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Dear Readers,

It is undeniable that Systems Engineering is at the very heart of product design. It is so fundamental to the process of developing and improving a product, that each iteration can be explained through its principles. Ironically, these principles have become so omniscient, and at the same time complex, that it is often easier to overlook them and focus instead on more superficial aspects of the product’s design.

With increasing consumer demand for smart, connected products, Systems Engineering has evolved to accommodate expanding system boundaries, a growing list of attributes, and even ‘systems within systems’ that define the myriad functionalities of a single product. Needless to say, product configurations have become so intricate that it is impossible to decompose its architecture into discrete design disciplines – software, mechanical, and electrical. Having transitioned from the age of single line, single platform production to the era of mass customization with segmentation for individual consumer, effectively managing product configuration is the key to achieving manufacturing and field agility.

Through the *Journal of Innovation and Transformation* (JIT), we at TCS examine how digitization has been a game changer in this regard. With connectivity becoming more ubiquitous, IoT has enabled manufacturers to directly link their design process to the production line. This Digital Thread is becoming a critical component for integrating and managing complex cyber-physical systems with extensive software content and interconnectivity capabilities. Through it, manufacturers are capturing engineering requirements to build two products – the actual physical object and its Digital Twin. Even before production begins, the virtually designed high fidelity prototype can be tested and validated using performance simulations to ensure that the final product functions exactly as expected.

The capability of the Digital Thread is enhanced further by tying it to a central Product Lifecycle Management (PLM) platform that converges multiple engineering disciplines and product configuration data to support Model Based Systems Engineering (MBSE). Doing so factors in complete system boundary parameters with the objective of influencing product and service design decisions. This concept is challenging the established document driven, BOM-based approach by opting to use the context laden, visually rich Digital Twin as its single source of truth for defining product configuration and tracking engineering changes.
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Once the final product makes its way off of the factory floor, its relationship with the manufacturer doesn’t end. The Digital Thread stretches further on and serves as an inconspicuous medium of real-time communication between the consumer and the enterprise. Captured customer intelligence is converged on to the PLM platform, ready to be analyzed for insights into how the product can be refined further. It enables one to quickly test and validate hardware, and more importantly, software updates on the Digital Twin before rolling it en masse, in field, on the move. In effect, it blurs the line between products and services by expanding system configuration boundaries to include the service cycle itself.

Change however is a difficult thing to bring about. Even with a PLM transformation roadmap in place, there are inherent risks, cyber security threats, and the spiraling costs of production to deal with. Increasing emphasis on collaborative innovation and the lack of technical awareness for facilitating it has made it difficult for enterprises to fully embrace this new paradigm. They often face several roadblocks trying to ramp up internal talent pools and knowledge repositories. The skill gap is more evident when one considers the ageing workforce and the organization’s failure to align with new talent skills, showing the lack of a proper Organization Change Management (OCM) plan. Enterprises must therefore look both within and outside the organization to harness the wisdom of the crowd for co-creating value.

Has all of this been done before? Although CAE was one of the first few to walk down this path, the emergence of pervasive computing and easy access to large volumes of product and customer data is democratizing Digital Product Lifecycle Management, enabling faster decisions and rapid cycles. Join us for this edition of TCS’ Journal of Innovation and Transformation (JIT) to explore its experience and the art of possible. TCS collaborates with several global think tanks, and considers it a privilege to present an article from our esteemed partner – CIMdata as well.

Happy reading.

Anurag Jain
Global Practice Lead - New Product Innovation and Life Cycle Processes
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Weaving the Future, with the Digital Thread

Today's organizations are tied together with shared information throughout the product lifecycle, across the extended enterprise with a digital thread across the product lifespan. Weaving the Digital Thread together is Product Lifecycle Management (PLM), to manage, control and disseminate the Digital Thread. Techniques such as automated EBOM-MBOM transformation support the Digital Thread and are employed to try to shorten the product delivery timeline and improve product quality. But even at more advanced companies, those with a Digital Twin vision (complete, connected, a digital definition of the product, how it functions, how it is manufactured, how it is serviced, and how it is handled at end of life), there are still gaps with manual tasks across the lifecycle. Innovative companies today are managing projects on install based monitoring, smart supply chain and smart operation of products. These connected products, smart products are demanding full lifecycle chain connectivity and a digital representation of connected products using PLM with MBSE (Model-Based Systems Engineering), SE (Systems Engineering), and service lifecycle kinds of initiatives.

