
  - Applicable to design, manufacturing, and usage processes
    - Operational consumers use resources
    - Contention when resources insufficient for consumers' needs
- Approach
  - Contention Complexity (overall) is sum of Resource Contention Complexities for all resources
  - Resource Contention Complexity is proportional to
    - Number of consumers that could request that resource
    - Expected amplitude and length of consumer resource use
    - Variance in amplitude and length of consumer resource use
    - Criticality of the consumer resource use

Contention Complexity

Contention Complexity is a function of

- ***%level(c,r)*** magnitude of consumer (c) use of resource (r).
- ***criticality(c,r)*** criticality of consumer's use of resource. (1 is very critical, 10 is not critical at all.)
- ***E[ ]*** is expected value and ***var( )*** is variance. (Evaluated numerically if needed.)

Contention Complexity of a resource:

$$ContentionComplexity(r) = \sum_{c \in DependsOn(r)} \frac{E[\%level(c,r)]\,var(\%level(c,r))}{criticality(c,r)}$$

Contention complexity represents a "propensity" for contention of resources.

Contention Complexity

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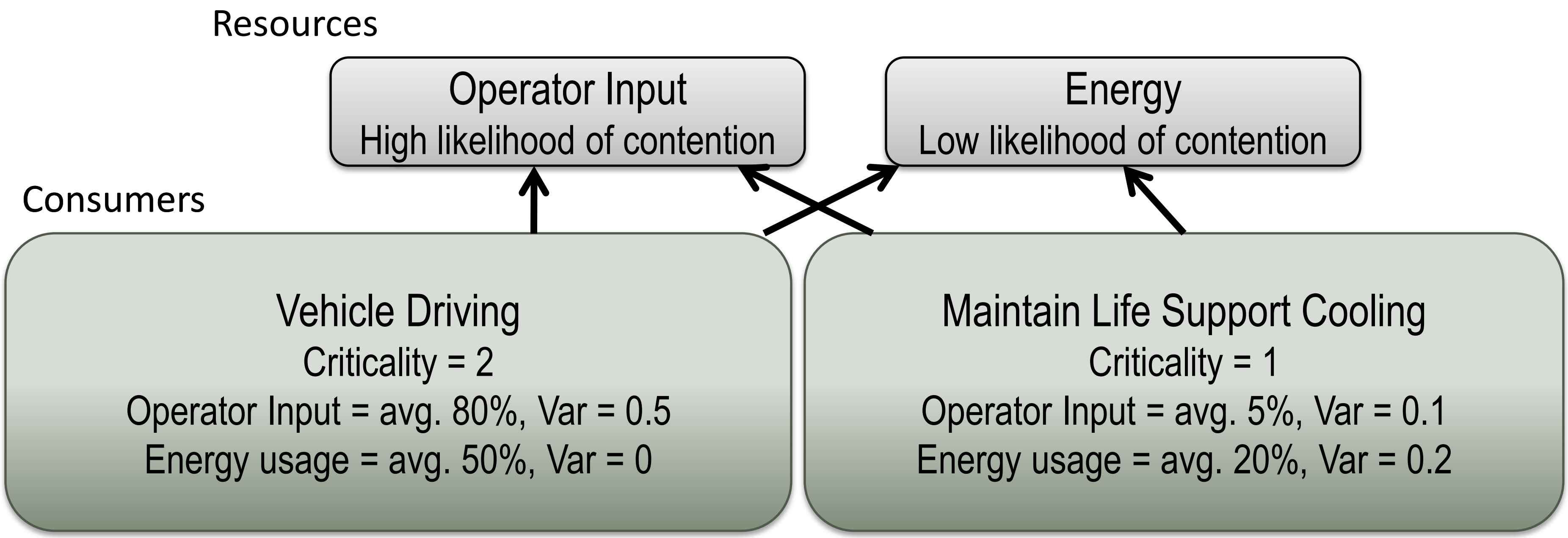

- ContentionComplexity(OperatorInput) = 0.8*0.5/2+0.05*0.1/1
  = 0.2 + 0.005
  = 0.025
- ContentionComplexity(Energy) = 0.5*0/2 + 0.2*0.2/1
  = 0.0 + 0.04
  = 0.04
- ContentionComplexity = 0.025 + 0.04 = 0.065 (approx)

Contention Complexity Application

- Contention complexity characterizes contention propensity based on expected values and variance measures
  - These lower-order moments are easily computable and easily modeled based on observed and estimated behavior
  - Contention complexity is generally expected to correlate with system cost and schedule drivers
- When relating the task and process complexity to schedule, interesting cases occur when distribution is not well behaved
  - “Fat tailed” distributions have outliers with high probabilities
  - May correspond to undesirable system development scheduling
  - Need numeric, experimental approaches without relying on probability distribution models.

