Systems Engineering Approaches to Product Development with DFMA

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Introduction

Companies that manufacture and sell products are always looking for ways to improve their approaches towards product development. Dynisco Instruments, Franklin, MA, producers of pressure and temperature sensors, controls, and analytical instruments for the plastics extrusion industry, is no different. Dynisco first launched a Continuous Improvement (CI) initiative back in 2009 by deploying Design for Manufacture and Assembly (DFMA®) and Lean Manufacturing techniques companywide to help improve their engineering and manufacturing practices. Today, Dynisco has started adopting Systems Engineering approaches towards product development to enhance their products through better feature definitions and voice-of-the-customer (VOC) requirements.

The following review will look at Systems Engineering tools and techniques utilized by Dynisco, what benefits come from their use, and how these tools are structured inside a product development process to maximize the results. Dynisco continues to be a strong supporter and user of Boothroyd Dewhurst, Inc.'s (BDI) DFMA® software in their product development process as well, using it since the 2009 CI Group started. DFMA® is a critical tool within the Systems Engineering toolbox. To understand how to apply Systems tools with DFMA®, a review of Dynisco's products and their role in the plastics extrusion industry will be covered to see how defining customer requirements early in the product development process is critical.

Dynisco manufactures the LMI 5000 series, laboratory melt flow indexer for testing the melt flow rate of polymers, with conformance to ASTM D1238. This product recently underwent design improvements, which resulted in the development of new model which has been released to the market. The LMI 5000 series melt indexer was launched in 2013 and has been in production since. The new LMI 5500 is an upgraded melt indexer recently launched to production that offers improved functionality for our customers, brought about with Systems Engineering thinking. The resulting LMI 5500 product will show how Dynisco applied Systems Engineering approaches to outline the product definition and DFMA® to the optimize the design.

Systems Engineering Overview

Systems Engineering techniques, like DFMA®, have been in use for some time. To get the benefits of these tools, it's a matter of how a company adopts them within their development process. Systems Engineering can be defined as a structured method to support world-class systems engineering and development. Credited with establishing the Systems Engineering structure, also known as Lean Product Development, are the following individuals: Professor Phil Barkan—Stanford University, Professor Don Clausing—MIT, Professor Kosuke Ishii—Stanford University, and Professor Allen Ward—University of Michigan.

The goals from using the Systems Engineering approach over traditional product development start with creating an expanded definition of competitiveness of products by thoroughly examining their features, cost, and time-to-market requirements, with a strong emphasis on early planning. Defining and benchmarking existing products is a large part of Systems Engineering development as most projects are based off existing products that are already being produced. These early steps create a clear vision for the project at hand and a strong product definition. An integrated use of Systematic tools focuses on the strategic combination and timing for using the tools. The end goal is defining and deploying value in the product to meet customer needs.

A tool to start with in applying Systems Engineering is called a Project Priority Matrix. This matrix takes the features, cost, and time-to-market goals of a project and combines them with three control factors. These three control factors are called constrained, optimized, and accepted. Each one of the three goals are assigned to one of the three factors and is only used once.

The three critical goals of a product development project are:

1. Features: the product must meet or exceed the performance, functional, or feature set requirements
2. Costs: the cost to manufacture must be at or below expected targets
3. Time: the product must launch on-time to meet the targeted launch date

This matrix can assist in arranging engineering program paths. For example, if the project is to provide a product that must show a clear, new, and improved level of functions and features in the product, then the features goal is defined as the constrained goal. Then the cost or time-to-market goals are assigned as either optimized or accepted. An example of a Project Priority Matrix is shown in figure 1. In this example project, the goal that is defined as constrained is the time-to-market. When the product is launched is the highest priority and must be met. The features goal is defined under the optimize column. This means the project will try to maximize the function and features in the product while the time-to-market is constrained. This leaves the cost in this project as the goal that will fall under the accept definition, again, while the time-to-market is constrained, and the features will attempt to be optimized. This is an example of how the Project Priority Matrix is applied in order help define the direction of the three main goals of a product development project.

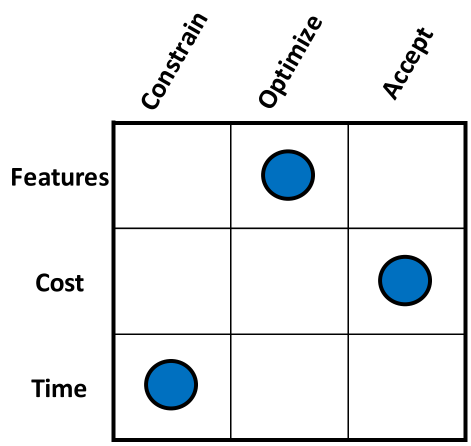


Figure 1 – Example of a Project Priority Matrix.

<u>Systems Engineering Tools</u>

VOC requirements for products are commonly obtained through sales and marketing departments based on feedback from the customers themselves. However, solely depending on VOC data may not provide a clear picture of all the criteria that is important to a specific design. Tools used to expand and combine with the VOC data are a Customer Value Chain Analysis (CVCA) and an Affinity Diagram with a Needs Assessment.

