Optimization of Cost and Performance in Complex Systems Using System Dynamics Modeling

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Overview

- The Challenge
  - Trades of performance versus cost with multiple variables
  - Sensor variables include aperture size, minimum radar cross section, and detection altitude.
- Previous Solutions
  - Static models such as Excel and Matlab would only handle one variable at a time
- Dynamic Modeling Solution
  - Model the trades individually
  - Integrate the results in a model to determine the optimal combination of performance and affordability (sweet spot)

Solving simultaneous variables in multiple scenarios

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Initial Problem Formulation

- The real challenge is solving multiple trades simultaneously
  - Previous trade studies occurred independently of one another, when in fact system design considerations impact one another and can have exaggerated affects on cost.
    - A modeling technique is needed that combines multiple performance and cost trades in a single environment.
    - Traditional analysis models hosted on Excel and Matlab solve the trades one at a time
    - System Dynamics provides a simultaneous solution environment.

Advanced modeling approaches are needed for complex analysis

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Performance versus Cost Examples

- **Performance/Cost in Radar Programs**
  - Radar Cross Section versus distance
  - Number of targets simultaneously tracked
  - Timeliness of target acquisition
  - Appropriate Power aperture size ~~versus cost~~
- **Other performance characteristics**
  - Data throughput
  - Data latency
  - Number of systems needed to be deployed versus mission requirements

Numerous trades identified when determining optimal solutions

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The Challenges

- Linking together previously independent trades
  - Trades such as Aperture area lend themselves to Dynamic Modeling due to their continuous nature.
  - Other trades such as transmit or receive polarization introduce mathematical complexity due to discrete variables levels (single, dual, etc.) This makes mathematical optimization challenging.

- Building a flexible simulation that is straightforward to update when costs or performance factors change.
  - This is critical to provide an accurate optimum design in terms of cost and performance.
  - With each architecture or design change there is a direct impact on cost.

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Solution Space

- Model individual trades in appropriate environments (Excel, MATLAB, Vensim, etc.)
- Typically the solution space is static; meaning that only one option can be evaluated for optimization at a time
- Integrate the trades in iSight© software, leading to a flexible model with excellent analysis capabilities
  - Generate optimal designs
  - Analyze cost drivers
  - Investigate risk factors
- Use of System Dynamics models to integrate multiple trade space scenarios together
  - Typically used for time variant analysis and optimization
  - Can be adapted to static analysis

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System Dynamics Methodology

- System Dynamics is a modeling methodology that facilitates problem solving through codifying and leveraging complex system interdependencies to perform optimization analyses
- Provides a structured process for the definition and analysis of an integrated trade space to find global system optimality
- Facilitates identification and leveraging of cross life-cycle system interdependencies
  - These interdependencies can take the form of cost and performance relationships
    - Radar sizing and performance versus operation and sustainment elements such as electricity and fuel use, manpower, and depot structures and their affects on cost.
    - System performance versus development and production costs.

Integration of multiple trade scenarios into TOC

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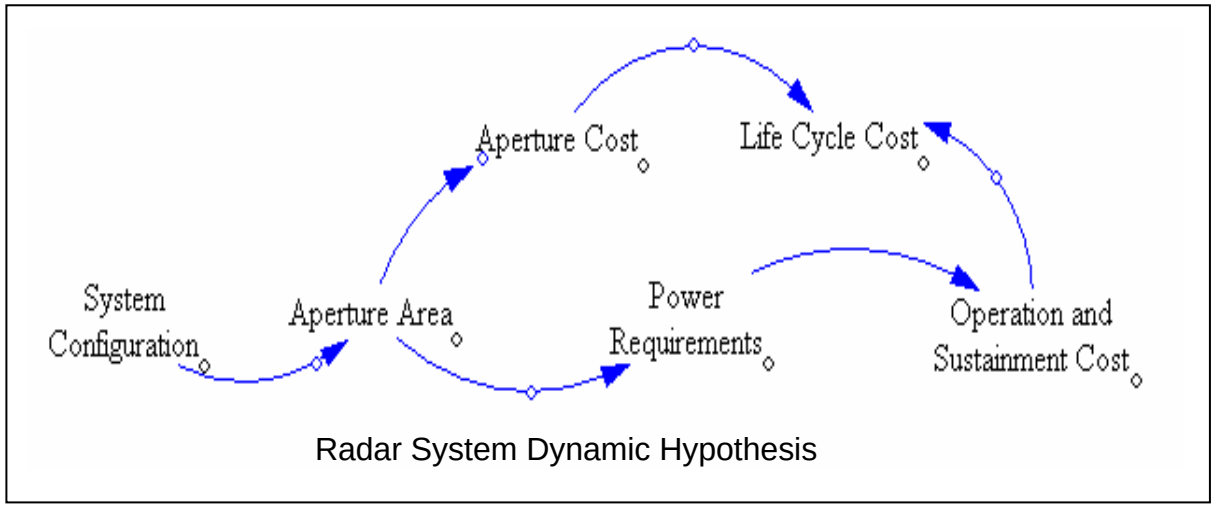
System Dynamics Methodology

