



DFMA 2017

**32st International Forum on Design for Manufacture
and Assembly**

DFI:

Design for the Industrial Internet [IIoT]

Design for the Internet of Things [IoT]

June 6, 2017

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DFI: Design for the Industrial Internet and the Internet of Things

by
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The definition of a product, and the look of a factory that makes it, will undergo transformation and redefinition across commercial, consumer, and medical industries in twenty-years time. The sooner companies can figure out an initial systematic approach, that can be continuously renewed as the Industrial Internet [IIoT] and the Internet of Things [IoT] and their numerous protocols head towards standardization, the better off they will be. Retrofitting to keep pace will be quite expensive. The IoT is a system-level feature and will be best implemented if it is designed-in to product families as a feature of their architecture and subassemblies. The bulk of the responsibility will fall to Product Development. Today's internet technology is developed outside most companies and designed-in to products. DFI, a new member of the DFX family, will be introduced in concept for the first time at the 32nd DFMA Forum. A few years from now, R&D and Advanced Development will get more engaged as next-gen sensors move from lab to industry. DFI will then become an end-to-end company process. New, recently created and largely untested, DFI operational frameworks and metrics that measure degrees of "IoT-Enabled" and "IoT-Capability" will be presented -- so as to encourage audience comment and feedback.

For the purposes of bounding and defining the terms "Industrial Internet (IIoT)" and the "Internet of Things (IoT)" that are widely used in this paper, it is important to keep in mind the great change that the value of information will have in the years to come. When software became widespread, companies did not know how to deal with it and it was simply given away with products. In the future, we will continue to give away much software in order to maximize the data and the benefits of the information that software encounters. Generally speaking, any device whether hard or soft, is soon to exist in an ecosphere where the lion's share of the real-time exercising of a product will be able to be captured and stored throughout the product life cycle - B2C and B2B. Therefore, it is advised, when thinking about the terms IIoT and IoT in the context of a product or product line that the collective set of on-board hardware to manipulate data (sensors, receivers, transmitters, processing, storage, etc) is included in the definitions. And, because it is the data that will generate disproportionate value, the collective set of tools that derive and squeeze out the value of the data (big data databases, cloud, analytics, rules-based decisions, fuzzy-logic, etc.) also be included in the definitions. While the preceding definitions are a giant body of knowledge across the various topics, the concepts and frameworks illustrated in this paper stop short of artificial intelligence and the ever-deepening ability of neural networks. The concepts and



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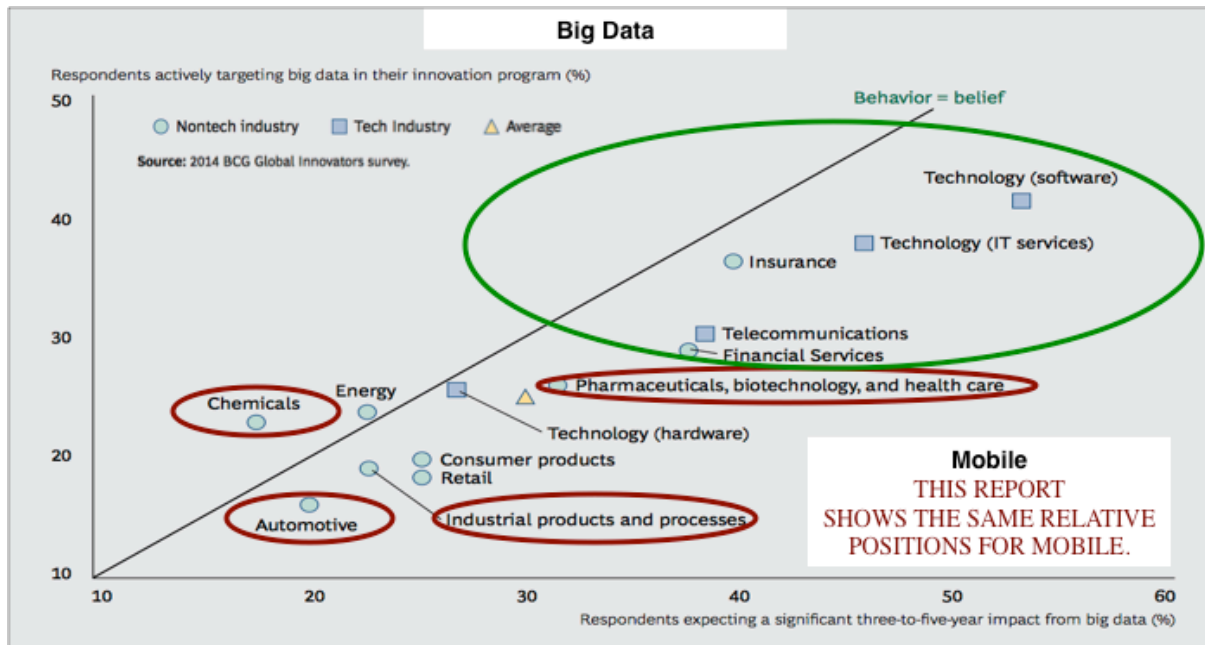
frameworks assume humans are still running things, with the leverage of controllable decision-making technologies like rules and fuzzy logic. Over a product's life cycle, in the years to come, the environment will become increasingly hybrid as AI pops up in islands of fully intelligent automation.

The rate of penetration, in industry and in society, of the internet and its associated technologies and infrastructure is not to be underestimated. In the 1980s and 1990s, technologies such as machine vision and robotics were touted to become mainstream within a decade. Having learned from inventions and innovations of years prior, most folks knew that it simply wouldn't be that fast. In all likelihood, because folks are used to a consistent over-hype of new things for decades that did not pan out fast, the Industrial Internet and the Internet of Things are likely to be underestimated.

Secondary and selected sample research findings indicate that cross-industry emphasis ranges from a top-five priority to not a priority. Regardless of where one's priority, GGI believes that the "internet ability" of products is doubling about once every three years. For most companies, that is a single product development cycle for any product with a significant amount of "new" in it. Even if the doubling every three years assumption is incorrect and it doubles in six years instead, the one product cycle tells the story. By the time one cycle passes, using 6 years, there would be a possible 50% difference between competitors that prioritize internet capabilities in products immediately, and competitors that do not.

Some sectors are already significantly outperforming other sectors. At fifty thousand feet, financial services and pure software industries are significantly outperforming. Using big data and mobile to make the case, the recent competitive positions of representative key industries are depicted in Figure 1¹.

Figure 1: Relative Industry Positions in Big Data and Mobile: Priority vs. Expected Impact