The Customer Value Chain Analysis (CVCA) method was developed by Edith Wilson during her work with Hewlett-Packard. The purpose of this analysis is to gain a better understanding of the needs of the customers and other stakeholders in relation to the value provided by products. The CVCA is a tool used to recognize the internal and external relationships that make up the value chain and to understand the value proposition for each stakeholder. To further assess the customer needs of a product, an Affinity Diagram is used. Referred to also as the KJ Method as it was named after Professor Jiro Kawakita from the University of Kyoto, Japan (Tague). A Needs Assessment then compiles the list of customer needs.

CVCA and Affinity Diagram

The first step in building the CVCA graph (figure 2) is to list all stakeholders that are involved with the product. Once all the stakeholders are listed, the relationships between each are identified to understand how the value flows between parties. To understand how the value flows between stakeholders, the various types of items that move between them are mapped on the CVCA graph. These items include: money, information, the physical product, and materials. On the graph, money is represented with a dollar sign, "$," indicating a transfer, or at times an allocation, of funds between two stakeholders. Flow of information between parties is denoted by an exclamation point, "!" on the graph and may be in the form of reports, orders, invoices, regulations, feedback, etc. The transfer of unfinished material is denoted by a picture of a gear and includes raw material, parts, subassemblies, and other goods that are not finished products. A "P" represents physical transfer of the actual finished product. Once the CVCA graph is completed, it can be studied to identify the critical customers within the system. The mapping of the flow of money and information between stakeholders helps those in product development to understand the value proposition for each one of them regarding the product.

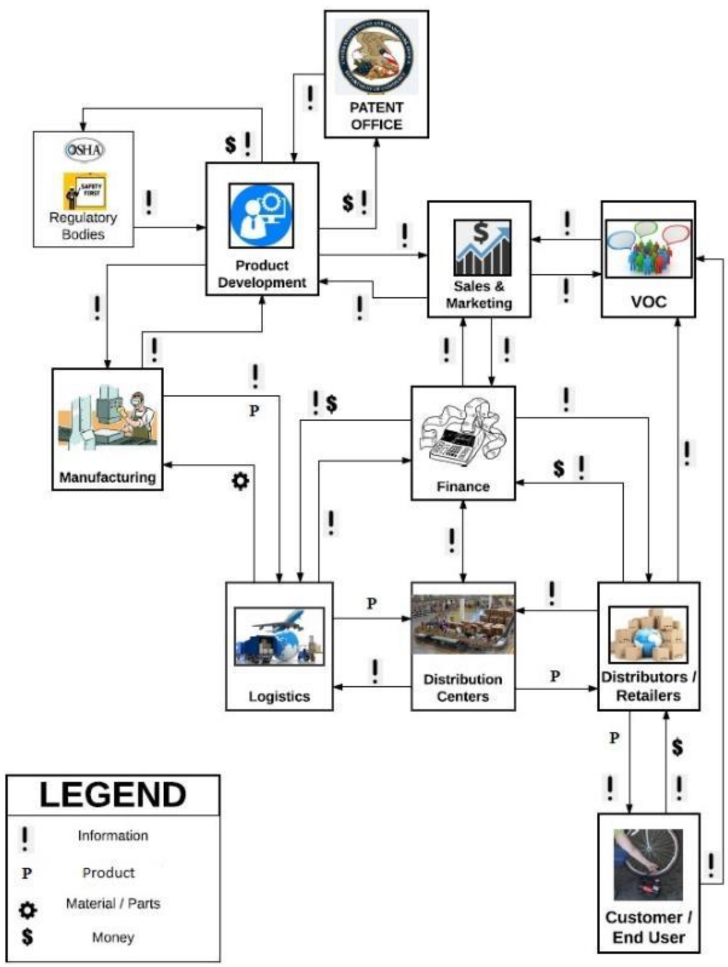


Figure 2 – Example of a Customer Value Chain Analysis graph.

After the CVCA is completed, the next step involves the development of an Affinity Diagram (figure 3) by brainstorming, organizing, and categorizing the customer needs for the product. The affinity diagram starts with brainstorming the raw needs of products. The data is then categorized to assist in defining the customer needs. From the affinity diagram, the results can be summarized in a hierarchical list of customer needs that can be addressed during product development. The KJ method suggests putting the ideas onto cards, labeling the cards and sorting the data, but software can also be used to develop the diagram. This step is performed to sort and cluster the data into categories that overlap in common areas that define features of the product. Once the affinity diagram is completed, the data can then be reviewed to develop the full needs assessment.

