STRUCTURAL COMPLEXITY METRICS APPLIED AGAINST PRODUCT GRAPHS

Predicting Market Price and Assembly Time from Function and Assembly models

CLEMSON UNIVERSITY

Sri Ram Mohinder CHERKADU VASALA , Sudarshan SRIDHAR, Joshua D. SUMMERS
scherka@clemson.edu, sudarss@clemson.edu, jsummer@clemson.edu
Clemson University, USA

CEDAR — Clemson Engineering Design Applications and Research

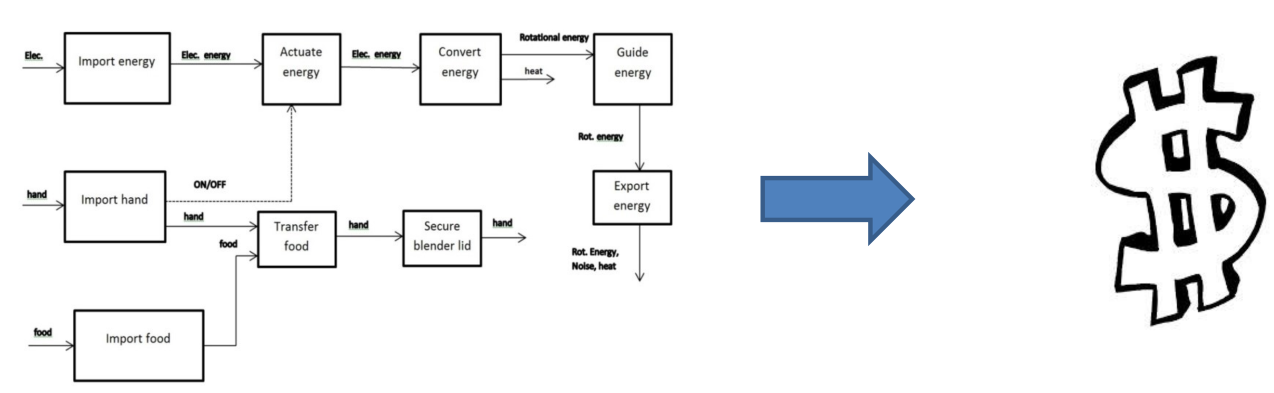
Objective

Understand and identify key complexity metrics of different product model graphs (assembly models and function structures) that can be used for surrogate modeling of product performance metrics (assembly time and market cost).

Background

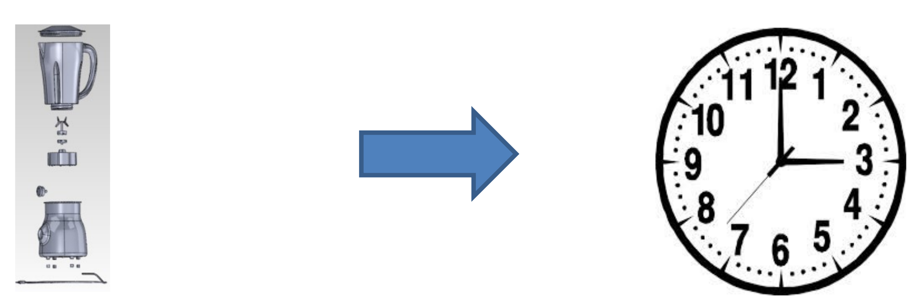
- Informed decision making can be done based on First principles, Engineering expertise and Historical pattern matching.
- Our research is based on historical pattern making since it is not possible to use the first two options in this case. The research focuses on developing four prediction models. Previous work was done on:

1. Market value (MV) estimation based on function structures (FS)



(Mathieson, JL L, and JD Summers. 2010. "Complexity Metrics For Directional Node-Link System Representations: Theory and Applications.")