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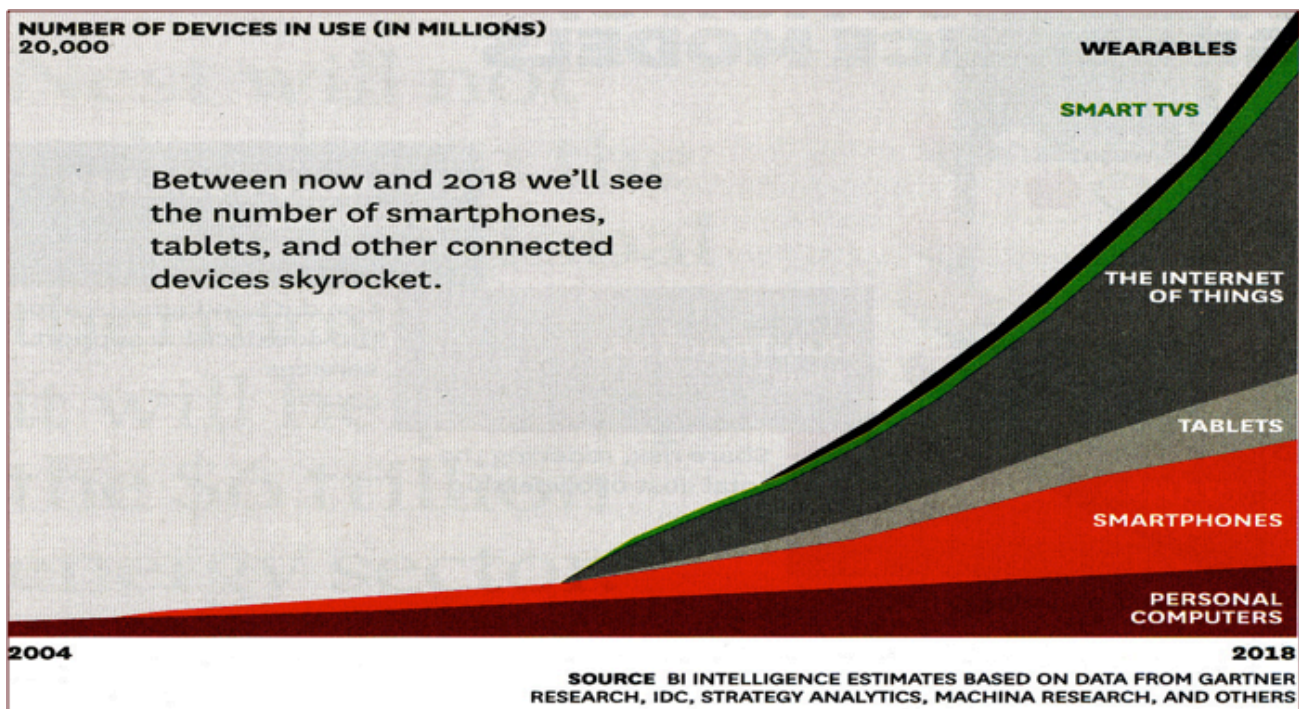
GGI's experience regarding industry's adoption of encompassing technologies such as the IIoT and IoT is that many years pass before executives realize that numerous solutions have evolved within their enterprise and it is costing money to support and maintain them all. Systems engineering logic is then applied and several years pass to achieve the simplified platform(s) or solution. The internet is arriving at a much faster rate.

There is a business opportunity for companies to grapple with all the uncertainty early, rather than sort out entrenched and owned partial solutions later, and define a systems approach to enabling products to maximize the value of the internet.

A NEW REALITY

Before describing the transformation of organizations and companies that is visible now and soon to be pervasive, it is useful to illustrate that industry is not in a period of linearity. The IIoT and IoT are growing at a geometric rate, and have been since around 2012ⁱⁱ (Figure 2).

Figure 2: Explosion in Connected Devices



Governments around the world are trying to get out in front of the rapid growth of internet technologies to foresee the expected impacts on employment, economics, and society in general. Companies and experts around the world are trying to get out in front to understand the organization structure they need, the types of people and where they are located, and the best way to derive value for the company.



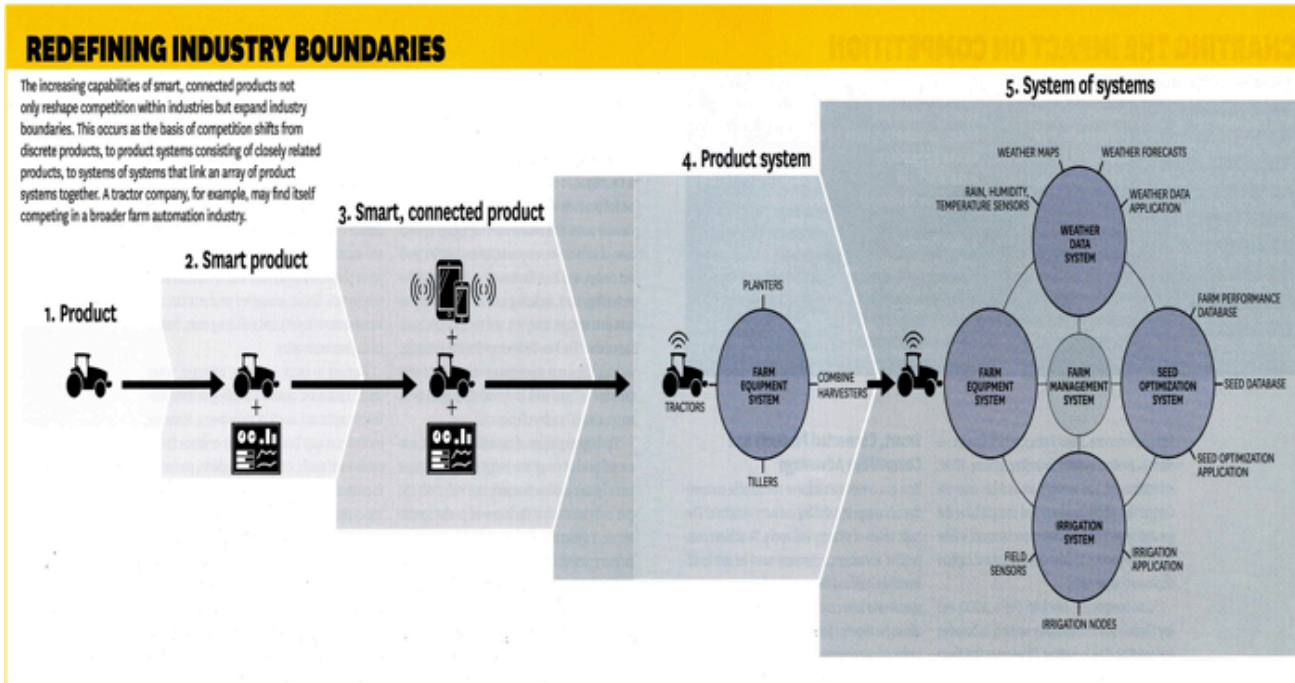
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A model put forth by Michael Porter in Harvard Business Review is getting some traction. The framework is broad enough that most industries are able to "see themselves" in the model. Porter describes the five evolutions that he expects for productsⁱⁱⁱ.

Figure 3: The 5 Expected Evolutions of Today's Products



Porter's frameworks show that smart connected products, enterprise data, and external databases will all contribute to creating new value with data^{iv} (Figure 4). Porter's frameworks show that businesses, their partners, and their customers will all be deriving value from the data.

Porter also describes a layered framework suggesting how companies might go about a systems-thinking approach to rationalize the complexity of implementing smart connected products while maximizing the value they generate. Porter's "Technology Stack" is a seven level framework, supported by identity and security services, enterprise data, and third-party data sources^v (Figure 5).

At the conclusion of this paper, having worked through a number of details of the internet's implication on product designs and capabilities, we will revisit Porter's work on how this all will impact the structure of companies.



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Figure 4: Changes In The Historical Value Of Data