- A solution is needed that solves multiple variables to determine the optimal architecture
- Dynamic Modeling provides a trade space that incorporates trade studies, cost models, and system performance
  - Provides trades for cost and performance using multiple variable inputs
  - Optimizes solution set by integrating trade study excursions



Radar System Dynamic Hypothesis

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Current use of System Dynamics

- System Dynamics is used in support of operations across a number of programs
  - Acquisition development and production
  - Operations and Sustainment
  - Performance Based Logistics
  - Logistics support improvements
- System Dynamics is also implemented to optimize support concepts
  - Sparing philosophy
  - Turnaround Time
  - Location and type of depots
- System Dynamics models are used in the development of OSCAM models

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Pros and Cons

- Pros
  - Flexible and Dynamic Modeling environment
  - Input data (costs, performance parameters) loaded as Excel files for ease of updating
  - Yields a provably optimal design based on established mathematical techniques (nonlinear programming, decision theory)
  - Complex systems can be represented visually for ease of manipulation.

- Cons
  - Some trades do not integrate cleanly, meaning iterations must be run by hand
  - Accuracy of the model is only as good as the input data, and will continue to improve with the system cost and performance estimates.

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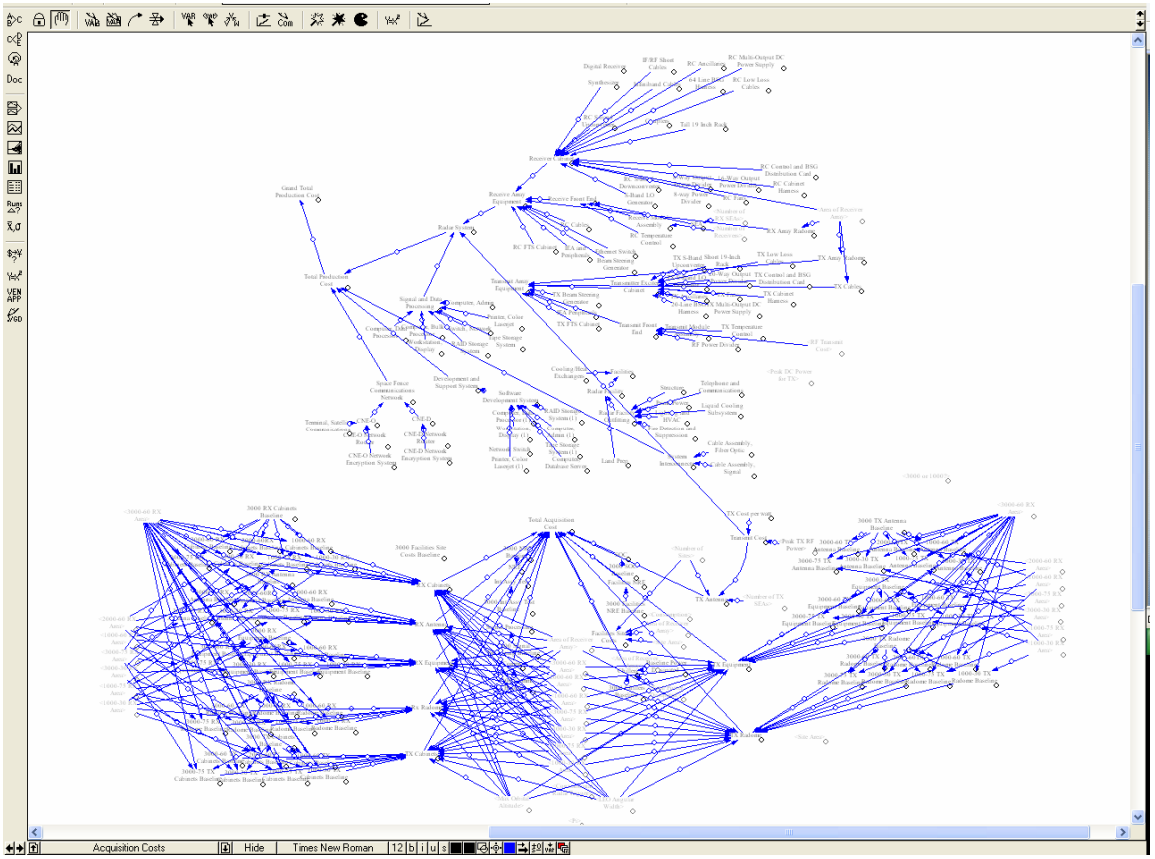
System Level View

