Statistical Analysis to identify the significant design complexity metrics in the estimation of product assembly time and market value

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Background

Previous research focused on developing four prediction models:

1. Assembly time estimation based on assembly models
2. Market value estimation based on function structures
3. Market value estimation based on assembly models
4. Assembly time estimation based on function structures

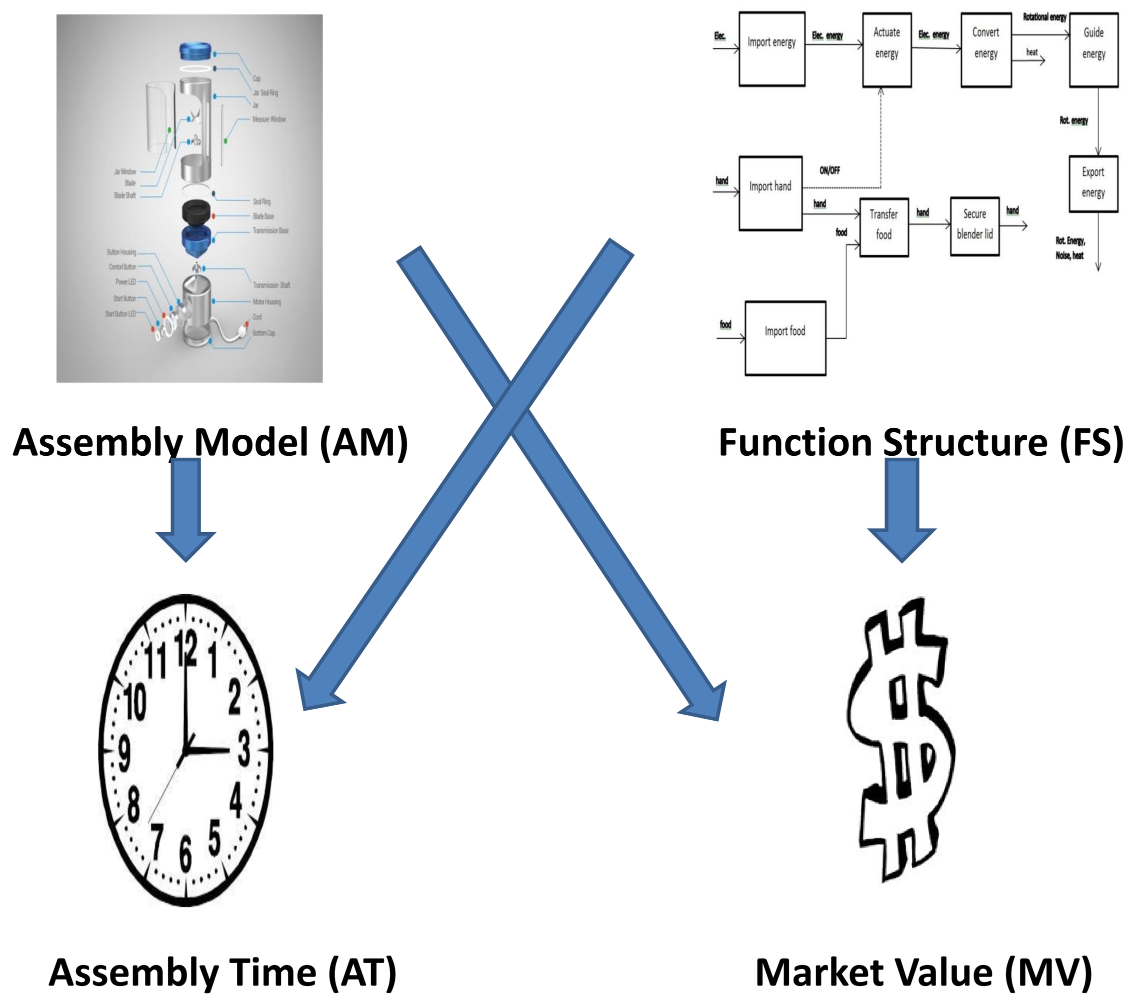

Figure: Four Prediction models

Motivation

1. Identify the complexity metrics which are significant predictors of assembly time and market value
2. See whether the set of significant metrics improves the prediction accuracy as compared to the original set of metrics
3. Analyze the metrics which are significant across all the four models
4. Figure out which characteristics make them significant independent of the output being predicted
5. These metrics can be used as the fundamental predictors for other design applications