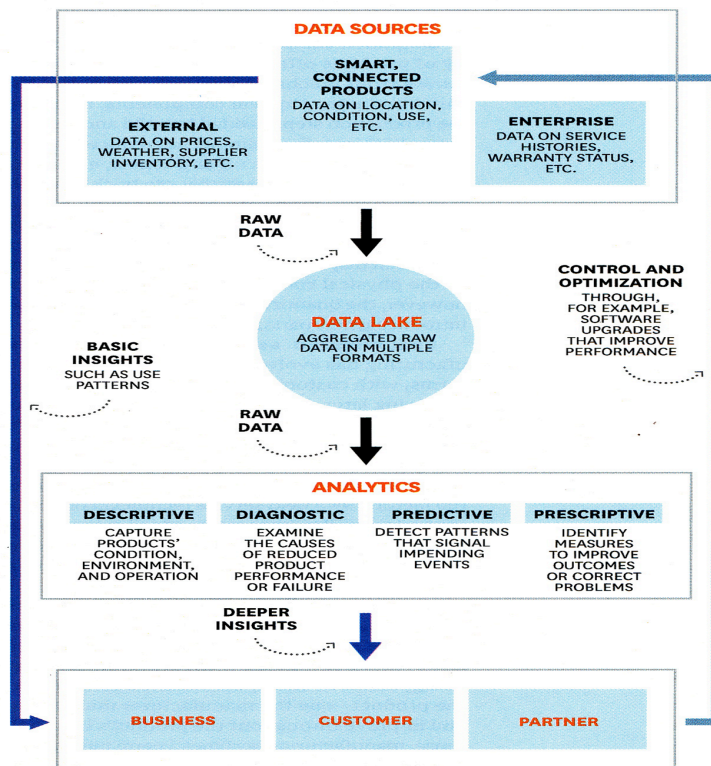
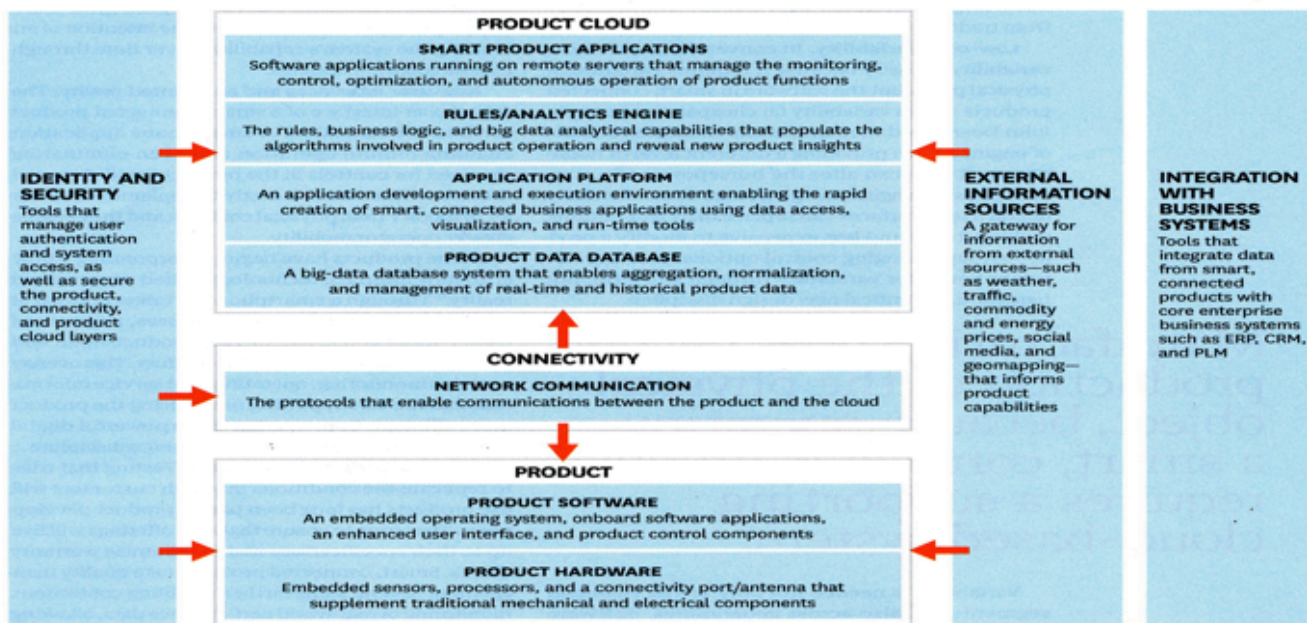


Figure 5: The New Technology Stack



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EXPLOSION OF IIoT & IOT

To make the point about the unprecedented rapid onset of the internet, some of which is depicted in Figure 1 which emphasizes technologies and products that are available to consumers, we investigated a number of technologies which a typical consumer doesn't typically see. But, these technologies enable the design and manufacture the products that people do see.

While examining high single digit and double-digit growth rates, remember that a 14% growth rate for 5 years results in a doubling of the initial parameter. These growth rates, when contrasted to average GDP growth rates of 2% around the globe, add energy to the argument that significantly smart and connected products will arrive within two or three product cycles.

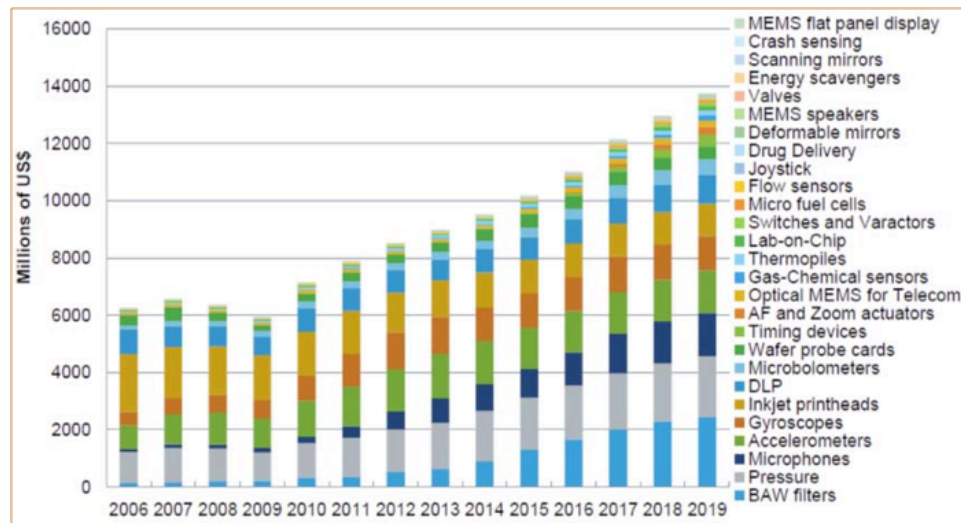
Automated Factory

Simulation and Analysis software has a compound annual growth rate of 12%^{vi}. Electronic Design Automation software is growing 10%^{vii}. Industrial Automation is growing 8%^{viii}. Robots are growing 15-20%^{ix}. Ethernet-Connected Nodes will double in the next five years^x. These areas together, combined with 3D Printing as an ever-closer alternative method of manufacture growing >20%^{xi}, are sure to transform the processes of design and manufacturing significantly.

Smart "Living" Products

Transforming the actual products that engineers create and design, and the equipment used to make them in the factory (because, after all, isn't the equipment just another product for engineers in other companies), will be a host of technologies to better enable smart and connected products. MEMS devices, a broad category, are growing around 30%^{xii} (Figure 6).

Figure 6: Total MEMS Market By Device: Forecast 2015-2019



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GGI believes that progress in technologies that can communicate with MEMS devices will hit a critical mass in the early 2020s. It will then be much easier to add a new sensor because the internet infrastructure that generates the value from the data will be generally available, both IIoT and IoT. The true incremental cost of a sensor will continue to drop and there will be explosive growth. Within five years, it will be hard to go anywhere at work, at home, or in public without some type of sensor tracking you or measuring you in some way.

And, practical nanotechnology applications will continue to grow. Nano is just a smaller than MEMS. Plus there will be new applications such as coatings with nanoparticles that can sense or transmit - electronically, optically, and chemically^{xiii}. Sensors and small sub-systems will continue to get cheaper and smaller, and more easily connected.

End-User Markets

Semiconductor sales in many natural internet markets all had growth in excess of 20%^{xiv} in 2016: Connected Homes 26%, Connected Vehicles 66%, Wearable Systems 22%, Industrial Internet 22%, Connected Cities (triple the size of the next nearest market) 15%. These are all growth rates resulting in a doubling in five years, two product cycles for most companies.

IoT Infrastructure

It is important that the IoT is its own product. Tens of thousands of people are continually building-out the internet infrastructure around the globe. That is a subject unto itself. The growth rate of IoT semiconductors is 15-19%^{xv}.

Next Five Years

Regardless of whether one examines growth in automated factory technologies, smart product technologies, end-user markets, or IoT infrastructure, it is all growing at rates that double in 5-7 years. Companies that do not rapidly adopt, and push their limits to gain expertise and prowess, are likely to find themselves struggling with less competitive products in five-years time.