- A major advantage to the System Dynamics approach is the ability to incorporate large levels of system complexity into an integrated optimization model.



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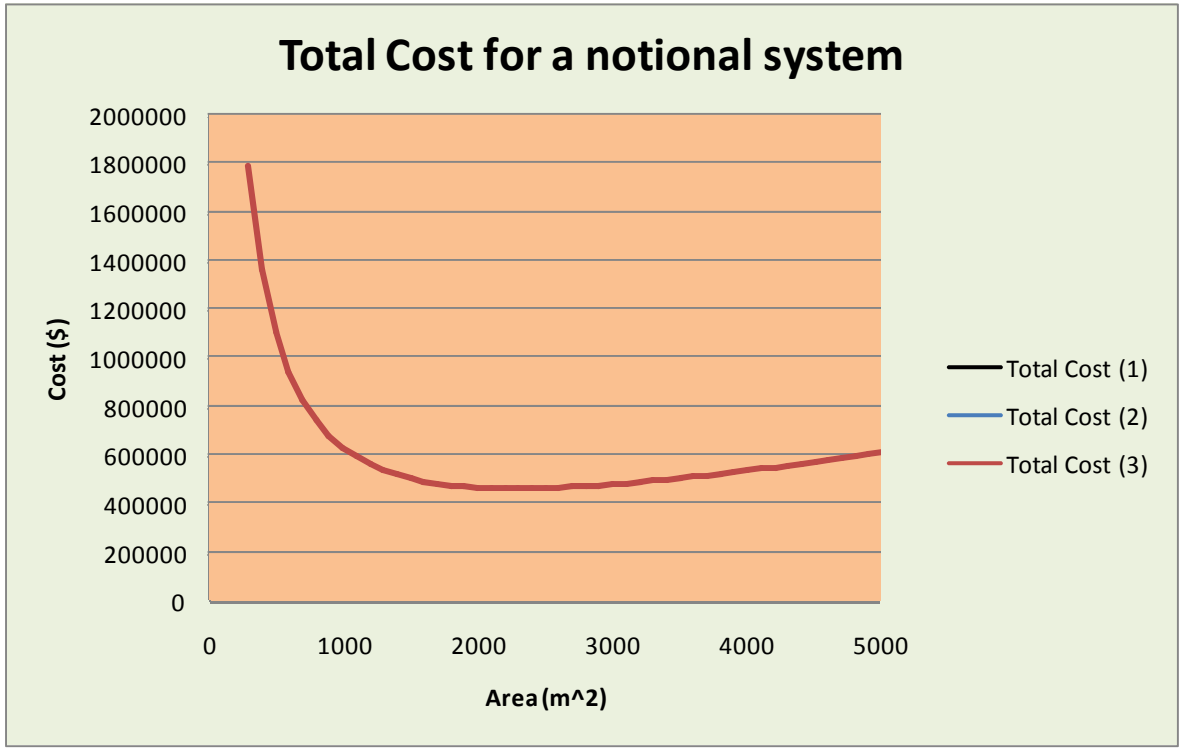
Modeling Results

- The graph below shows a notional optimization on aperture size, and demonstrates how changes in requirements can be shown alongside quickly and efficiently.
  - The three curves shown below represent system cost curves under three different altitude requirements.