Analysis – Contention Complexity

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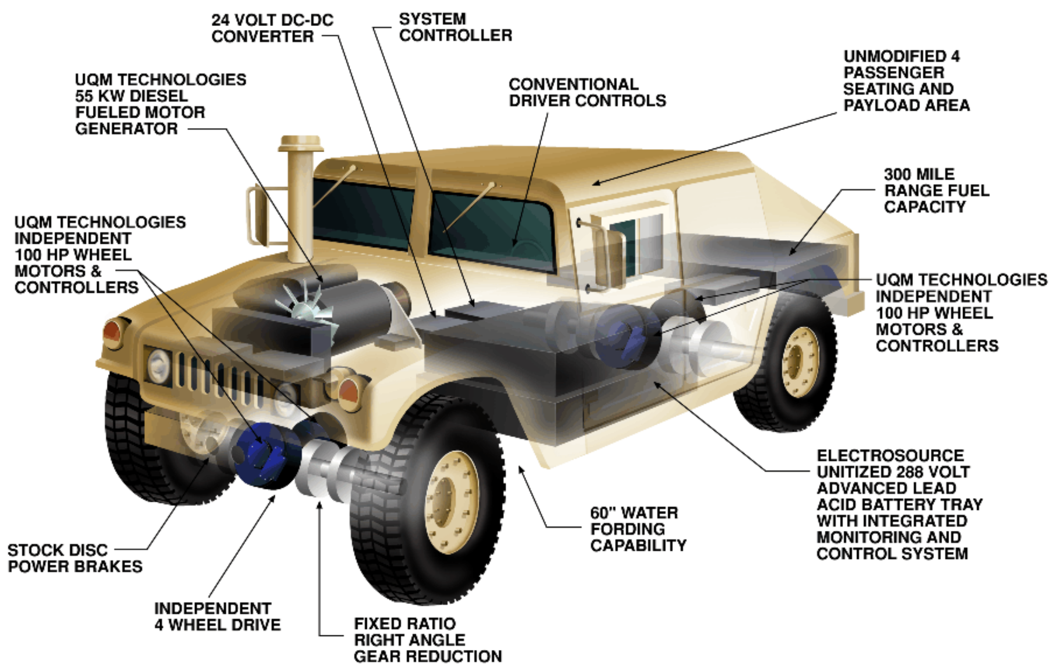
Analysis Question:

What battery configuration minimizes maintenance resource contention complexity on hybrid-electric HMMWV?



HYBRID ELECTRIC HMMWV

We want to select a battery and control parameters to minimize contention complexity of maintenance resources.

Resources:

- Labor
- Replacement Cost

Later complications:

- Kinetic Failures
- Heating/Cooling

Battery Selection

- Battery Types: Lead Acid, NiCad, Li-Ion
  - Variations in:
    - Replacement cost (Lead Acid is cheap!)
    - Power density (Li-Ion is powerful.)
    - Robustness (Lead Acid can take more abuse and can sometimes be serviced in the field.)

- Depth-of-Discharge (DoD) parameter selection
  - DoD represents how “deep” battery is discharged.
  - Large DoD mean you get more power on every charge.
  - Deep DoD changes battery chemistry and reduces number of charging cycles a battery can support.

Experimental Setup
– Contention Complexity

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Complexity Simulation Model:
- Monte Carlo simulation of hybrid HMMWV moving at 20mph over US terrain model.
- Representative control model of battery charging/discharging while moving.
- Assuming regenerative braking.

Model Output:
- Over multiple runs, model estimates number of hours until battery failure and maintenance cost for various battery types and depths-of-discharge.
- We compute maintenance resource contention compexity from assessments of expectations and variances over simulation runs.