Already we are seeing the emergence of many new technologies that are based on the capabilities herein discussed becoming available and usable. Many of the "Innovation Triggers" will fall out, but it will only take a few of these to make it over the hump to significantly change our daily work and life^{xvi} (Figure 7).

Gartner has identified three key trends^{xvii} from its 2016 analysis. The first is a "transparently immersive experiences." Technology will create transparency between people, businesses and things. The second is "the perceptual smart machine age." Smart machine technology will create the most radical change of all technologies in the next decade. Third is "the platform revolution." "Emerging technologies are revolutionizing the concepts of how platforms are defined and used. The shift from technical infrastructure to ecosystem-enabling platforms is laying the foundations for entirely new business models that are forming the bridge between humans and technology. Within these dynamic ecosystems,



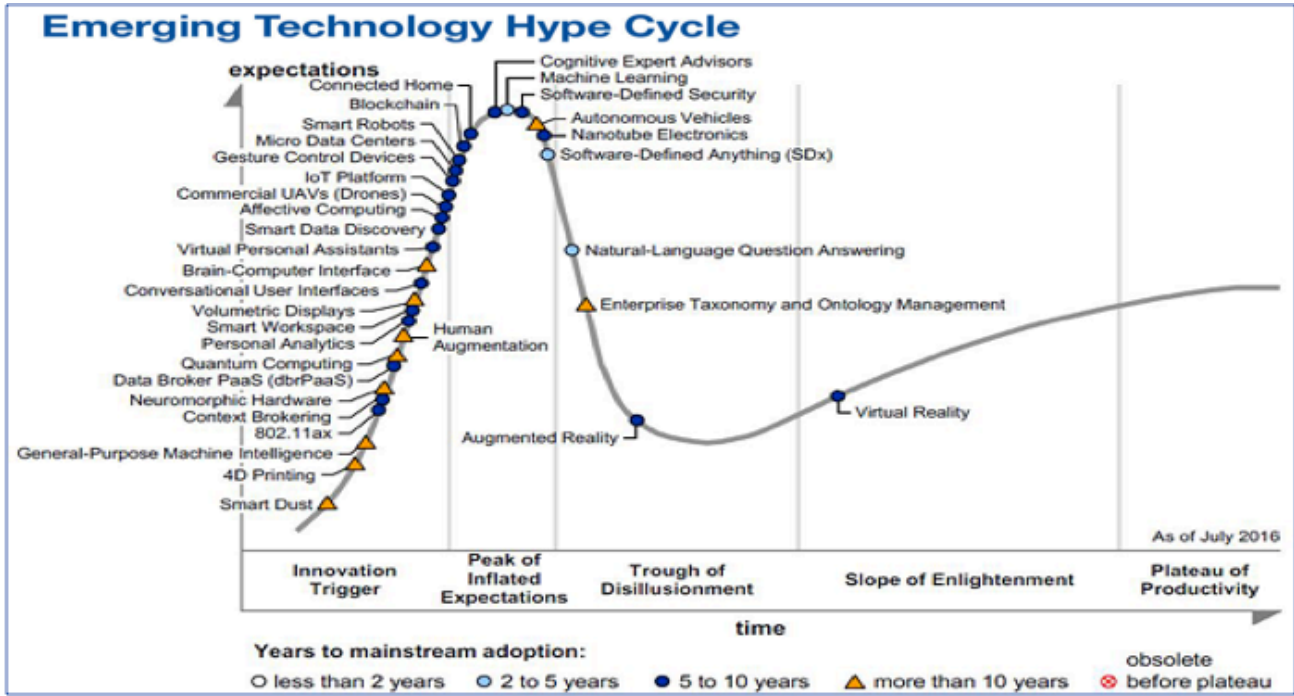
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organizations must proactively understand and redefine their strategy to create platform-based business models, and to exploit internal and external algorithms in order to generate value."

Figure 7: Gartner's 2016 Hype Cycle



Companies will struggle to keep their factories and products evolving at the same rate that technology is evolving. But, worse, their historical thinking about what automation means and how to do it will be further stretched as they struggle to implement open and shared business models that they do not fully control - something that was unheard of and considered to be heresy twenty-five years ago.

DFI STRATEGY

As previously discussed, company priorities range all over the map regarding their propensity to claw through the complication of this giant internet system and rapidly enable their products to take the full advantage of it. This is what separates the bleeding edge, from the leading edge, from the rapid adopters, from the followers, from the laggards. This is to be expected. What has been constant in the past that allowed all to survive has been a much slower rate of penetration of any "new X" technology. There is likely to be a much greater fall-out for the followers and laggards come seven years time.

What separates the front of the pack from the back of the pack is the availability of standard solutions. Bleeders, leaders, and adopters all have to do something on their own. Purchasable solutions do not exist. Followers and laggards wait until the front of the pack has sorted it all out and third party suppliers and vendors are now selling solutions to enable what the front of the pack had to custom

develop. It will be quite difficult, five to seven years from now, to catch up on five years of data and analytics about everything a product encounters during its life journey. In the past, catching up translated into buying every major competitor's product and reverse engineering it to see the thinking that went into it - or hiring away their key people. In the era of internet competition, the back of the pack will have no equivalent catch-up methodology and quite likely won't have any idea what could possibly exist. Data and analytics will be secured locally, or secured in the cloud - invisible unless a competitor wishes it to be seen or known or sold.

Porter has reduced-down the strategic decisions that companies face in a smart connected to a list of ten^{xviii} questions (Figure 8).

Figure 8: 10 New Strategic Decisions In A Smart Connected World

- 1 Which set of smart, connected product capabilities and features should the company pursue?**
- 2 How much functionality should be embedded in the product and how much in the cloud?**
- 3 Should the company pursue an open or closed system?**
- 4 Should the company develop the full set of smart, connected product capabilities and infrastructure internally or outsource to vendors and partners?**
- 5 What data must the company capture, secure, and analyze to maximize the value of its offering?**
- 6 How does the company manage ownership and access rights to its product data?**
- 7 Should the company fully or partially disintermediate distribution channels or service networks?**
- 8 Should the company change its business model?**
- 9 Should the company enter new businesses by monetizing its product data through selling it to outside parties?**
- 10 Should the company expand its scope?**

With regard to leaders and laggards, cultures are deeply embedded and the companies at either end will be who they are. If your company is a rapid adopter or a follower, in the middle of the continuum, deciding whether to do some custom work or wait for a purchasable solution could significantly change the outcome and branding of your company in the 2020s.



GGI's DFI Model

It suffices to say, given the complexity, rapid growth, and potential industry fall-out from the challenges previously described, that enabling smart connected products that are "alive" from birth to end of life is best not attempted in an ad-hoc manner. The internet is a system. From the "view of the internet," products are just another point of data input and output - a node. A systems approach is needed to best enable products, product lines and families, and entire companies and multi-company alliances to put forth their best value offering. And, the internet infrastructure is a series of platforms and one must adhere to those platform specifications.

With systems thinking in mind, and the way the internet looks at a node in its network, GGI developed a "product-centric" conceptual model using a "black-box." It does not matter what the product is, or what it does or does not do. The only thing that matters is the data, and the need for or value of the information that can be derived from the product-related data. Just about everything that needs to be designed-in to enable smart products is in addition to the current bill of materials or formulation. And, at this time "appended" to the product in some way. Over time, as internet-based designs become optimized, we can expect to see existing components (fasteners?) become active in some way to save parts and space. For the next two or three product cycles, appending/attaching/affixing is likely the primary design alternative.

Certainly every product starts in some early stage of raw materials or a box of components, but it is already accumulating technical product and process design data and ERP business data - being stored in enterprise and PLM systems. At some point, the product reaches a sufficient stage of form and function and is outfitted with its "internet abilities." For lack of a better word, the product is now "live" or "alive." It may be young and nascent to the world, but it has an ability waiting to be exercised.