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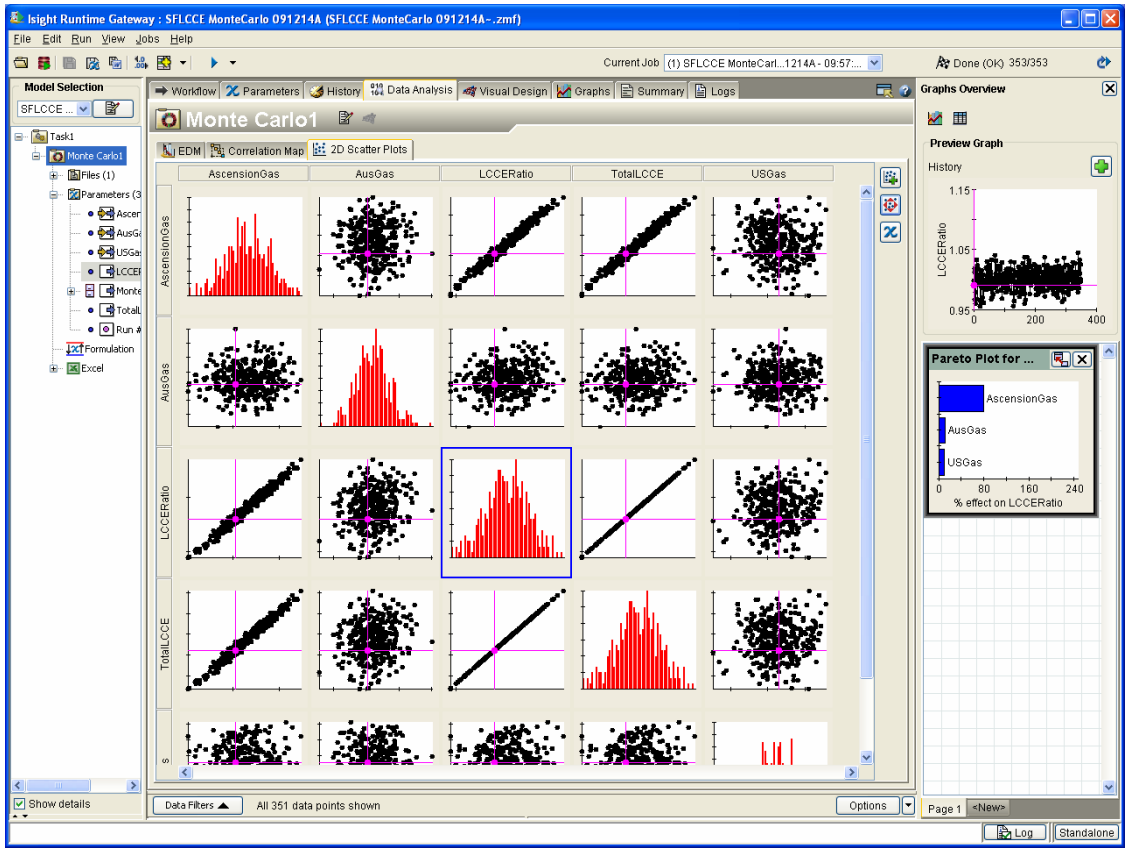
Data Visualization

- iSight© software provides a suite to integrate System Dynamics Models with other data sources (Excel, MATLAB, Vensim, etc.)
- Provides a powerful analysis toolset (Nonlinear Programming support, DOE, Monte Carlo simulation)