Experimental Method

1) Generate function structures and assembly models of products

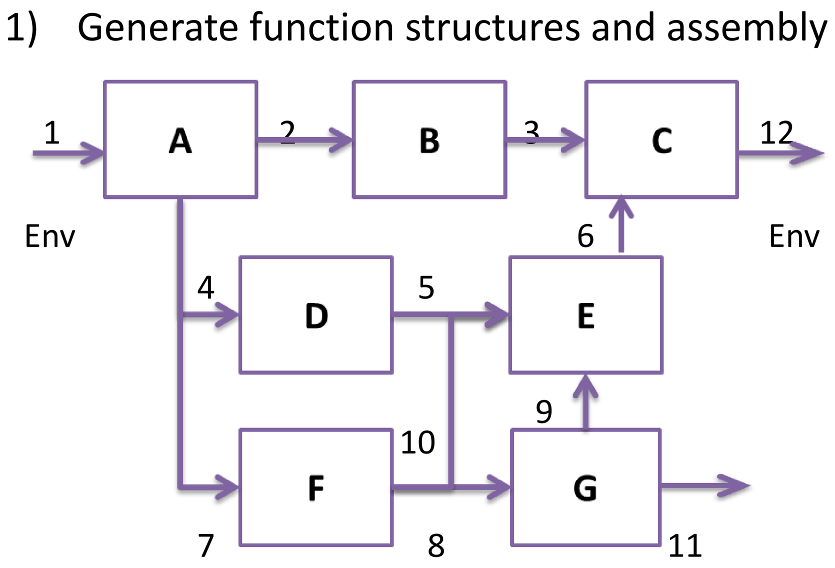

Figure: Function structure

Figure: Assembly model

2) Create bi-partite graphs of these structures and models

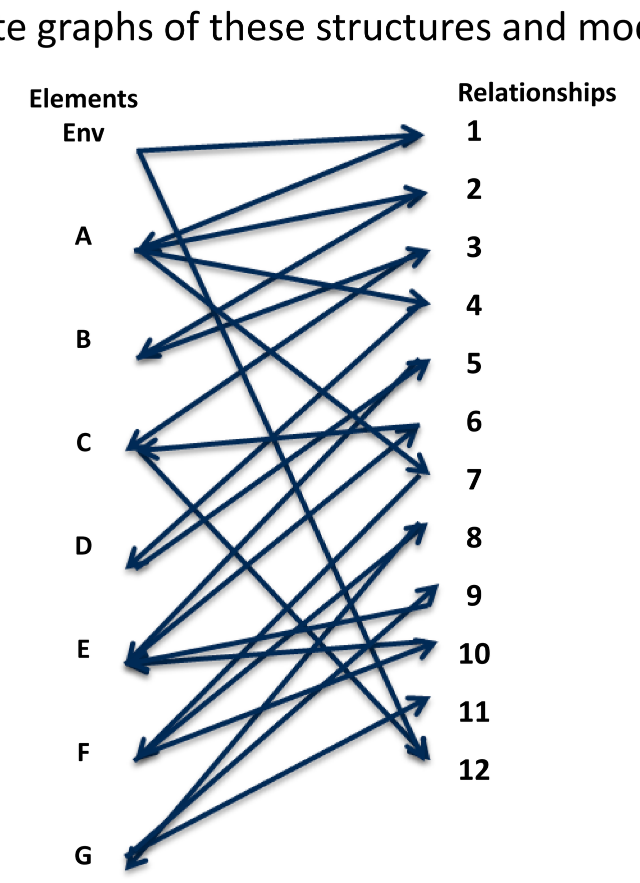

Figure: Bi-partite graph

3) Build the 29 complexity metric vector metric using these graphs

Class	Type	Dir.	Metrics
			Comp. vector
Size	Dim		1 Elements
			2 Rel
	Conn		3 DOF
			4 Conn
Interconnection	Shortest Path		5 Sum
			6 Max
			7 Mean
			8 Density
	Flow Rate		9 Sum
			10 Max
			11 mean
			12 density
Centrality	Betweenness		13 sum
			14 max
			15 mean
			16 density
	Clustering Coefficient		17 sum
			18 max
			19 mean
			20 density
Decomposition	21 Ameri Summers		
	Core Numbers	In	22 sum
			23 max
			24 mean
			25 density
		Out	26 sum
			27 max
			28 mean
			29 density

Figure: 29 Complexity metrics

4) Store Assembly Times and Market Values of Products as Target Values
5) Train Artificial Neural Networks(ANNs) using Complexity Metrics and Target Values
6) Test the five selected products against the trained Artificial Neural Networks
7) Analysis of the test results

Research outline

- ANN is trained using complexity vector of each product as input and the known market value/assembly time as the training target
- ANN design used generates 189 architectures with 100 repetitions each
- This results in 18900 market value/assembly time estimates
- Multiple linear regression is conducted to identify the complexity metrics which are significant predictors
- For the analysis, the 29 complexity metrics are used as the explanatory variables and the 18900 estimates are used as the response variables
- This regression analysis is done for all the four prediction models