From a business perspective, things now get interesting. The product on the floor has an ability to sense, react, and possibly interact. Data is on the doorstep. Who owns the data? What data do companies consider private and must be partitioned? What data is available to suppliers and partners? What data will customers/users have access to? What data will customers have to pay extra for? And, the product hasn't shipped yet. To this point, all the data is internal.

GGI's DFI model (Figure 9) breaks this internal data into two types, that which remains internal for the purpose of product and process optimization (Operational Data Package-ODP) and that which has value and can be given or sold to customers or third parties in addition to the price for the product itself (Market Data Package-MDP). This data is depicted by white text.

When the product leaves the building, with the gray area being the shipping dock to the point of purchase where the product will be in multiple custodies, one can argue that the lion's share of post-shipping data is of interest to the customer/user. Further, one can also argue that customers/users have legal rights to know about the product from the moment it becomes alive. For example, was it reworked or failed a test anywhere in its history? That is another whole subject, but that is why the red text in the model is present in the pipeline before the product begins its 1-N years product life cycle. And, analogously, the data sets are broken down into ODP and MDP. With the internet, manufacturers and



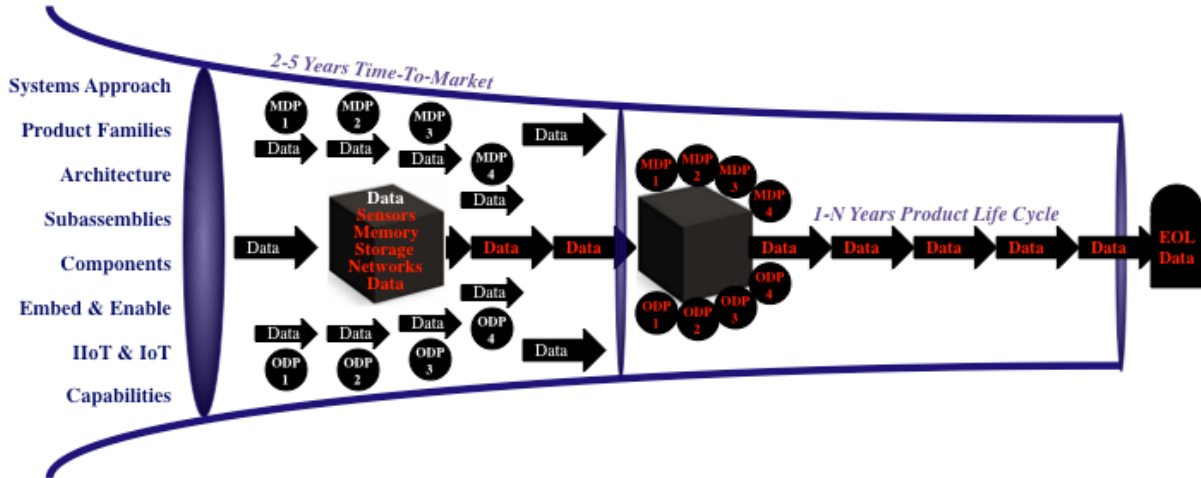
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producers will be able to know more about their products after they leave the building than ever before. Some of that data is surely to be kept private, there ODP.

Figure 9: GGI's Black Box DFI Model



The Product Ecosphere

When customers and users start exercising their products, when multiple customers exercise the same product, when different customers use the same product in different environments, and time elapses, terabytes of data will be available to the original producer and whomever that producer has agreements with. The possibility will now also exist to create myriads of new information-based products and services additional value. Some would naturally be sold to a producer's existing markets and customers. Some new information-based products will open up whole new markets, ones which could not be foreseen until executives operate in a big data environment. This is indicated by MDP A-D in Figure 10.

The addition of real-time product life cycle performance data feeding back into the originating factory and company on a regular basis will also transform the ways designs are done, and corporate views on continuous improvement. Closed-loop feedback has never truly been possible before. This is indicated by ODP A-D in Figure 10.

Product Ecosphere Metrics

Shortly thereafter, executives will begin asking for ODP and MDP metrics. How much has the continuous stream of life-cycle data allowed us to improve productivity? Is the cost of capturing the real-time data, and extracting the value from it, greater than the benefits it is creating? Are we getting an ROI from the ODP data?

At the same time, the mirror-image question will be asked on the MDP side. How much money are we making from MDP sales? Can we grow that segment of our business? How many new products and



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services were made possible by the data that we are collecting on our products? Are we making more than we are spending? No one knows for sure how big a boon the MDP-related opportunity might be, but many think it will be significant. If so, expect to see a Vitality Index (New Product Sales) that would depict MDP-related revenues (Figure 11) and company goals to increase it over time. After all, MDPs are new products!

Figure 10: A Product Life Cycle In The IIoT & IoT Ecosphere

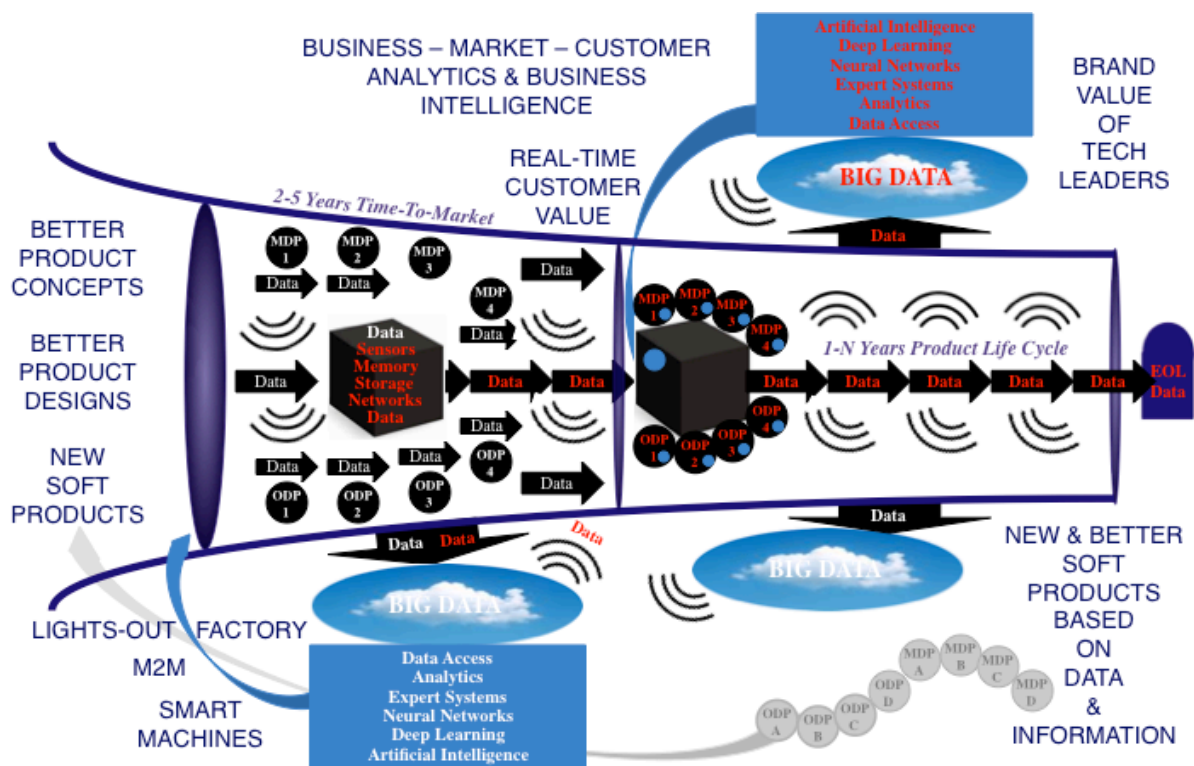
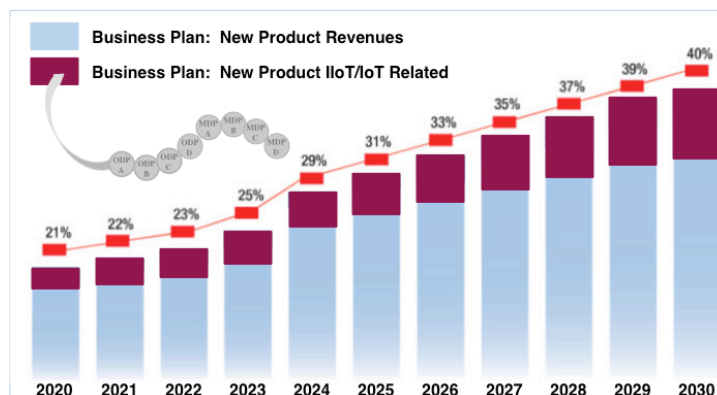


Figure 11: Hypothetical Vitality Index Chart Showing New MDP-Related Revenues
(Percentages indicate hypothetical percentages of total new product revenues.)