Typical System Trade IPO Diagram

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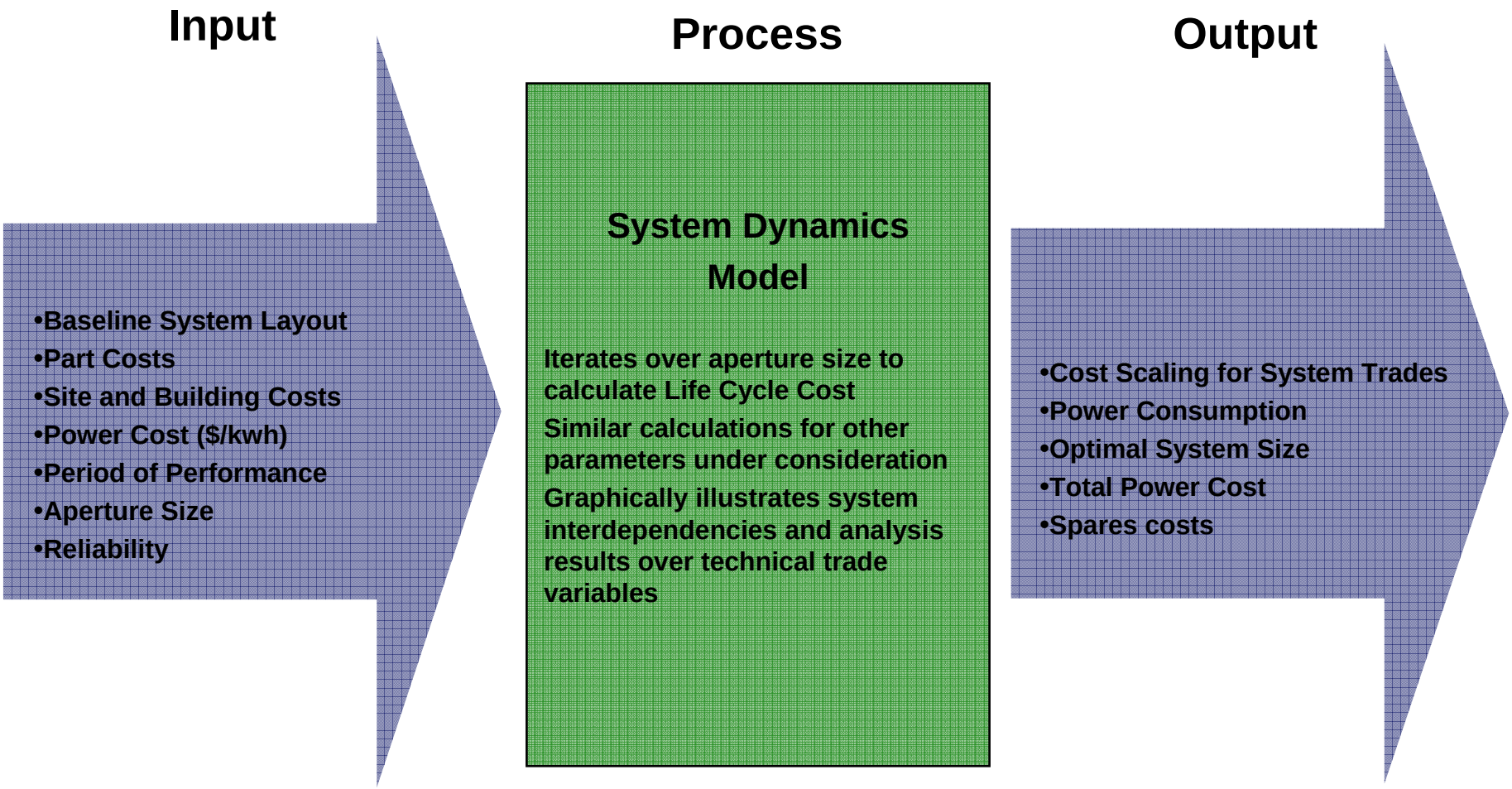
Problem Statement: Quantify cost drivers in radar system trade studies to support the definition of optimal system design with respect to Life Cycle Cost.