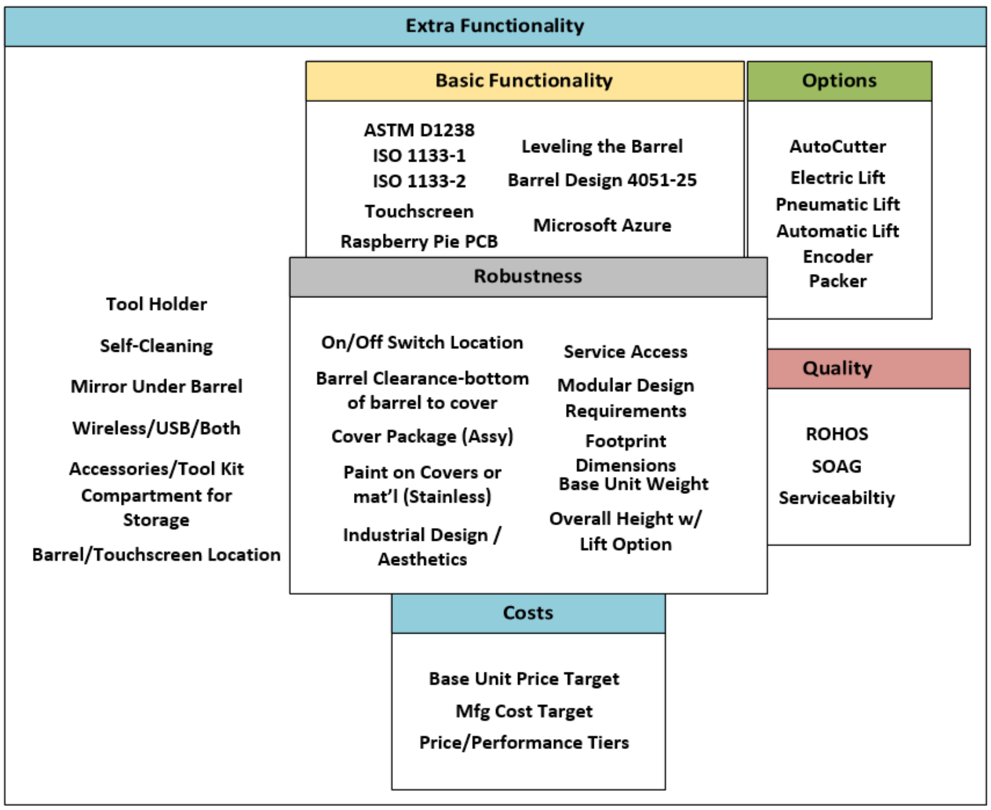


Figure 3 – Affinity Diagram for Dynisco's LMI product.

Next, reviewing the product with a Needs Assessment process is valuable in that it provides a way to discuss additional features that could be included into a future state product. This is important as it asks engineers to consider alternate items in the value stream that may be important to the customers. A customer needs list can be developed for products from the use of the CVCA diagram and Affinity Diagram. The CVCA graph exposes the engineer mindset to a broader method of product analysis and the entire value stream by focusing on how information and dollar values flow between internal and external stakeholders. The benefit to the engineer is this: the process helps answer the question of fundamental product value to the customer and related stakeholders.

These tools provide a structured method to understand the value stream, clearly identify stakeholders, and directly develop customer needs from the total VOC. Cross-functional teams would likely be committed to gathering the raw data that drives the customer needs. Tools such as brainstorming, interviews, focus groups, observation of the product in use, and product case studies could all be brought to bear on developing a clear assessment of customer needs. Data gathered from these various sources and tools is combined with the VOC data that can be filtered into the customer needs and product requirements.

Function Analysis

Analyzing a product's functions early in the development process can also contribute to the customer needs list. Function analysis helps understand what the product must do before thinking about how the design assembly is put together to provide the functions. Function analysis can also help with the transition from the customer needs to designs. There are multiple techniques used for function analysis within Systems Engineering.

The Functional Decomposition method starts at the highest function of the product and works through how and why questions to break down functions further. The Subtract and Operate Method, matches functions to generic descriptions of the product parts or subassemblies, so it does examine the parts slightly. The Function Analysis System Technique (FAST) diagram stems from the Value Engineering world and is the method that Dynisco uses. FAST diagrams also use a how-and-why logic to build the diagram of functions. The highest order function is determined for the product and then a major critical logic path of functions is built. An example of a fast diagram is shown in figure 4. A Function Analysis is conducted to contribute to understanding customer needs by determine what functional requirements the product must have and help transition to how the design is then developed.