This is but one corporate metric that is possible. There are also product, project, functional, technical, and improvement metrics. This subject will be further explored in a subsequent section.

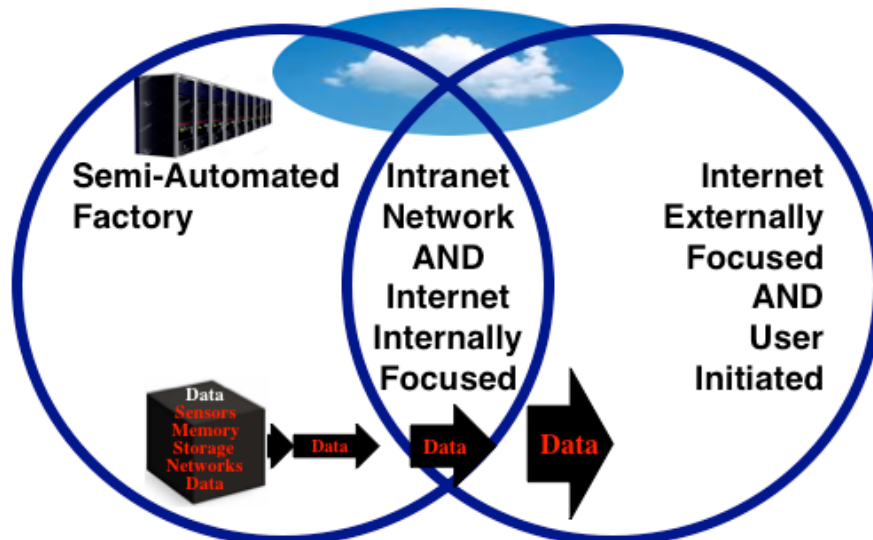
DFI PRACTICES

To this point, there has been a greater discussion on the IoT. The IIoT is equally important. Factory automation has been chugging along for fifty year, beginning with automated material handling systems in the 1970s and flexible manufacturing systems in the 1980s. The Manufacturing Automation Protocol, "MAP Protocol," by the SAE and SME in the mid-1980s was the first vision of an Industrial Internet - PLCs and other numerical control devices all connected together. This is important as what designers and engineers now have fifty-years of experience in is to design their products for the "internally controlled" growth and evolution of the factory. The entire envelope of parameters and constraints was communicated in-house from one engineer to another.

What Is DFI² or DFI²

This will be a big design challenge in the years ahead. Manufacturing will insist on design approaches that automate the factory. The IoT will cause product managers to specify many MDP enablers to maximize the possibility of incremental sales and new products. Everybody will want their sensors, transmitters, receivers, and protocols - their "internet space". Engineers will take on additional decision responsibility (Figure 12) as upstream product management and downstream manufacturing operations will both be jumping up and down when trade-offs are necessary for everything from electromagnetic interference to product cost.

Figure 12: Venn Diagram of DFI for IIoT and IoT



Software is easy to modify, certainly there is less tooling required. Customers and users figured this out rapidly. Much of the software today is actively modified from user feedback. More and more power is being put in the hands of the user to create their own experience. There is every indication these trends will continue. Designers, the ones that are still fortunate enough in many "traditional" industries to not have users directly inputting to them, are also soon to have users join marketing and manufacturing in their ear.

Soon, engineers will be engaged with finding components to enable capabilities for both ODP and MDP in a single sensor, processing device, or whatever level of "smart" that companies target their smart connected products to be. DFI², or DFI², is the intersection and optimization by engineers of internal and external design requirements in a single solution so as to minimize parts, assembly/test time, and product cost.

New Enabling IIoT & IoT Technologies For Smart Products

The number of design alternative available to enable big data from products will increase greatly in the years ahead as they work through the trade-offs necessary to achieve DFI² optimization. Sensors and sensitivity are evolving at an amazing rate. MEMS components (Figure 6) are constantly growing and new enabling technology is nearing commercialization abilities (Figure 13).

Figure 13: Additional DFI and DFI² Design Alternatives



Simultaneously, the "receptive and contactable" infrastructure will grow on its own, enabling a near contiguous environment and not just an ecosphere. Companies are doing it already, but it is hard to research because it is completely confidential. The only glimpse we get is from the research^{xix} is that of the public sector where, previously mentioned, the market for semiconductors for "smart cities" is three times the size of the next largest market - which is Industrial Internet semiconductors. Soon, products will approach 100% up-time from the moment they become alive enabling products that engineers design to be constantly enabling big data.

Targeted Designs & Design Levels

What we see emerging in industry at this time is a series of "levels of smart connected products." After all, every product cannot be a Cadillac. Tesla markets products as "Level 2, 3, or 4 connected." Driverless cars are attempting Level 5. The Society of Automotive Engineers is refining a 6-level standard for driverless cars^{xx} (Figure 14). It is used widely throughout the industry.

Figure 14: SAE Levels Of Smart Connected Cars

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the <i>driving mode</i> -specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the <i>driving environment</i> and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the <i>driving mode</i> -specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the <i>driving environment</i> and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes
4	High Automation	the <i>driving mode</i> -specific performance by an automated driving system of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes

Levels of connectivity is a good way to go about the design challenge. And, there is much precedent for rating systems across industries and time. Rating the degrees of smart connected cars is likely the beginning of many rating systems. Associated price and design-to-cost ranges will then begin to bound them.



Design requirements will increasingly incorporate some level of standard or emerging standard for a level of automation. The IIoT and IoT will be a series of platforms. Jumping off the highest board will cost more money.

DFX Logic

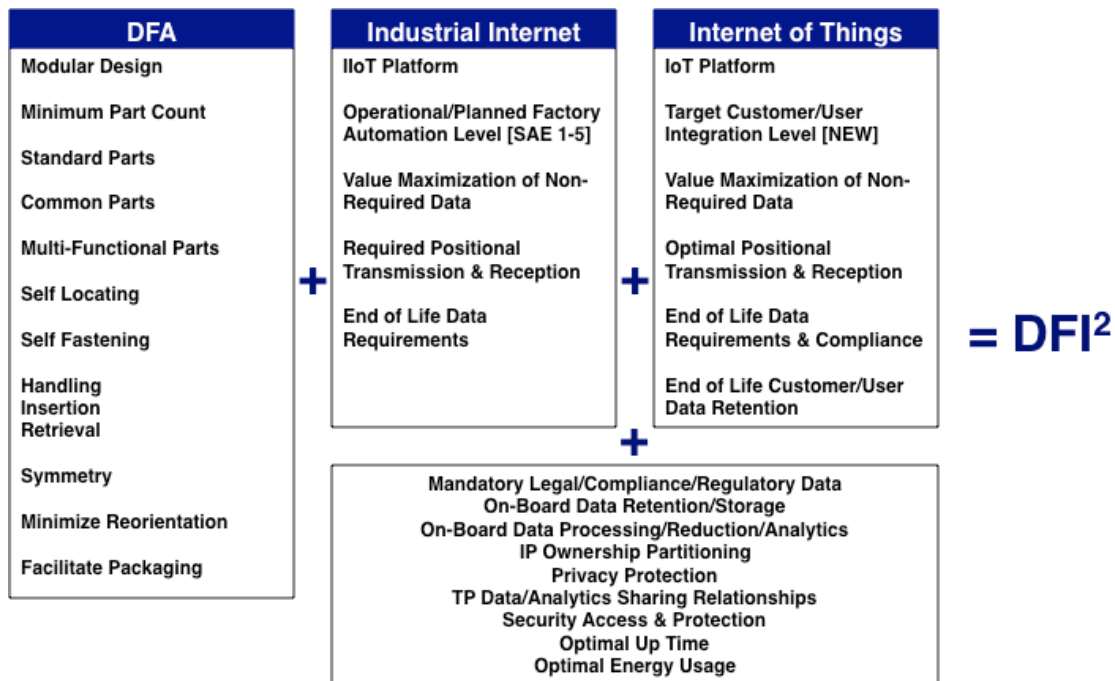
Knowing the expanse of the giant DFM and DFA bodies of knowledge, and the lesser but still substantial bodies of knowledge for other DFX subjects like Reliability, Disassembly, Recyclability, Environment and others, this is but a small introduction to what will become a DFI body of knowledge - named as such or otherwise.

