CENTER FOR COMPACT AND EFFICIENT FLUID POWER

A National Science Foundation Engineering Research Center

CCEFP Project 2E

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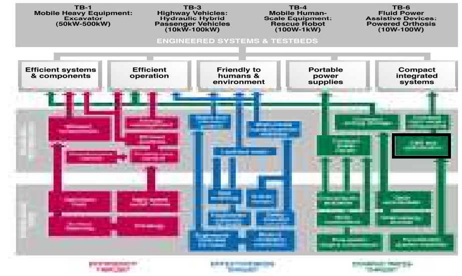

Project 2E: Model-Based Systems Engineering for Efficient Fluid Power

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What fluid power-related question is being answered?

- ***How can one most effectively represent design knowledge about fluid power systems?***
- Can one significantly reduce the time and effort required to formulate and solve fluid power design problems through composition and re-use of synthesis and analysis models?
- How can one capture analysis knowledge about fluid power components from multiple disciplinary perspectives and at multiple levels of abstraction?
- How can one use fluid power models at different levels of fidelity to search the system design space most efficiently?

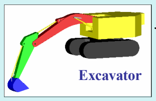
How does this fit into the Center's overall strategy?

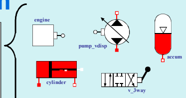
- Enable designers to make efficient and effective comparisons of different system architectures relative to their preferences for system-level trade-offs → Efficient Systems and Compact Integrated Systems
- Enable the evaluation of the impact of introducing new component technologies → Efficient Components
- Enable the fluid-power industry to predict the impact of technology trends on overall system performance → Efficient Systems and Compact Integrated Systems

On which test bed will it be demonstrated?

- The model-based systems engineering approach for fluid-power systems will be used to perform a thorough exploration of the space of system architectures for both **TB1 (Excavator)** and **TB3 (Hydraulic Hybrid Passenger Vehicle)**

The Problem





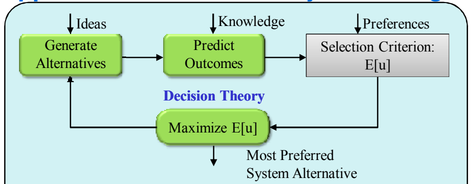
How to connect and size these components?

Given:
- Knowledge about the domain
- Objectives / preferences

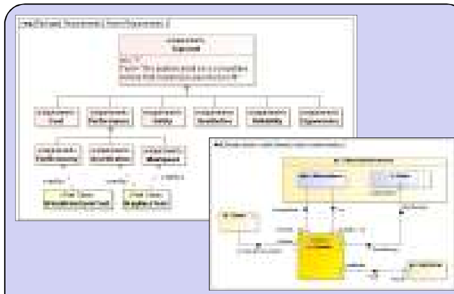
Find:
- Best system architecture
- Best component parameters

Why is this a hard problem?
- Many competing objectives
- Many potential system alternatives
- Many component types/sizings
- **Large Amount of Domain Knowledge**
- **Large Optimization Problem**

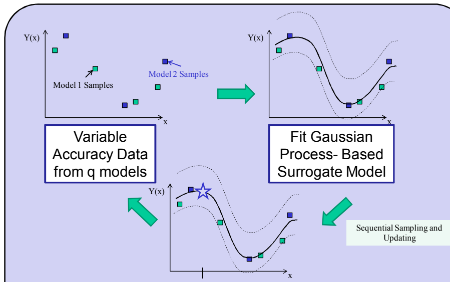
Approach: Model-Based Systems Engineering



Based on **Decision Theory**. Want to make *rational* decisions *efficiently*.

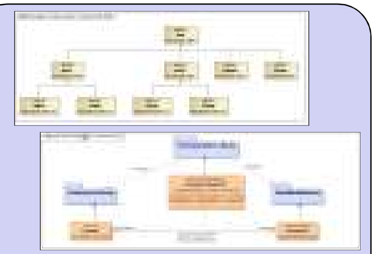


Explicitly define the problem in **information models**.

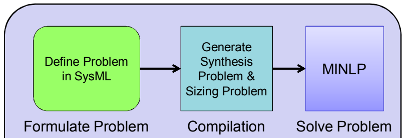


Use models at *varying levels of fidelity* during optimization to predict outcomes. Use **Value of Information** to choose locations to explore.