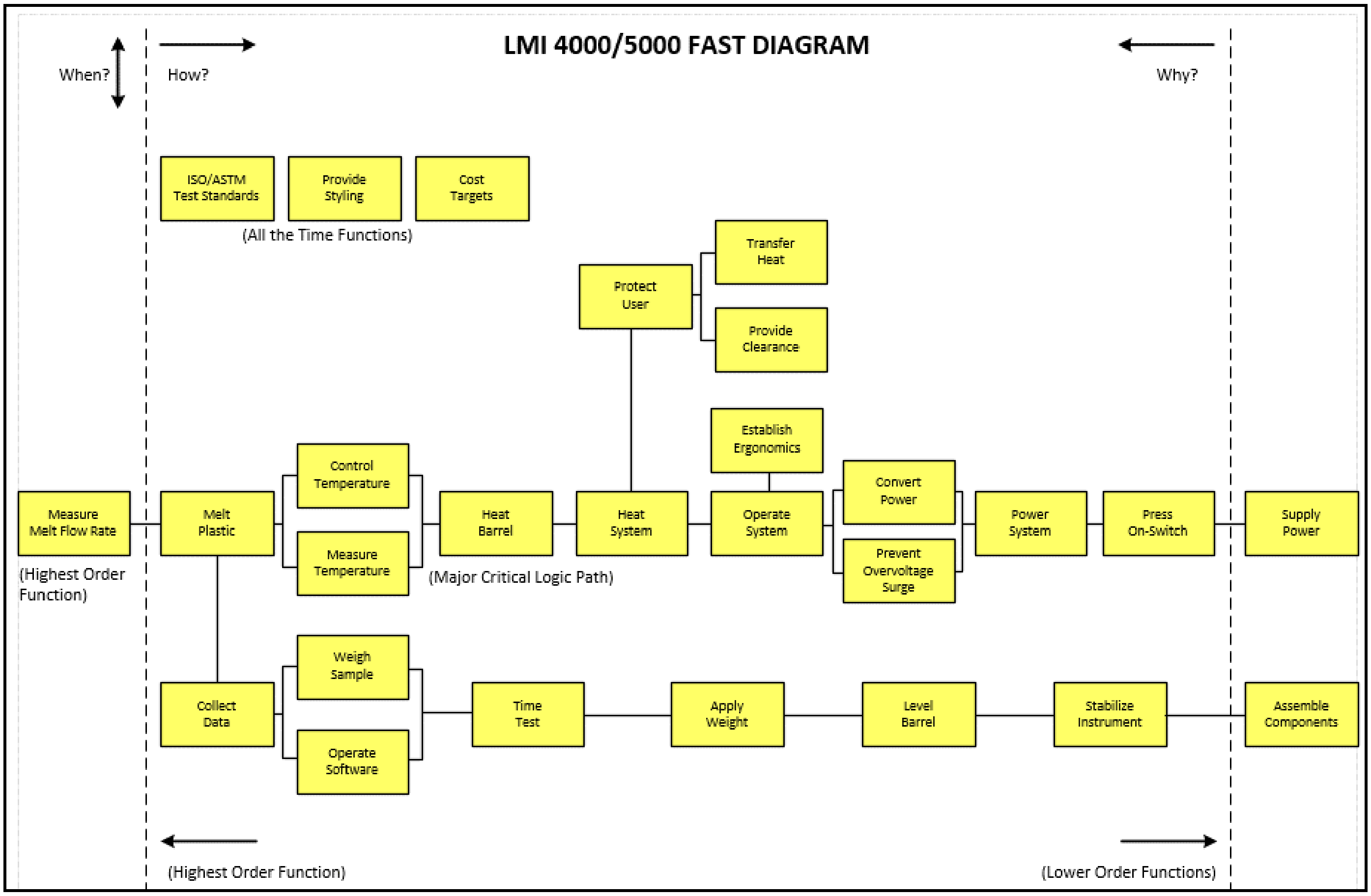


Figure 4 – FAST Diagram for Dynisco's LMI product.

Product Benchmarking

Most development processes start with an existing product so it's important to understand the current product offerings from one's own company and the competition. Product Benchmarking can be referred to as a review of one's own product, currently in production, where the desire to improve functionality and performance for the customer exists. Competitive Benchmarking is important to understand how your product stands up to other offerings from competing companies. It is common practice to obtain competitor products for disassembly and study. The intent would be to gain a full comparison of performance testing, product teardowns that would provide insight into design decisions, and an understanding of product and part costs based on materials and manufacturing processes that were chosen.

The Product Benchmarking for any product consists of noting all pertinent attributes that affect the overall sales appeal of the product, such as brand/model name, price, and styling, along with several related product factors. This is followed by a review of the product packaging in relation to the benefits it supplied the customers. Next, operating characteristics are considered, utilizing customer feedback information to rate the overall performance. Finally, a complete tear down of the product is performed to identify and examine each critical system, subsystem, and functional component.

The data gleaned from one's own product and competitors can then be combined with the customer needs list in a Quality Function Deployment (QFD) analysis. The customer needs developed from the CVCA, Affinity Diagram, and Product Benchmarking exercises are used to convert the needs into engineering requirements (metrics). The ultimate purpose of these activities is to define the engineering requirements that will assist in developing a plan for a future state product.

QFD- Phase I

QFD (figure 5) is the next tool used to analyze products. QFD is an analysis approach that takes the customer needs and translates them into engineering requirements that aide in developing a product that meets those needs. QFD was developed by Yoji Akao of Japan, who also is recognized as the developer of Hoshin planning. The QFD technique made its way to the U.S. in the mid-80's via Dr. Don Clausing, when he introduced QFD to Ford Motor Company.

The QFD Phase I process starts with entering in the customer needs from the CVCA, Affinity Diagram, Needs Assessment, Product Benchmarking, and VOC feedback would be filtered down and entered. This list of customer needs is entered in the left side of the QFD matrix under the Customer Requirements heading. The QFD process stresses the importance of fully understanding and clearly defining the customer needs since the engineering metrics are developed from them. Once the engineering metrics are entered, the user can further understand them through completing the roof matrix portion of the QFD Phase I. The roof matrix helps the engineer see where design goals conflict or mesh together. Weights are assigned in the matrix with a value of 0, 1, 3, or 9 that link the importance between customer needs, engineering metrics, and Product Benchmarking data. This portion along with the customer needs and technical benchmarking inputs really help towards defining the technical targets. Filling out this portion of the QFD Phase I matrix is the heart of QFD. The raw score and calculated relative weights of each engineering metric sum up the important needs. This process connects the voice of the customer to the engineering requirements that can be used to develop a clear, definable path for how the product functions to answer the customer needs.

QFD – Phase II

Once the Phase I QFD matrix is completed and engineering metrics are developed for the product, those metrics populate into the Phase II portion of the QFD spreadsheet. The list of engineering metrics developed in Phase I also populates into the vertical column for Phase II. The next step in the Phase II QFD section is to relate these engineering metrics to the product components. Product components or Part Characteristics of the existing product are entered in the top horizontal row for Phase II. The same weighting system of assigning values of 0, 1, 3, and 9 are used to correlate the engineering metrics to the part characteristics. The relative weights are again calculated for Phase II that determine which parts carry the most weight in terms of meeting the engineering metrics. Correlating the parts to the engineering metrics in this manner from the Phase II QFD matrix provides direction for engineers for redesigns and total product refreshes. And this is one area for DFMA® application within the Systems Engineering framework.