After examining the various DFX bodies, the DFA body of knowledge was most closely aligned with DFI requirements and opportunities. That is especially true given the technologies of the next 5-10 years. Eventually, materials science will evolve that sensors will be integral with the product design simply by material selection. There are some examples already. When that evolution gets to a certain state of maturity, there are likely to be many more analogies with the several codified DFM bodies of knowledge than exist today.

DFI Framework

There are three groups of considerations to design products for either the IIoT or the IoT. There are four groups of considerations to design products for both, DFI2 or DFI² (Figure 15).

Figure 15: Design for IIoT, Design for IoT, and DFI2



Most of the goals of DFA are consistent with DFI needs at a high level. More study is needed to cull-out a DFA subset that optimizes DFI.

DFI METRICS

Metrics are needed to both track and drive the IoT-ization of products in the years ahead. You get what you measure. If prior pervasive improvements to product design and value are representative, such as IP protection and licensing, some fifty new metrics will be tried-out and a dozen will stick at various levels in organizations during the next twenty years.

One metric, different and placed elsewhere in an organization than SAE's five levels for smart connected cars (Figure 14) or the Vitality Index for internet-related new products (Figure 11), is "sensor density." Sensor density is the number of sensors on a product, or on a square area of fixed size of a product. The wearables industry is already tracking this metric and promoting it. According to IHS, the average wearable device shipped in 2019 will incorporate 4.1 sensor elements, up from 1.4 in 2013^{xxi}. Industry researchers are using the approach to estimate the growth of sensors in other industries.

With these three metrics in mind, GGI conducted a brainstorming session to project the types of metrics that may be tried-out in the future. Consistent with GGI's Linked Metrics Portfolio® framework, we grouped the metrics into Corporate (Figure 16), Project/Product (Figure 17), Functional/Technical (Figure 18), and Improvement (beyond the scope of this discussion).

Figure 16: New Corporate & CXO-Level IIoT/IoT Metrics

NEW & SUSTAINED PRODUCTS	PRODUCT PORTFOLIOS
% of Vitality from IoT Products \$ Revenue from IoT Products % Patent-Protected IoT Revenue	\$ Revenue Risk Due To Chg'd/Obsoleted IoT Protocols % Revenue Risk Due To Chg'd/Obsoleted IoT Protocols
% New Product Profits from IoT Products \$ New Product Profits from IoT Products	\$ Revenue Growth From IoT Revenues % Revenue Growth From IoT Revenues
\$ Revenue From IoT Licensing	% Product Revenues IoT-Enabled vs. Company Goal % Product Profits IoT-Enabled vs. Company Goal
# New IoT Products Released [Pure + Co-Design IoT] % IoT-Enabled of Total New Products Released	
% IoT Products In Development [Pure + Co-Design IoT]	



Figure 16 (continued): New Corporate & CXO-Level IIoT/IoT Metrics

TECHNOLOGY & IP PORTFOLIOS	FINANCIAL INVESTMENT & PERFORMANCE						
# Active IIoT Nodes % IIoT Node Plan Achieved # Active IoT Nodes % IoT Node Plan Achieved % Critical IoT Technologies From External Sources % Critical IoT Technologies Without Source Access # IoT-Related Gigaflops Under Management <ul style="list-style-type: none"> - % Proprietary Data - % Market/Customer-Shared Data - % Direct User Access Data # IoT Patents [Filed, Pending, Awarded, Rej., Abandon] # IIoT Patents [Filed, Pending, Awarded, Rej., Abandon] IIoT Process Automation Intelligence Levels <table style="width: 100%; border: none;"> <tr> <td style="width: 50%;">% Level 1 Product Lines (PLs)</td> <td style="width: 50%;">% Level 4 PLs</td> </tr> <tr> <td>% Level 2 Product Lines</td> <td>% Level 5 PLs</td> </tr> <tr> <td>% Level 3 Product Lines</td> <td>% Level 6 PLs</td> </tr> </table>	% Level 1 Product Lines (PLs)	% Level 4 PLs	% Level 2 Product Lines	% Level 5 PLs	% Level 3 Product Lines	% Level 6 PLs	\$ R&D Spending on Internet of Things [New, Sustain] % R&D Spending on Internet of Things [New, Sustain] \$ Internet of Things Capital % Internet of Things Capital of Total Capital % of Portfolio Revenues from IoT Products & Services % of Portfolio Profits from IoT Products & Services \$ IoT-Related Revenues In Pipeline [1, 2, 3 Yrs]
% Level 1 Product Lines (PLs)	% Level 4 PLs						
% Level 2 Product Lines	% Level 5 PLs						
% Level 3 Product Lines	% Level 6 PLs						

Figure 17a: New Product & Project IIoT/IoT Metrics Categories

USER	Measures of IoT user or customer experiences with the product
BUSINESS	Measures of IIoT & IoT business and financial value of the product.
MARKET	Measures of overall IoT market and marketplace coverage and compatibility.
FACTORY	Measures of overall IIoT factory and operations coverage and compatibility



Figure 17b: New Product & Project IIoT/IoT Metrics

TYPE	METRIC NAME	ACRONYM	DESCRIPTION
USER	User IoT Satisfaction Index	UISI	IIoT/IoT component of Customer Satisfaction Index
	% User IoT Satisfaction Level	UISL	User rating of product vs. others in their IoT ecosphere
	User IoT Connectivity Index	UICI	Degree to which user controls connectivity options
	Product IoT Attractability Index	UIAI	Degree to which user s/b attracted by IoT features
BUSINESS	Product IoT Branding Score	PIBS	Degree of brand value derived from IIoT/IoT features
	Product IoT Connectability Index	PICI	Degree of post-sale data value accruing to producer
	% Product Data Value	PDV	Degree of IoT data/analytics value of product offering
	# Product Data Package AddOns	PDPA	Soft information product modules offered w/ product
	% Product IoT Price Premium	PIPP	Product price premium enabled by IoT features
	% Product IoT Maintenance Premium	PIMP	Maintenance price premium enabled by IoT features
MARKET	% Product IoT Compatibility Risk	PICR	Degree of risk that product fits w/ customer ecosphere
	% Product IoT Readiness Risk	PIRR	Degree of risk to realize IIoT/IoT product specs
	% Product IoT Capability Approval	PICA	Targeted ability level including sensors, s/w, ecosphere
	% Product IoT Sensorization Level	PISL	Targeted sensorization level for marketplace activities
FACTORY	Factory IIoT Enablement Index	FIEI	Overall capability for lights-out manufacture
	% Factory IIoT Communicability	FIC	Overall ability to interact with factory processes
	% Factory IIoT Transmittability	FIT	Targeted ability to inform factory processes.
	% Factory IIoT Receivability	FIR	Targeted ability to react to factory stimuli
	% Factory IIoT Sensorization Level	FISL	Targeted sensorization level for automated assembly
	% Product Cost for IIoT/IoT	PCI	The % of product cost for IIoT/IoT related features
	% Software Cost for IIoT/IoT	SCI	The % of S/W budget for IIoT/IoT related features