Capture Knowledge For Domain → Define Problem → Generate Alternatives → Predict Outcomes → Select Most Preferred Alternative

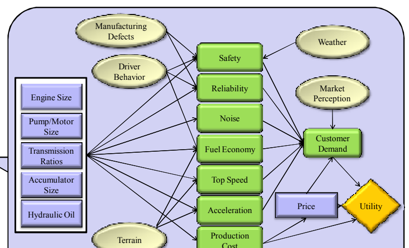


Capture knowledge about the domain in **information models** to allow for *review* and *reuse*.



Represent knowledge about domain in **logical constraints** + **algebraic constraints**:
- isConnected(x,y) <=> isConnected(y,x).
- (x.flow+y.flow)*isConnected(x,y)=0

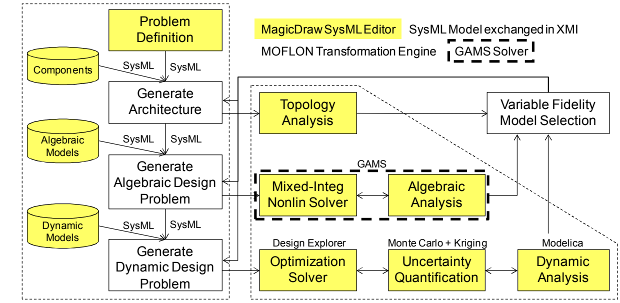
Compile problem formulation into a **MINLP problem**. Solving problem gives both **plausible alternatives** and **initial sizings**.



Value-Driven Design perspective where the objective is to maximize value design provides.

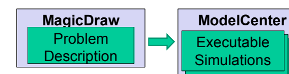
What progress has been made?

- ***ModelCenter Framework***



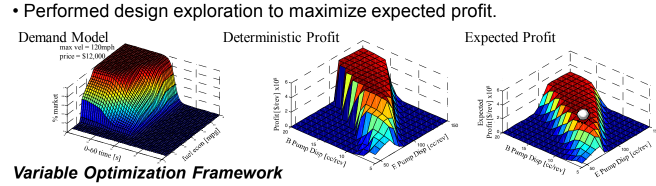
SysML and ModelCenter

- Implemented integration between SysML authoring tool and ModelCenter.
- Allows designers to explicitly define their problem in SysML and then perform design exploration in ModelCenter.



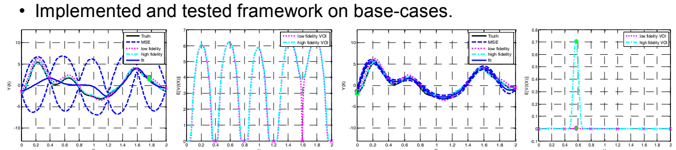
Hydraulic Hybrid Vehicle (TB3)

- Formulated TB3 optimization as value-driven design problem.
- Performed design exploration to maximize expected profit.



Variable Optimization Framework

- Implemented and tested framework on base-cases.



Publications

- Kerzhner and Paredis, "Model-Based System Verification: A Formal Framework for Relating Analyses, Requirements, and Tests", *4th International Workshop on Multi-Paradigm Modeling - MPM'10*, October 2010.
- Malak and Paredis, "Using Support Vector Machines to Formalize the Valid Input Domain of Predictive Models for Systems Design Problems," in *Journal of Mechanical Design*.
- Malak and Paredis, "Using Parameterized Pareto Sets to Model Design Concepts." *Journal of Mechanical Design*.
- Shah, Kerzhner, Schaefer and Paredis, "Multi-View Modeling to Support Embedded Systems Engineering in SysML." in Graph Transformations and Model-Driven Engineering - Essays Dedicated to Manfred Nagl LNCS 5765, Springer-Verlag, Berlin/Heidelberg (2010).
- Shah, A. A., C. J. J. Paredis, Burkhart, R., and Schaefer, D., "Combining Mathematical Programming and SysML for Component Sizing of Hydraulic Systems," *Proceedings of IDETC/CIE 2010*. Montreal, Quebec, Canada, 2010.

Who are the industry and university collaborators?

Industry	University
Deere & Co.,Sauer-Danfoss, Lockheed Martin, No Magic Inc., Phoenix Integration	Linköping University, Univ. of Darmstadt, Univ. of Stuttgart, Univ. of Bath