Analysis Output

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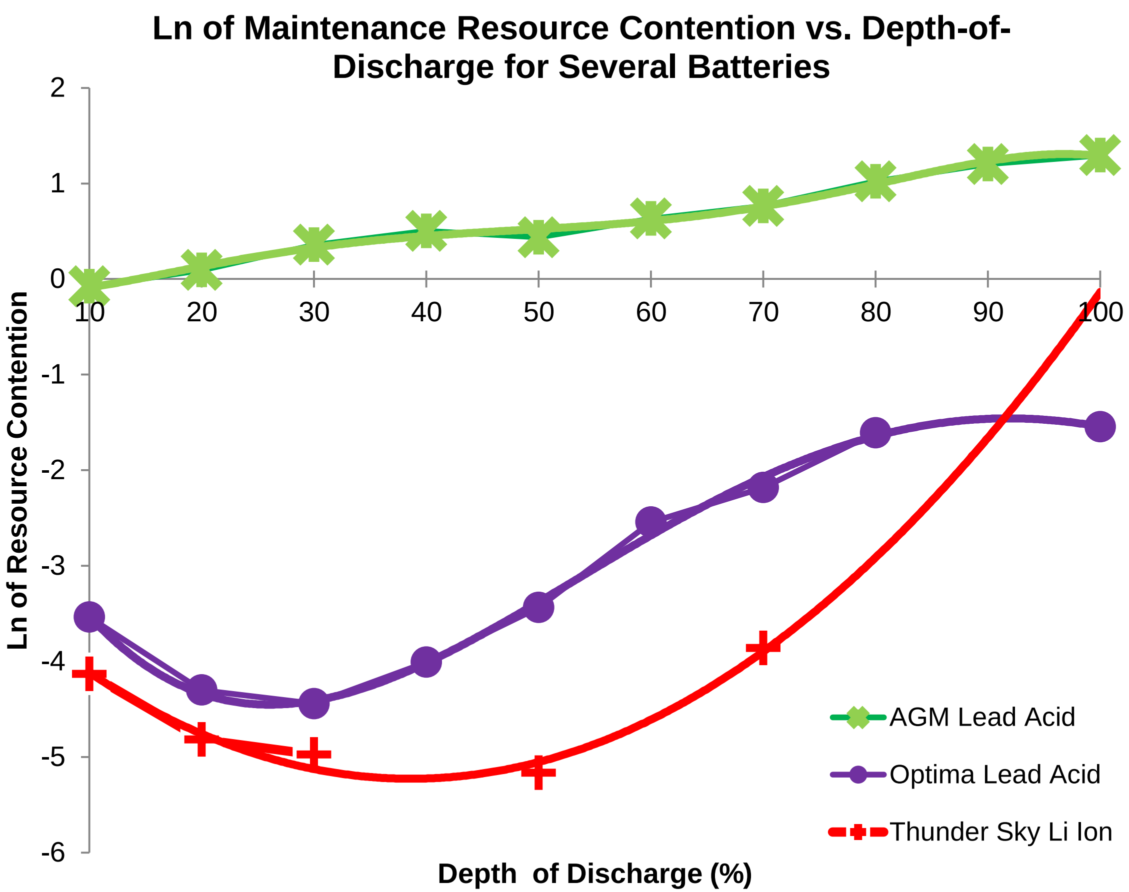

Li-Ion battery with 30%-50% DoD minimizes maintenance resource contention complexity.

This aligns well with “real-world” results from carmakers.

Process Complexity

- An additional metric we are analyzing
- Underlying Theory
  - Process complexity represents the propensity of (partial) task failures to occur that negatively impact mission success
  - Applicable to design, manufacturing, and operation
- Approach
  - Processes have tasks that depend on one another
  - Process complexity is directly proportional to
    - Task complexity
    - Task dependency relationships
  - Task complexity is a function of
    - Difficulty of task
    - Maturity of task
    - Quality requirement of task
    - Schedule pressure of task