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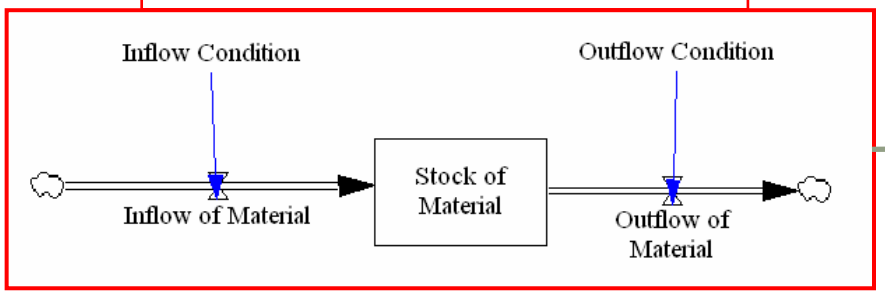
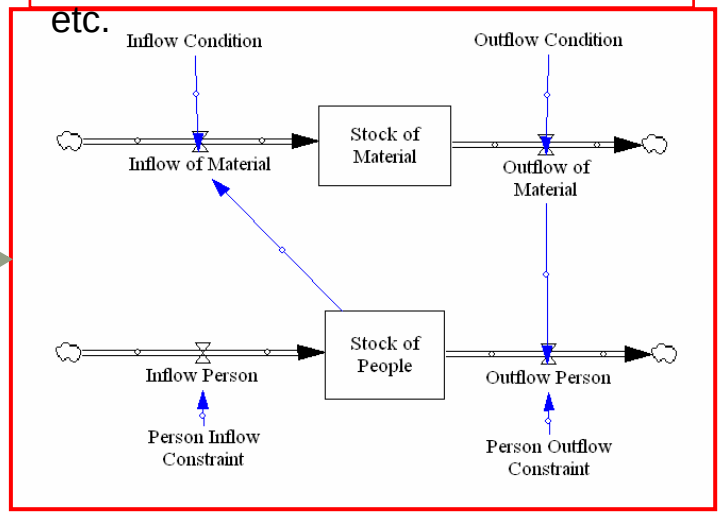
System Integration Application

- System Dynamics (SD) is an established simulation methodology that incorporates time-based, discrete events
- Detailed interdependencies provide realistic models

Models use the flow of materials, people, information, etc. The larger structure is called a Stock and Flow Diagram



Multiple structures can be linked together using detailed interdependencies. These interdependencies can be inventory constraints, personnel availability, etc.



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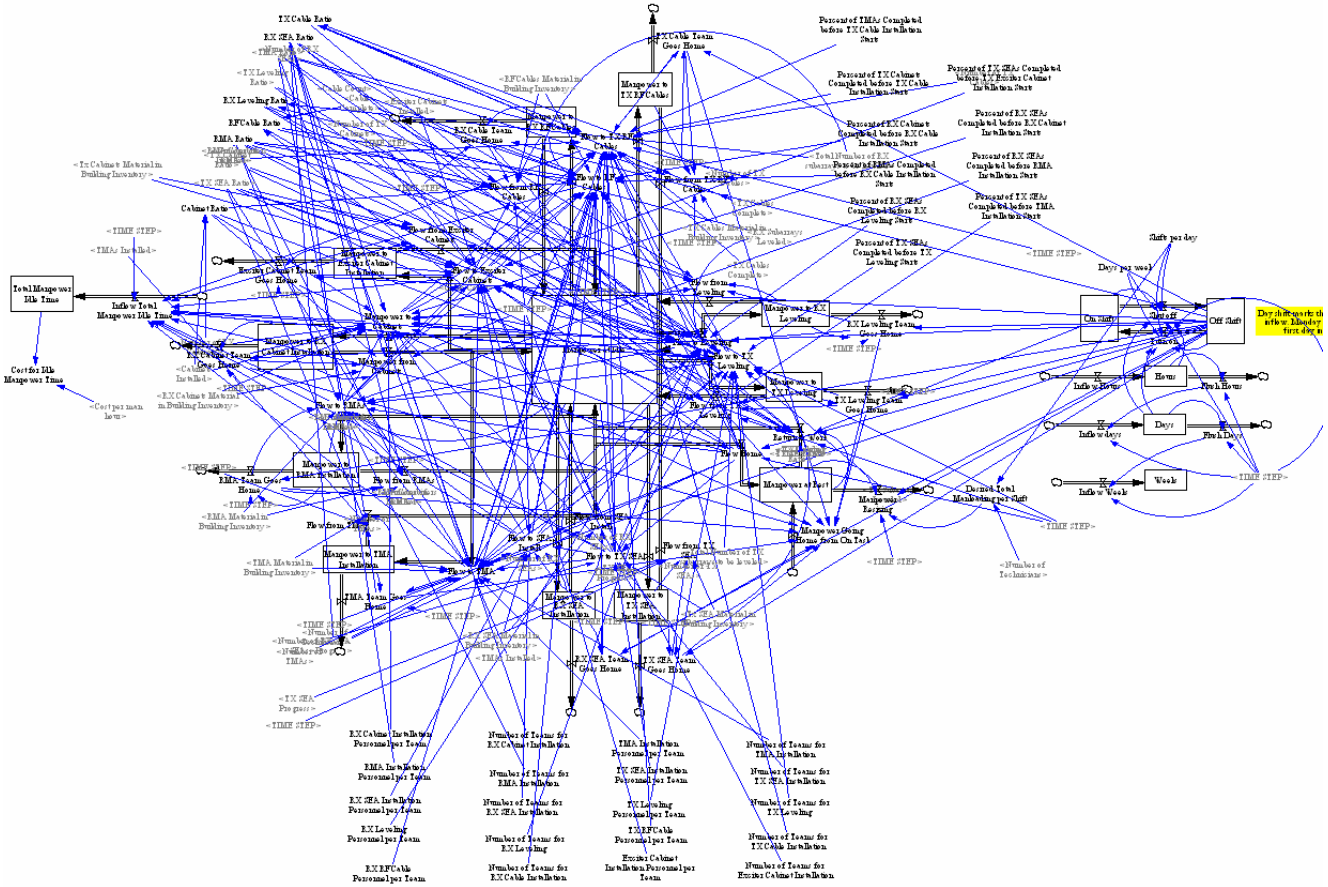
System Integration Application