Figure 5 – Example of a QFD Phase I & II diagram in abstract form. This is shown to simplify the intricate spreadsheet that is used for QFD analysis.

<u>DFMA® – Areas of Application</u>

Like many of the Systems Engineering tools, BDI's DFMA® software has been available for companies to put into practice towards product development for many years. How and when the tools are used strategically together is the important part of integrating Systems tools into a company product development process. In DFMA®'s case, it's important to understand the critical areas of application to products and parts.

DFMA® is commonly viewed as a "cost reduction tool." While this is true, DFMA® can provide much more value based on where it is used. This year BDI is hosting its 33rd International Forum on DFMA®. There have been many papers and case studies through the years describing successful application of the Design for Assembly (DFA) and Design for Manufacture (DFM) modules of their software toward product design. DFA provides a method to optimize product designs through minimizing part count to provide ease of assembly and quality designs, while DFM aides in developing cost effective parts by selection of the appropriate materials and processes. For the set of Systems Engineering tools previously reviewed, DFMA® is analogous, in that, early application in the design process provides the best results.

As mentioned, as a cost reduction tool, DFMA® can help reduce costs for products already in production. It's important though, to apply DFMA® up front in the design process to tie in with the other Systems tools. Dynisco has heavily used DFMA® for the last 9 years and considers it THE tool to use for the product and competitive benchmarking process. For any company starting out with DFMA®, training always starts with analyzing their existing products with the software. DFMA® is the ideal tool to examine your company product designs and for use in teardowns of one's own products or competitors. The most important area of application of DFMA® is toward concept design. Once an initial concept assembly is developed, this is the time to apply DFMA®. Doing so will early will reduce the number of design iterations or cost reduction activities later.

Concept design, product and competitive benchmarking, design iterations, and post-launch cost reduction are all areas to apply DFMA®. The best results come from its application towards concepts, which also can tie-in to early product definition that comes from the Systems Engineering approach.

<u>Dynisco Products</u>

Dynisco manufactures pressure and temperature sensors, as well as laboratory/quality control testing instruments for the plastics extrusion industry. Shown in figure 6 is a representation of a plastics extrusion line. Dynisco sensors are installed at critical points in the extrusion line to measure pressure and temperature. Burst plugs, or "rupture disks," are also used along the extrusion line for emergency relief of excess pressure in a system. Dynisco also sells process indicators and controllers that are tied with the sensors to monitor and control the extrusion process. The other side of Dynisco's business are the quality control testing instruments. Referred to as Polymer Test or "Polytest," these products are table-top laboratory instruments that measure plastic material properties that can be correlated to the

“Online” products to ensure process verification for the extruder. Examples of online systems Dynisco sells are also shown on the far right of figure 6, the ViscoIndicator and ViscoSensor. Collectively, these products provide our customers a “window into their process.” The information provided by Dynisco products keeps the extruder’s processes consistent, minimizes material waste, and, most importantly, drives uptime, which saves them money.