Figure 18: New Functional and Technical IIoT/IoT Metrics

CAPACITY & THROUGHPUT	COMPETENCY & CAPABILITY
% IoT Project-Needs Outsourced % IoT Asset Maintenance Outsourced % IIoT Project-Needs Outsourced % IIoT Asset Maintenance Outsourced % Capacity To Internet of Things Development % Capacity To Internet of Things Maintenance/Sustain # IoT Project FTE Requests Unable To Be Met # IIoT Project FTE Requests Unable To Be Met	% IoT Skill Readiness Overall % IoT Skill Readiness by Skill % IoT Training Completed # IoT Certifications # IoT Internal Blackbelts % IIoT Skill Readiness Overall % IIoT Skill Readiness by Skill % IIoT Training Completed # IIoT Certifications # IIoT Internal Blackbelts % Employees With ≥1 Internet of Things Degrees
RECRUITMENT & RETENTION	INVESTMENT & RETURN
# IoT Hires Planned % IoT Recruiting Plan Met # Key IoT Employees Hired # IoT Employees Hired # Avg Number IoT Credentials per IoT Employee Hired # Key IoT Open Positions # IoT Open Positions # Key IoT Employees Lost # IoT Employees Lost % IoT Employee Attrition # IIoT Hires Planned % IIoT Recruiting Plan Met # Key IIoT Employees Hired # IIoT Employees Hired # Avg Number IIoT Credentials per IIoT Employee Hired # Key IIoT Open Positions # IIoT Open Positions # Key IIoT Employees Lost # IIoT Employees Lost % IIoT Employee Attrition	% R&D Budget IoT-Related Development % R&D Budget IoT-Related Maintenance % R&D Budget IIoT-Related Development % R&D Budget IIoT-Related Maintenance % R&D Budget To Internet of Things



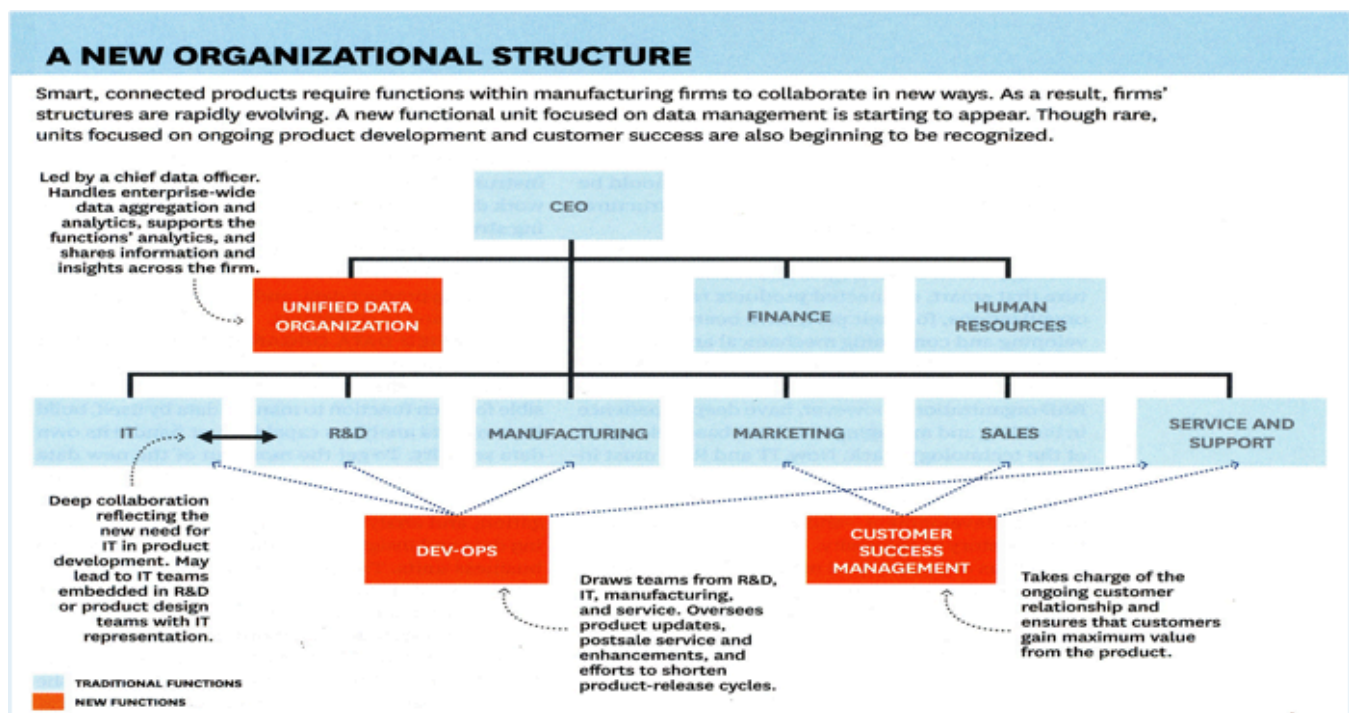
DFI ORGANIZATIONS

As the emphasis on the value of data overtakes the traditional value of the product itself, the organization will transform to reflect the new skill sets and their position in value creation. There was a transformation when mechanical companies became electro-mechanical, another when they became electronic, and most professionals are still living the advent of software and software-driven hardware.

The IIoT and IoT will drive the next transformation. The emergence of "Development Operations" a decade ago was among the first steps due to the IIoT and IoT of a more radical change in organization structure that we see little by little each day.

Porter offers a projection of a future organization^{xxii} where a major data organization reports directly to the CEO (Figure 19).

Figure 19: Next Generation Organization For The Smart Connected Company



The traditionally important functional tiers of R&D and Manufacturing and IT get smoothed into a Development Operations organization while Marketing, Sales, and Service/Support get smoothed into a Customer Success Management organization.

If so, and Porter is more right than he is wrong, the structure of companies since the dawn of the assembly line in 1920 would change in the 2020s - after a hundred years.



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SUMMARY

Pre-launch internal product creation data and post-launch external customer and marketplace data will create large, statistically valid data sets that will lead to new products and services. Over time, as experiences across products in a family are logged, a family data set will arise and lead to even more new products and services. The definition of a product as we know it will be forever changed.

Design engineers will be at the crossroads of incoming requirements from product marketing, manufacturing automation, and likely also customers and users. Each requirement will have hardware addition and product cost implications.

DFI2, or DFI2, will challenge designers to identify single solutions that can satisfy the multitude of requests and requirements while staying true to the platform standards of the IIoT factory and the IoT marketplace. Standard "DFI methods" will emerge as best design practices.

A systems approach is needed to systematically address the nearly unlimited complexity. Ad hoc design approaches and retrofitting products will be more chaotic and expensive than grappling early with evolving standards.

The basis of competition will be changed. Laggard companies will be unable to catch up given the rapid onset of the internet and the inability to reverse engineer competitor products. For this technological revolution, companies cannot wait as they have in the past for others to figure out the answers. Design for the IIoT and the IoT in the next product cycle should be a company priority.

A Note About The Author: Bradford L. Goldense NPDP, CMfgE, CPIM, CCP is president of GGI. Founded in 1986, the consulting-market research-education company is recognized across the major industrial continents for expertise in R&D, advanced and product development, innovation, and the metrics that drive corporate performance. Mr. Goldense has worked with 200 of the Fortune 1000 and over 500 global manufacturing locations. GGI is based in Needham, Massachusetts.

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