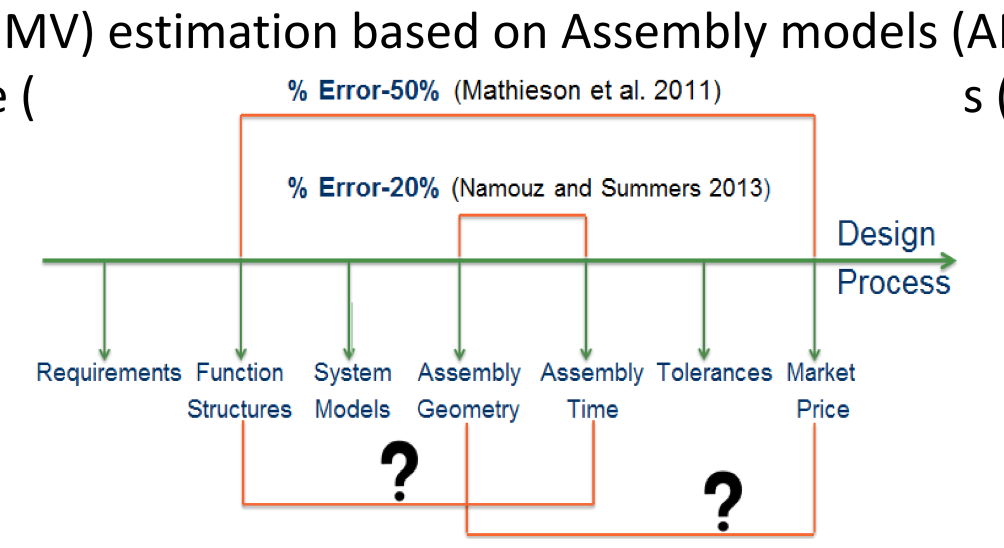
2. Assembly time (AT) estimation based on assembly (CAD) models (AM)



(Namouz, Essam Z., and Joshua D. Summers. 2013. "Complexity Connectivity Metrics – Predicting Assembly Times with Low Fidelity Assembly CAD Models.")

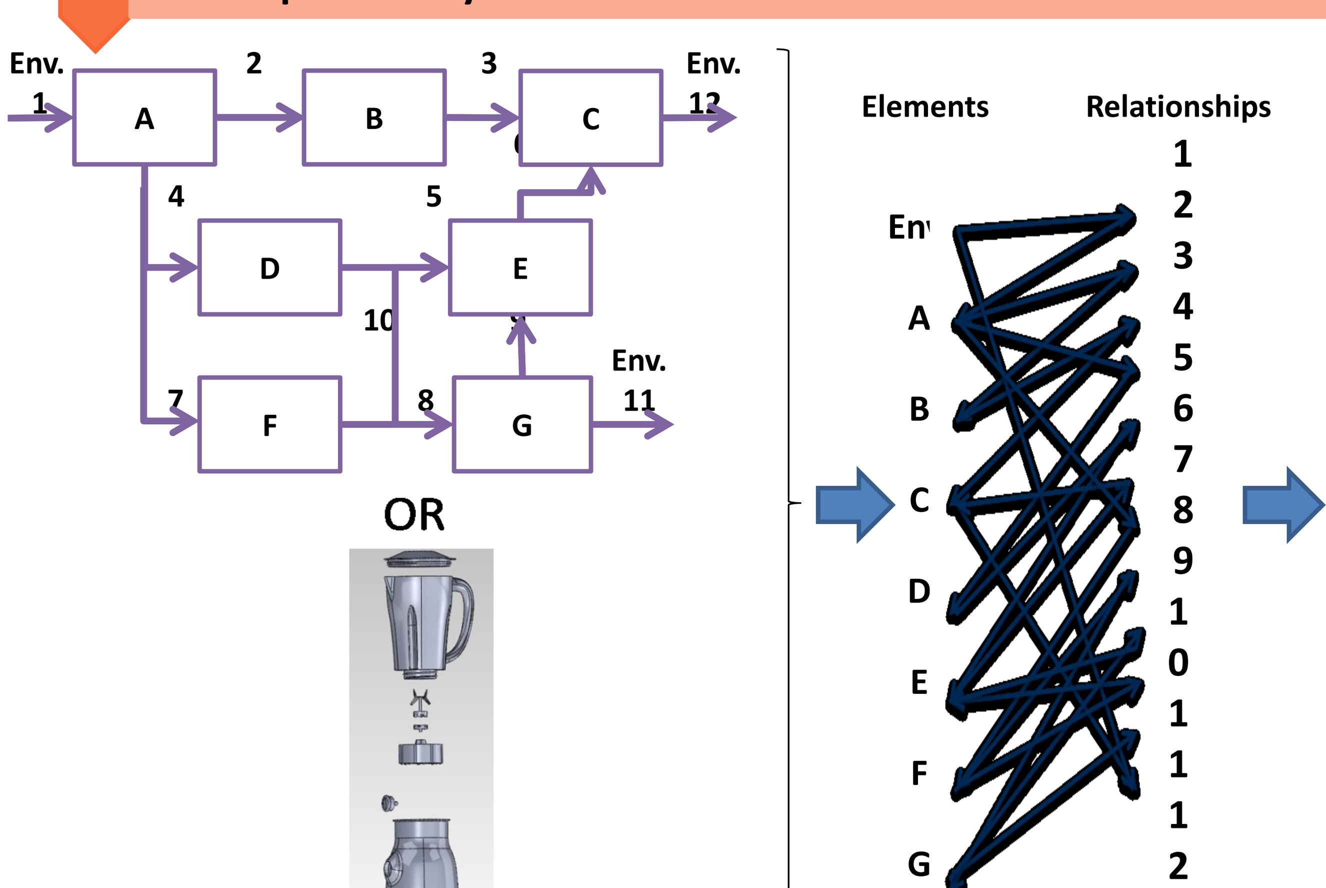
- This previous work has shown that historical data in the form of product graphs reduced to a vector of twenty nine complexity metrics coupled with performance metrics can be used for performance prediction through artificial neural network surrogate modeling.
- Current work being done on:

3. Market value (MV) estimation based on Assembly models (AM)
4. Assembly time (s (FS)



Outline of The Experimentation Method

- **Generate Function Structures and Assembly Models of Products.**
- **Create Bi-Partite Graphs of these Structures and Models.**
- **Build the 29 complexity metric vector metric using these graphs.**
- **Store Assembly Times and Market Values of Products as Target Values.**
- **Train Artificial Neural Networks using the Complexity Metrics and Target Values.**
- **Test the five selected products against the trained Artificial Neural Networks.**
- **Compute Analysis on the test results.**



Class	Type	Dir.	Metrics
Size	Dim		Elements
			Rel
	Conn		DOF
			Conn
Interconnection	Shortest Path		Sum
			Max
			Mean
			Density
	Flow Rate		Sum
			Max
			mean
			density
Centrality	Betweenness		sum
			max
			mean
			density
	Clustering Coefficient		sum
			max
			mean
			density
Decomposition	Ameri Summers		
	Core Numbers	In	sum
			max
			mean
			density
		Out	sum
			max
			mean
			density

Figure: Co… of FS and AM to bi-partite graphs to 29 complexity metric vector

Artificial Neural Networks

- ANNs serve as a surrogate model to map the graphs to the performances values.
- ANNs are chosen, as they explore the relationships due to their ability to perform nonlinear statistical modeling (Tu,1996).
- For this research, a population size of **189** architectures are used and are replicated **100** times to predict the performance values of the products.