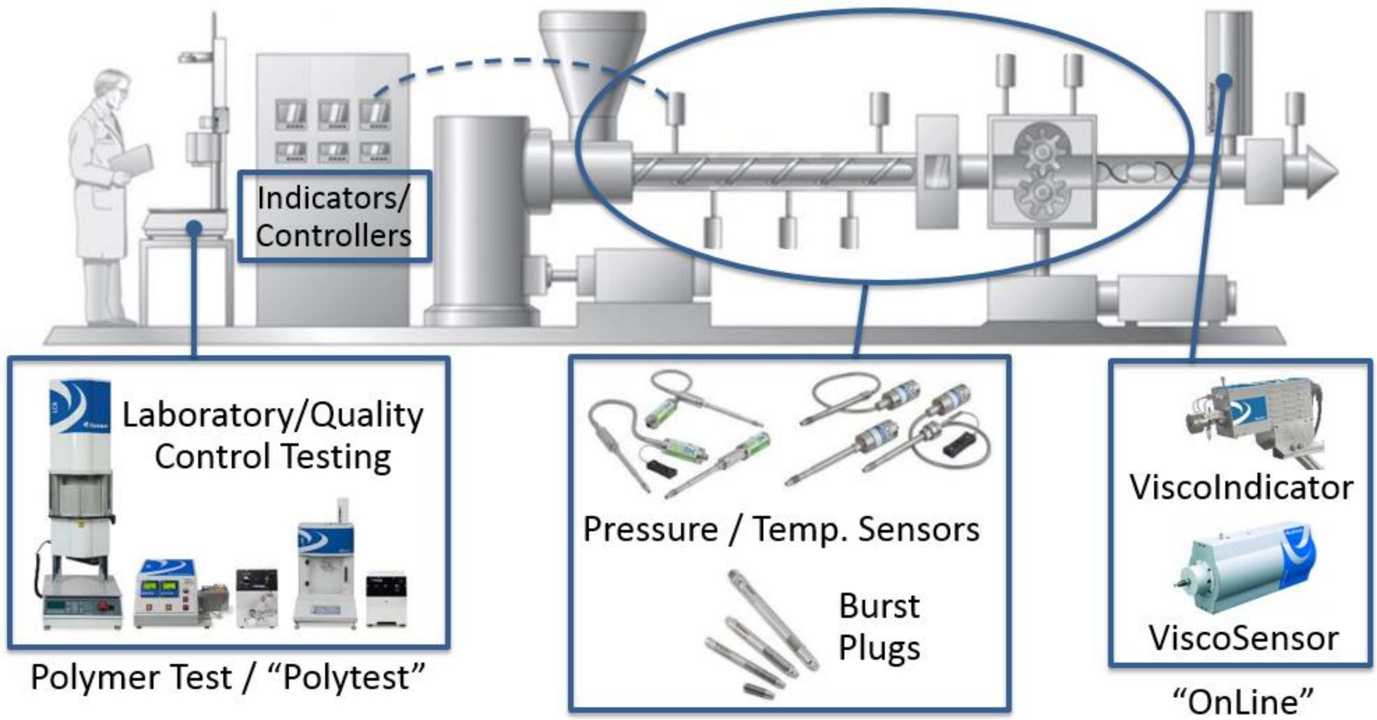


Figure 6 – Example diagram of a “plastic extrusion line” and where Dynisco Sensor and Polymer Test products are used so extruders can keep their processes consistent.

<u>Laboratory Melt Indexer (LMI) 5000</u>

One of the polytest products to examine in this review is the LMI 5000 series melt indexer. The LMI 5000 is a culmination of feedback from customers incorporating a series of key features and options. The latest development in Melt Flow Indexers is the capability of delivering a wide range of data that includes not only melt index values, but also shear stress, shear rate, viscosity and melt density, as well as testing conditions. The addition and improvements of key attributes make the product easier to operate and improves data repeatability.

Dynisco's LMI instrument's main function is to measure the melt flow rate of plastic materials for quality control purposes. The melt flow rate is used as a quality control measure in the manufacture of the virgin plastic pellets. The other use for melt flow rate is as a quality control check and process measure for the operators of the extrusion processes that use the plastic pellets.

To operate the LMI equipment, one must first place 6 grams of the plastic pellet material into the bore of the LMI barrel. The location and the temperature are set by the operator through the touchscreen interface. The standard test measurement takes the LMI 10 minutes. During this 10 minutes, the LMI exposes the plastic materials to temperatures and pressures that will be applied in the extrusion/injection molding process. The sample pellets are melted as they pass through the length of the heated barrel, which then flows through a small die at the end of the barrel. The operator is notified when the measurement is completed by a beeping sound and the plastic must be cut from the bottom of the barrel using a laboratory knife or can be automated with the auto-cut option. The operator must then weigh the extruded plastic sample. Using the weight, the operator can calculate the melt flow rate of the plastic in units of grams per 10 minutes.

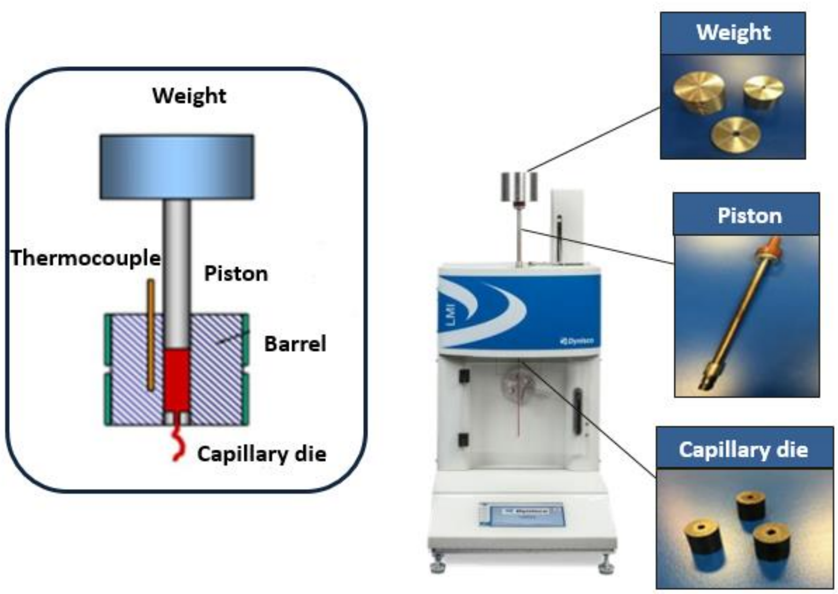


Figure 7 – Dynisco's LMI 5000 product.

<u>LMI 5500</u>

Based on initial VOC feedback, Dynisco decided to pursue a project that would enhance the LMI's functionality for our customers. Dynisco then embarked on the yearlong project and used Systems thinking to create the product definition and apply DFMA® to improve the overall assembly of the product.

Increased functionality in the LMI 5500 (figure 8) starts with moving to a Windows 10 IoT (Internet of Things) core and a single board computer with the integration of the Microsoft Azure Cloud option. Combined with a new modular capacitive touchscreen assembly, initially used in a previous Dynisco product launch, the Windows 10 platform consolidates software across Dynisco's Polymer Test Product Portfolio. Additional functionality also includes built in Wi-Fi, ethernet, Bluetooth, HDMI, and multiple USB ports. A removable magnetic test inspection mirror is included in the LMI 5500 product. The 5500 continues to measure melt flow values to all industry standard test methods.