Obtaining the PLM related goal of the integration of digital data, the Internet of Things (IoT), Industry 4.0, predictive analytics, and enterprise asset management (EAM) are being deployed to help define the Digital Thread and enhance the use of the Digital Twin. These technologies and processes are impacting the way solution providers approach the solutions they offer to the market. The art of possible is now upon us, to realize the full potential of the dream, all we need to do assemble the pieces together. This article will discuss some of these - including PLM extension, data analytics, and services delivery.
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About the Author

Michael Fry,
Manufacturing Systems Engineering Practice Director, for CIMdata

Michael Fry is the Manufacturing Systems Engineering Practice Director, for CIMdata—an internationally recognized authority on Product Lifecycle Management (PLM). He brings to CIMdata and its clients over 39 years of PLM and manufacturing industry experience. He has worked in the disciplines of product development, manufacturing automation, and Systems Engineering. He has extensive experience in client management, solution design, sales, consulting, business analysis, testing, course development / training, and hardware support.

Prior to his consulting career, he was an aerospace design engineer with Beech Aircraft and Martin Marietta. While at IBM and later Dassault Systèmes, leading PLM solution providers, he worked with global manufacturing companies in the automotive, aerospace and defense, building products, fabrication, industrial equipment, and marine industries. He holds a BS in Aeronautical Engineering from Arizona State University.
Defining the Digital Twins

The process, digitalization, and systems complexity will continue to profoundly affect the way we do product design, development & sustainment. Multiple Digital Threads are evolving in organizations based on the business requirements and specific application use cases. The product innovation platform must be open and sufficiently extensible to enable the ‘Digital Thread/Digital Twin’ vision. Organizational culture, process change, and people skills are also major factors to implementation and financial ROI.

CIMdata defines a Digital Twin as a smart (dynamic), virtual representation (model) of the physical product, production process or product’s utilization. It has the required accuracy and fidelity to predict actual, physical performance. The Digital Twin mirrors real-world product throughout its lifecycle and is updated to reflect improvements in product and process development.

While most companies talk about and define a product digital twin, there are in fact many Digital Twins that need to be created. These include the:

- **Digital Product Twin**: used in product development
- **Digital Performance Twin**: used in simulation
- **Digital Production Twin**: used in manufacturing

Together these make up the actionable Digital Twin that can be used throughout the product lifecycle.
The Actionable Digital

An actionable Digital Twin is a living model fed by analytics and exercised by math-based simulations. These are multi-function simulations involving mechanics, electronics and embedded software functions used together to create a predictive engineering analytics function that tells companies how to improve their product design, process design, and maintenance approaches. It allows users to see how the part/product/system will function before it is produced.

An actionable Digital Twin allows a company to completely duplicate and simulate the properties and performance features of a physical product, a product line, a process or a complete plant in the virtual world, before a single item needs to be physically acquired to produce.

More than ever, products of today contain significant electronics and software content, creating constant feedback through the use of the IoT, new materials, and manufacturing processes. Markets are requiring products with the latest features, rapidly obsoleting previous product iterations.

**Model-based enables system engineering**

*Digital collaboration high-value information continuity across lifecycle processes*

![Diagram](Figure 1: Model-based enables system engineering)

Digital Twins the Art of the Possible

The digital product twin is used in the creation or modification of a part or product forming the basic digital database (model) where the geometry and product attributes are stored. This is the most familiar form of the digital model used today. But it is not sufficient to form actionable processes that incorporate the extended Digital Twin’s lifecycle. PLM acts as an interactive management system across the entire lifecycle of the part or product. This includes management of the other Digital Twin representations and their interaction with each other.

**Business Challenge:** A consumer appliance manufacturer needed superior data capture and analytics for its next generation consumer product.

**Solution:** The solution was initially focused on appliance warranty management and field service to enhance support processes, optimize product service, and provide new and differentiating experiences for customers. An embedded IoT based solution encompassing software, services, cloud, and predictive analytics was created to support the appliance.