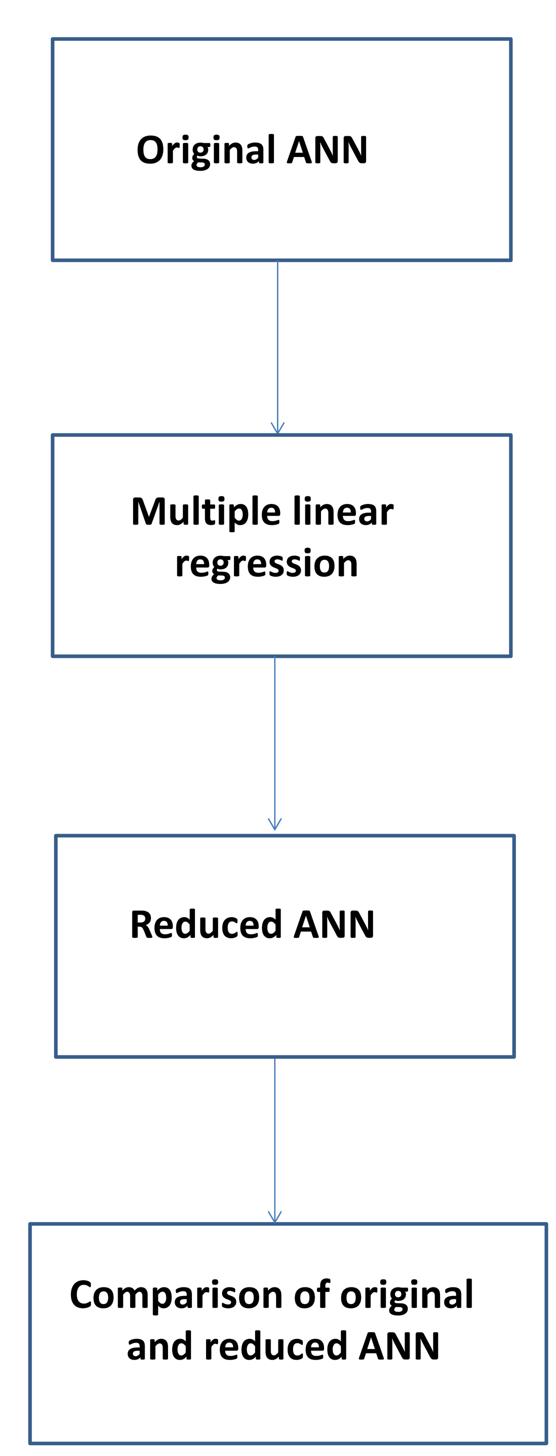

Figure: Research outline

Analysis

Parameters:

Confidence level for all intervals: 90 (i.e. Alpha= 0.1)

Type of confidence interval: Two-sided

Method: Stepwise selection

Software used: Minitab

Results

	AT	MV
FS	**Metric no. 1**, 4, 9, 10, 11, 12, 14, **25**, 29 Size- 2 Interconnection- 4 Centrality- 1 Decomposition- 2	**Metric no. 1**, 4, 9, 10, 12, 13, **25**, 29 Size- 2 Interconnection- 3 Centrality- 1 Decomposition- 2
AM	**Metric no. 1**, 5, 8, 11, 17, 18, 20, 22, **25** Size- 1 Interconnection- 3 Centrality- 3 Decomposition- 2	**Metric no. 1**, 5, 8, 11, 17, 18, 20, 22, **25** Size- 1 Interconnection- 3 Centrality- 3 Decomposition- 2

Figure: Significant metrics for the four combinations

- These significant metrics will now be used to train the ANN
- This ANN is a reduced ANN since not all of the original 29 metrics are used for the training
- The five test products will then be tested against the reduced ANN
- The results obtained would be compared to the results from the original ANN

Conclusions

- Interconnection is a significant predictor across all the four prediction models
- In AM prediction models, centrality and interconnection have the most number of significant metrics
- In FS prediction models, interconnection has the most number of significant metrics
- AMs comprises of parts which are connected to other parts whereas FS is like a tree wherein you have different levels. So not every source/sink will have multiple connections.
- Centrality is significant for AMs as the more central a component is to the others makes the assembly either easier or difficult

Advantages

- Using this information, designers can develop multiple design solutions with more focus on the significant metrics
- Helps channelize design concept development efforts in the right direction
- Reduces computation time and effort

New research questions identified

- Can this experimental method be applied to predict other design parameters such as quality
- Find out which characteristics make certain metrics significant across all the four models
- Would the significant predictors be the same for a different set of training and test products

Acknowledgements

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[3] Essam Z. Namouz, Joshua D. Summers, "Complexity Connectivity Metrics – Predicting Assembly Times with Low Fidelity Assembly CAD Models", ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference

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