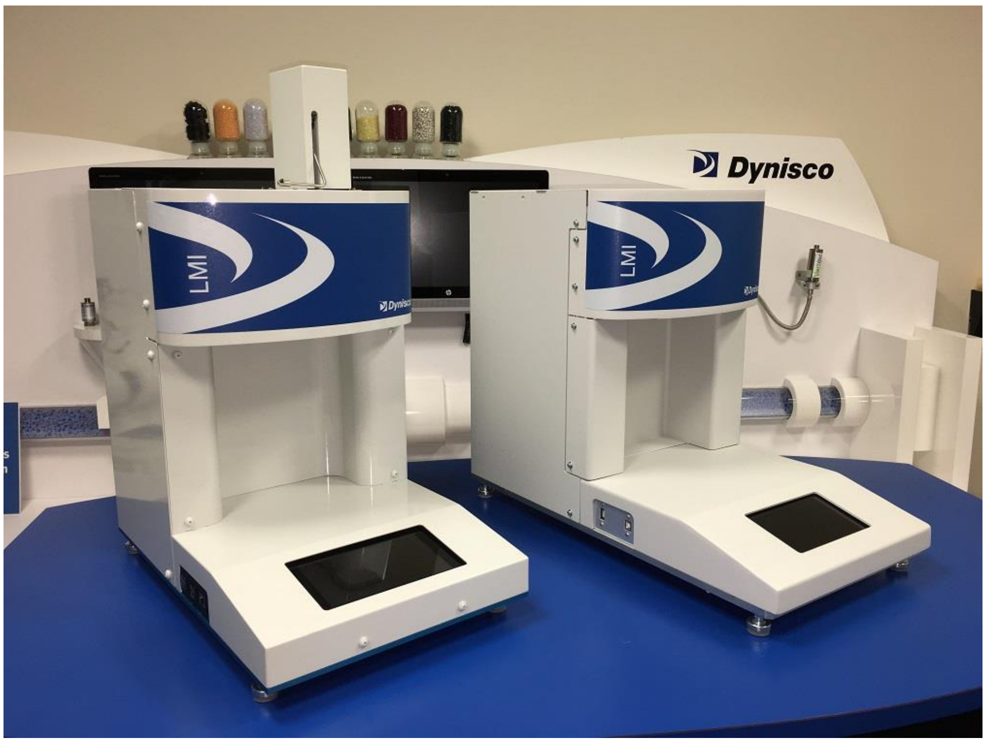


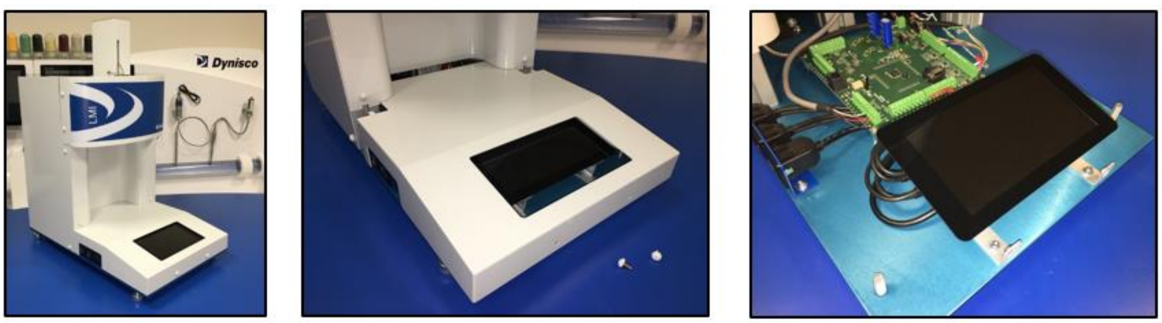
Figure 8 – Dynisco's LMI 5500 (left) and LMI 5000 (right) series products.

From an assembly perspective, Dynisco was able to make improvements in the LMI 5500 product to reduce assembly time based on DFA analysis recommendations. For example, the existing LMI 5000 touchscreen assembly was based on the previous model design that had the touchscreen cover on a hinge. The hinge design provided access to the interior of the LMI for service requirements. This design was carried over to the 5000 series LMI, so the touchscreen itself was assembled to the touchscreen-cover and moved when the cover was opened. To rotate the touchscreen cover, the front cover, fastened with 4 screws, had to be removed first (figure 9).

LMI 5000 Assy | Remove 4 Front Cover Screws | Cover & Touchscreen Rotate to Open | Hinge Design: 40 parts

Figure 9 – LMI 5000 touchscreen assembly hinge design.

The design for the LMI 5500 touchscreen assembly was simplified. The touchscreen assembly is now mounted on 2 sheet metal brackets assembled the LMI base plate. These two brackets also allow the touchscreen cover to be assembled with only 2 screws and the front cover does not need to be removed. The LMI 5000 touchscreen assembly had 40 parts in the assembly, which was reduced to 22 parts on the LMI 5500. This reduced assembly time, was easier to assemble, and provides easier access for service (figure 10).



LMI 5500 Assy | Remove 2 Touchscreen Cover Screws | New Touchscreen Module Design: 22 parts

Figure 10 – LMI 5500 touchscreen assembly design.