The digital performance twin can be used in several ways. We are familiar modeling with the physical performance of parts or products that include the finite element processes. However, there should also be data associated with test and results that are looped back into the part to refine the simulations. The logical extension is to include the product reliability data as it is captured in service. We have the technology to monitor many products in service through the IoT today and need to capture and act on this data. Once captured the data can be analyzed and predictive analytics can begin to be incorporated. These new data elements are to be stored and managed by the PLM system.

**Business challenge:** An aircraft engine manufacturer collects a large amount of data about its engines through various databases and sensors, but it had no way of integrating and analyzing the information to proactively address engine issues.

**Solution:** A performance Digital Twin was created with an analytics platform to create predictive models that automatically alerted the manufacturer to different types of impending engine events. The alerts and a dashboard visualization of engine-fleet health and risk status enabled the company to take proactive measures such as ordering and arranging preventive maintenance. These helped prevent a range of engine issues and potentially helped the company’s customers avoid millions of dollars in costs associated with grounded planes.

The digital product twin has been around and used now for decades in the form of NC models and production process simulation to enable manufacturers in any industry to efficiently plan, manage, and optimize their global industrial operations. Again through the IoT and Industry 4.0 practices we can capture actual production data and refine the digital production twin. With the implementation of predictive analytics, we can also begin to predict when a part or process is about to go out of specification and make preventive corrections. These corrections must also be stored and included in a feedback loop to the product value chain increasing the intellectual capital of the parts and processes and organization.

**Business Challenge:** A manufacturer of battery production equipment, the company needed to differentiate itself by providing value-added functionality on its machines.

**The Solution:** Resetting the parameters on battery-production machines requires precise calibration. This manufacturer added an analytical modeling solution to its machines that analyzes battery manufacturers’ requirements. It models them against engineering expertise data to find the optimal production process - including materials
used and drying temperature and timing - to continuously improve quality control and enable faster production changes. This solution helped achieve extremely precise error tolerances in battery production.

**Final Thoughts**

The emergence of the product innovation platform can enable end-to-end lifecycle digitalization required to be successful. We need to continually rethink the PLM/MBSE/MBE/MBD and the Digital Thread to enable our ability to design and deliver innovative, and value added products and services. To accomplish, we need to create use case driven business models based on the digital enterprise, the IoT, industry Digital Twins, and so on. The use cases need to be created using platform integration strategies based on evolving standards, solution and services offerings, new delivery and pricing models such as cloud and SaaS.

**PLM is the required End-to-End Connectivity**

*PLM touches all phases of a product's life-digitalization demand it*

Digitalization makes everything subject to rapid change. The Digital Twin isn't a new concept and our ability to enable it from an end-to-end perspective is possible and much more practical today than ever before. PLM’s extension through the implementation of a true product innovation platform is key to defining and managing the Digital Twin which must include the virtual product and the virtual process definitions to maximize benefit. With this, the Digital Twin is a key enabler of new business models. The IoT, Big Data, analytics, and other technologies and initiatives are furthering the economic enablement of the Digital Twin, the combination of these...
Digital Twin definitions are being managed by the PLM system as the source of record and the starting point for interrogation. Expanding and combining the Digital Twins will now allow users to better manage parts and processes over the entire lifecycle bringing value to the user and their customers.

To implement these Digital Twins requires the collaboration of experienced software providers, service providers, and their clients. This transformation can take place in a step by step payback scenario where specific use cases are identified and collaborative projects are created to architect, design, and implement. Today, the promise can be made real.

**About CIMdata**

CIMdata, an independent worldwide firm, provides strategic management consulting to maximize an enterprise’s ability to design and deliver innovative products and services through the application of Product Lifecycle Management (PLM). CIMdata provides world-class knowledge, expertise, and best-practice methods on PLM. CIMdata also offers research, subscription services, publications, and education through international conferences. To learn more about CIMdata’s services, visit our website at http://www.CIMdata.com or contact CIMdata at: 3909 Research Park Drive, Ann Arbor, MI 48108, USA. Tel: +1 734.668.9922. Fax: +1 734.668.1957; or at Oogststraat 20, 6004 CV Weert, The Netherlands. Tel: +31 (0) 495.533.666.
Today, product innovation faces multiple disruptive forces along the value chain, including the increasingly global nature of manufacturing networks, growing competitive pressures, diverse local demand, rapidly emerging technologies, and new regulations. Most of these forces are either the result of, or lead to, digital transformation in manufacturing companies.