- Models such as those used to model the installation and integration of a radar system are much larger and consist of many substructures.



Structure defines the flow and operation of the on-site installation manpower. Additional structures define inventory, task execution, and overall progress tracking

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Model Outputs – System Integration

- Time to complete assigned installation tasks
  - Individual tasks can be examined to a resolution of ~4 minutes
- Cost/Schedule to complete assigned tasks
  - Based on known labor rates for integration personnel
- Integration Constraints
  - The model shows where manpower is either idle or saturated with work
  - The model also whether overall integration progress is being slowed by the delay of a certain individual task

Rapid Optimization of Schedule, Cost, and Manpower

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Enabling Customer Success

- Providing an integrated solution space that allows rapid investigation into the balance of cost and performance
  - Allows for quick turnaround results in the face of customer requests/requirement changes.
- Provides an optimal set of design choices under a large number of requirements changes
- Provides a transparent look into the entire system trade space

Optimization of trade space affordability is key to future contracts and benefits Customers

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Conclusions/Future Directions

- Dynamic Modeling provides an environment where cost and performance trades can be integrated simultaneously
  - This generates an optimum design based on customer requirements

- Future Directions:
  - Integration of additional trades, ideally reaching a full system design space that includes all aspects of radar system design.
  - Improved data visualization techniques, useful for more accurate optimization conclusions.
  - Automated data import/export to more easily integrate System Dynamic models with other techniques.

The goal is complete trade space optimization

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Backup

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Abstract

- Analysis of trade spaces between cost and performance is critical to win new contract pursuits in today's highly competitive environment. The overall goal in a program is to design and produce a system that maximizes both performance and affordability.

- In attempting to balance cost and performance, traditional cost models only allow for experimentation with one variable at a time. This can be very cumbersome on large systems, and inhibits how much of the trade space can be explored under time constraints. Altering one variable at a time also limits the number of cost estimating relationships that can be incorporated into the analysis.

- System Dynamics Modeling (SDM) provides a framework under which cost and performance models can be integrated rapidly to provide a broader view of the trade space. It allows for multiple independent variables with their associated degrees of freedom to be analyzed dynamically using interdependent relationships and probabilistic outcomes. This approach results in a systems oriented outcome based on both individual trades and integrated results of multiple trades.

- The ability to alter variables in a system and quickly analyze cost and performance impacts is of great importance in demonstrating design optimality. An analysis methodology is presented for integrating cost and performance in order to provide optimal designs for customer success.