Process Complexity

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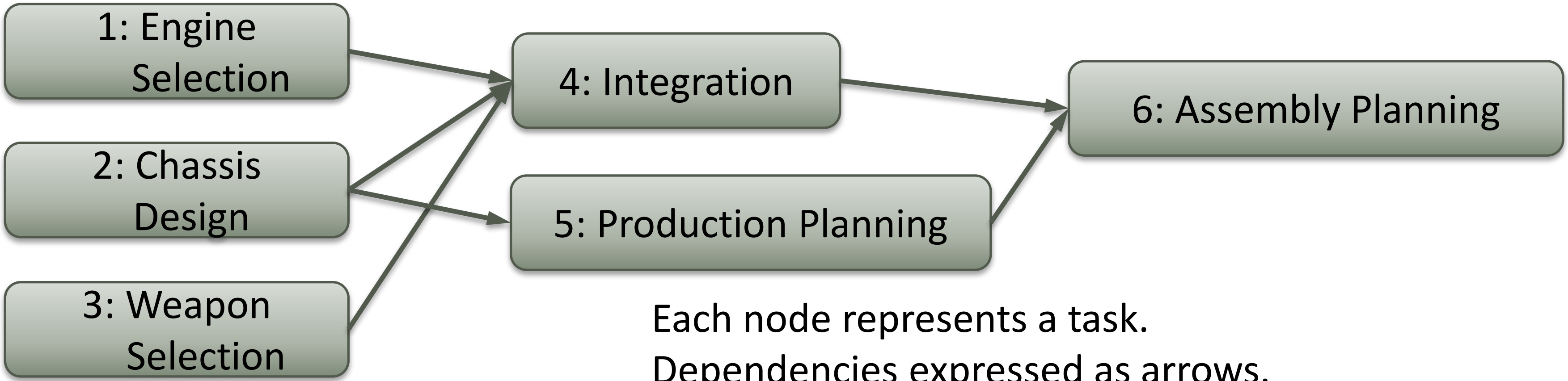
- Process complexity is directly proportional to
  - Complexity of the processes' tasks
  - Structure of task dependency relationships

Design Process Task Dependency Diagram



Each node represents a task.
Dependencies expressed as arrows.

Process complexity is weighted sum of task complexity.

Task complexities weighted by number of their dependence paths.

$$PC = \sum_j w_j TC_j$$

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Process Complexity

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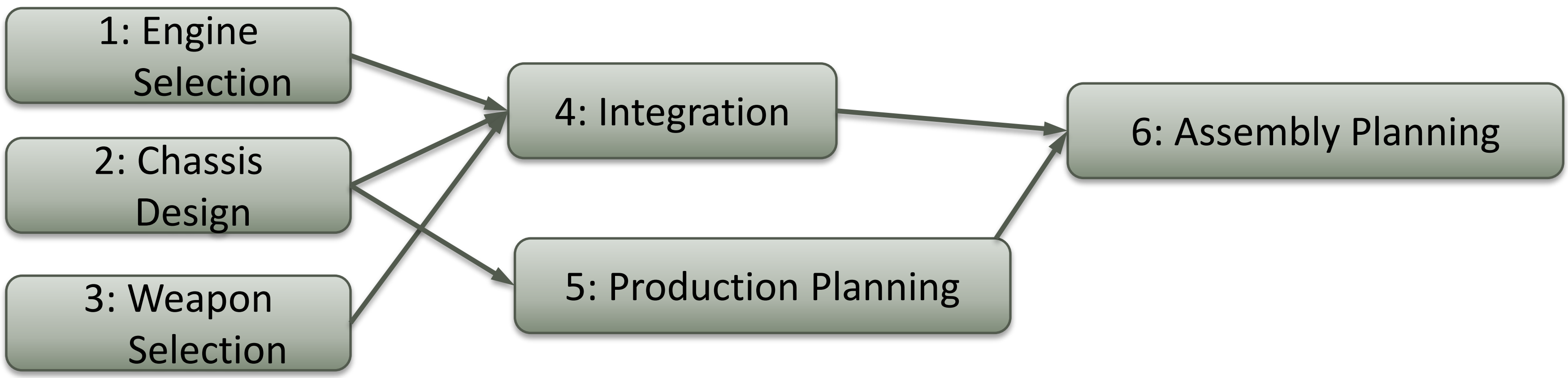
Design Process Task Dependency Diagram



- PC=TC(1)+2TC(2)+TC(3)+TC(4)+TC(5)+TC(6)
  - Two dependency paths from chassis design to assembly planning
  - One path for all other tasks
- Example Task Complexities
  - TC(1)=2.0, TC(2)=3.2, TC(3)=1.0, TC(4)=4.3,TC(1)=2.2, TC(2)=1.5
- Computed Process Complexity
  - PC = 17.4

Process Complexity

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- Task Complexity is a function of
  - D(t): difficulty of task t – Measured by number FTEs, for example.
  - M(t): maturity of task t – Measured by number of years, for example.
  - Q(t): quality requirement of task t – Measured on scale of 1-100%.
    - User-defined parameter. Could represent importance of high quality or how much functionality is provided if task fails.
  - S(t): schedule pressure of task t – Measured by schedule slack in days, for example. (This could also be a stochastic measure.)
- Task complexity

$$TC = \frac{D(t)}{M(t) * Q(t) * S(t)}$$

Metrics Review

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Thanks!
Questions?

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