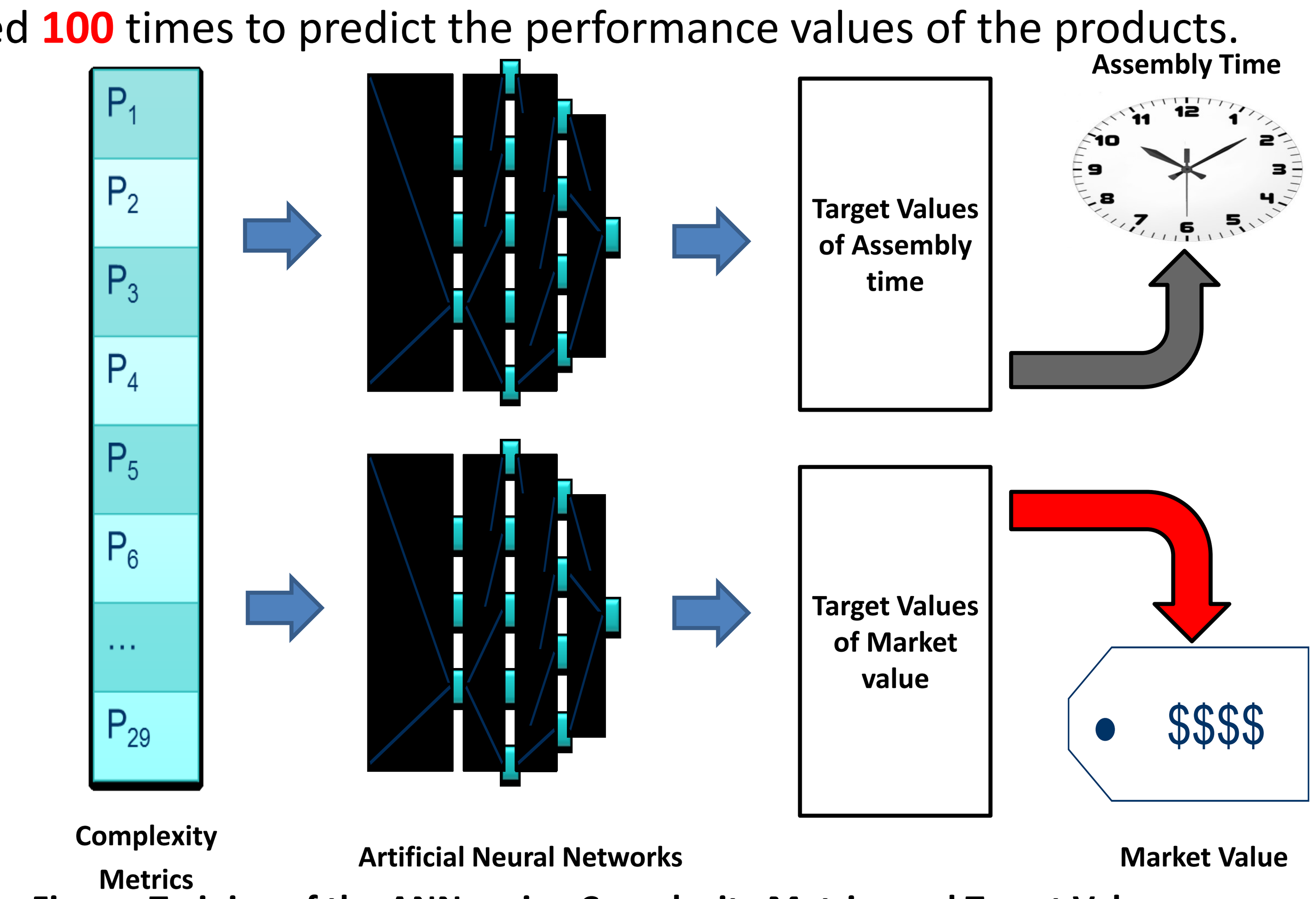


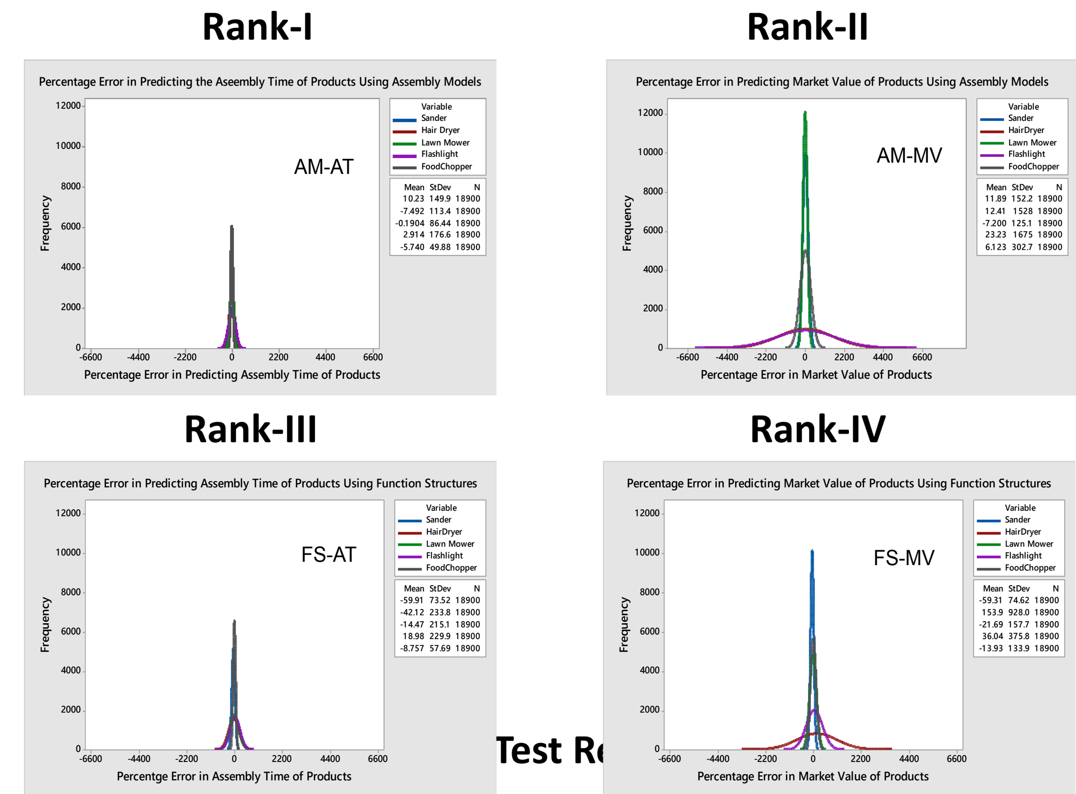
Figure: Training of the ANNs using Complexity Metrics and Target Values

Test Results

Table: Absolute Average Percentage Error of four prediction models

	AM-AT	AM-MV	FS-AT	FS-MV
SANDER	10.2%	11.9%	-59.9%	-59.3%
HAIR DRYER	-7.5%	12.4%	-42.1	153.9%
LAWN MOWER	-0.2%	-7.2%	-14.5%	-21.7%
FLASH LIGHT	2.9%	23.2%	18.9%	36.0%
FOOD CHOPPER	-5.8%	6.1%	-8.6%	-13.9%
ABSOLUTE AVERAGE	5%	12%	29%	57%

- Percentage Error (< 10%) – Green Color
- Percentage Error (10%-20%)- Yellow Color
- Percentage Error (20%-40%)- Orange Color
- Percentage Error (40%-60%)- Red Color
- Percentage Error (>100%) – Dark Red Color



Conclusion

- Between assembly models and function structures, use of assembly models for prediction has a lesser absolute error percentage.
- The prediction model of 'Assembly time estimation based on assembly (CAD) models' has the lowest absolute error percentage.

Table: Comparison of four prediction models

	Assembly Time	Market Value
Assembly Models	Absolute Average Percentage Error of Five Test Products is 5% [maximum-10%] {20%- Namouz et al. (2013)}	Absolute Average Percentage Error of Five Test Products is 12% [maximum-23%]
Function Structures	Absolute Average Percentage Error of Five Test Products is 29% [maximum-60%]	Absolute Average Percentage Error of Five Test products is 57% [maximum-154%] {50%- Mathieson et al. (2011)}

Future work

- Analyze the level of significance of each complexity metric in the prediction of performance metrics.
- Explore both principle component analysis & linear and nonlinear regression analysis to refine the complexity metric vector.