Overall, the LMI 5500 design takes approximately 16 minutes less to assemble than the LMI 5000. The DFA comparison of the two LMI designs, shown in figure 11, illustrates the assembly improvements on the 5500. Assembly operations and part count (total entries) were reduced from 323 to 284. The DFA application on this design led to the reduced assembly time, an increase to parts that meet the minimum part criteria questions, and improved DFA index or assembly efficiency. Through Systems thinking and DFMA® application, Dynisco was able to take a stand-alone quality measuring device and turn it into an analytical system with greatly improved functionality to meet our customer needs.

Entries including repeats	LMI 5000	LMI 5500
Parts meet minimum part criteria	37	41
Parts are candidates for elimination	180	162
Analyzed subassemblies	2	2
Separate assembly operations	104	79
Total entries	323	284

Assembly labor time, s		
Parts meet minimum part criteria	554.01	569.18
Parts are candidates for elimination	2765.92	2056.08
Insertion of analyzed subassemblies	42.58	40.00
Separate assembly operations	1653.76	1439.55
Total assembly labor time	5016.27	4104.80

Design efficiency		
DFA Index	4.79	6.48

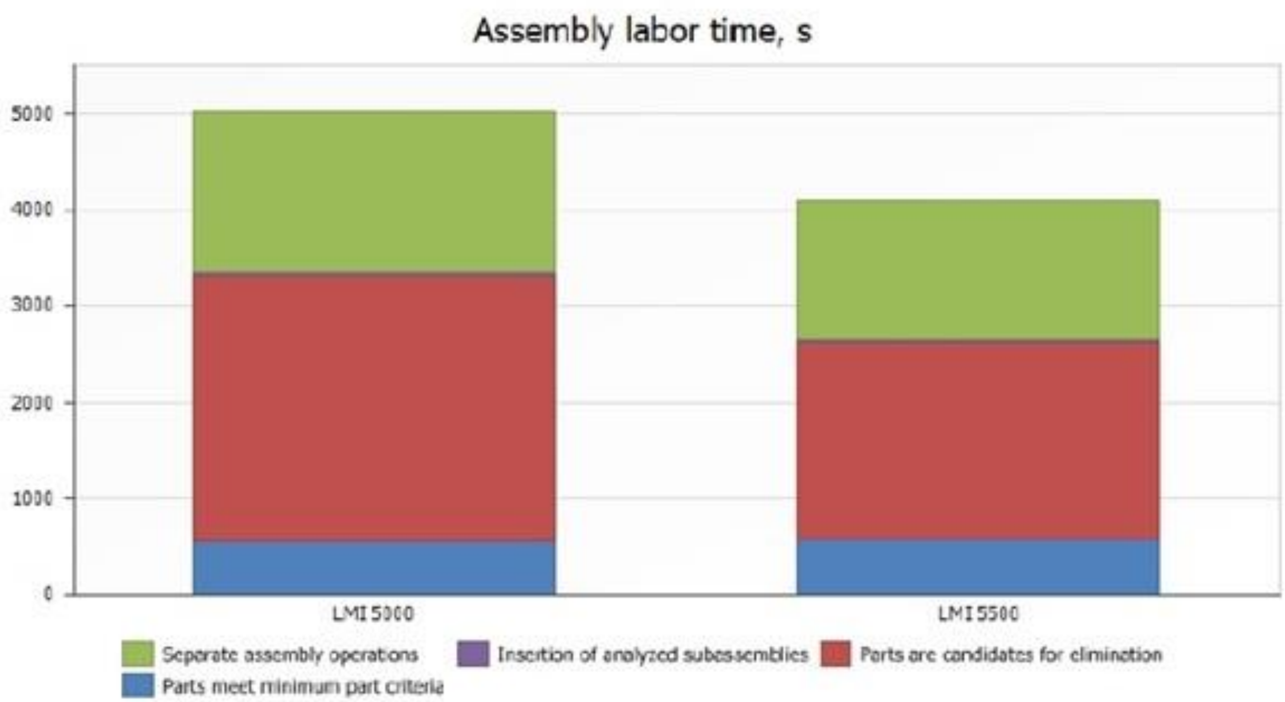


Figure 11 – DFA comparison of the final LMI 5000 and 5500 designs.

Summary

Systems Engineering's structured approach to product development offers many benefits. It creates a clear vision for the product through early planning in the development process. Typically, systems tools are applied at the very front end of the development process when the opportunity for the product and preliminary assessment of the markets are examined. The tools used strategically together, such as CVCA, Affinity Diagrams, Function Analysis, Value Analysis, QFD, and DFMA®, provide steps to clearly define the customer needs for the product. With DFMA® used as a part of the Systems Engineering approach, these techniques provide a path to clearly define and deploy value during the product development process.

Like any new business initiative, it will take time for Dynisco to fully adopt Systems Engineering into their company procedures for product development. As shown through the LMI 5500 project results, early planning with systems thinking of the product definition resulted in more functionality from the product for Dynisco's end users. With improvements to the product designs such as these, Dynisco will continue to grow the Systems Engineering initiative as well as continue their use of DFM—structured with the other systems tools. Both Systems Engineering and DFMA® stress early use in the product development process. DFMA® complements the product definition and customer needs identification from systems thinking with strong application towards concept designs, product and competitive benchmarking, and design iterations. Dynisco believes that successful application of these tools will lead to further improvements within their product designs.

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