While most organizations are in the process of ‘going digital’ today, what sets digital transformation leaders apart from the rest is the preparation they undertake before embarking on the transformation journey. For engineering organizations, digitalization also means added complexity in product management, which makes product and part simplification a top priority for these organizations.

After highlighting key challenges faced by manufacturers on their path to digital transformation, this paper outlines a proactive approach for products and part simplification that can lay a robust foundation for such a journey.
Go Simple to Go Digital: A Blueprint to Product and Part Simplification

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About the Authors

**Samrat Chatterjee,**
Samrat Chatterjee is a New Product Innovation (NPI) Consultant with the ITG unit of TCS. He works closely with global manufacturing organizations to simplify their products, parts, and processes, as well as implement transformational simplification programs across the value chain. Certified in Lean Manufacturing from CII and Theory of Constraints (TOC) from Goldratt Schools, Chatterjee leads consulting engagements focused on part standardization, product life cycle management, and classification. He holds a Management Degree in Operations and Strategy from Indian Institute of Management Lucknow.

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Industry 4.0 is here and so is product, process, and part complexity

The benefits of digitalization are indisputable and manufacturing companies are no laggards in the digitization game. In a PwC survey of over 2000 manufacturing companies, respondents indicated that they expect to dramatically step up their digitization initiatives. 33% of manufacturers rated their digital capabilities as advanced while 70% said they are poised to achieve that level by 2020. Clearly, Industry 4.0 is here to stay and some of the key trends that distinguish it include:

- Global business services or shared services supporting multiple functions with a larger global footprint
- Collaborative ‘design anywhere, build anywhere, service everywhere’ models
- Factories of the future that harness flexibility in terms of measurability, scalability, and adaptability, ensuring higher quality at a lower cost
- Platformization of product innovation, involving a set of evolving functional domains orchestrated at the enterprise level

To realize value from these trends, organizations are undertaking business, process, and IT transformation programs of varying magnitudes. Although these initiatives deliver a good return on investment (ROI), the numbers hide an unintended consequence of the programs: increasing complexity in products, processes, and parts. This is largely because organizations tend to adopt measures to rapidly resolve problems, without realizing that the solutions might be complicated and could lead to increased complexity within their functions, regional operations, or departments. Typical examples of such initiatives include resolving region-specific processes or IT problems using custom solutions or addressing the growing need of external differentiation through heavy customization of products. Developing project specific solutions can also lead to parts proliferation.

So, how can organizations identify beneficial complexity as opposed to avoidable complexity, in such situations? It starts with a detailed understanding of the types of complexity within the organization. Product designers, research, and development leads, change managers, Program Leads and Information systems(IS) managers, and CXOs across the industry vouch that complexity is the new normal in manufacturing. Table 1 details various categories of complexities in the industry and the typical organizational initiatives that lead to such complexities.

<table>
<thead>
<tr>
<th>Complexity Types</th>
<th>venues of Concern / Opportunities for Simplification</th>
<th>Typical Organization initiatives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Complexity</strong></td>
<td></td>
<td><strong>Product Structure complexity</strong></td>
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<tr>
<td></td>
<td></td>
<td>Modularization of Products, Mass customization</td>
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<tr>
<td></td>
<td>Product number of Product variants</td>
<td>Platform strategies, New regulatory mandates, product variants etc.</td>
</tr>
<tr>
<td></td>
<td>Need of Product/ Portfolio Rationalization</td>
<td>Internal standardization and External differentiation</td>
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<tr>
<td><strong>Part Complexity</strong></td>
<td></td>
<td><strong>Parts Proliferation</strong></td>
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<tr>
<td></td>
<td></td>
<td>Expansion, M&amp;A, Distributed design decisions, Autonomy of regional</td>
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<tr>
<td></td>
<td></td>
<td>business units.</td>
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<tr>
<td></td>
<td><strong>Lack of Part Standardization</strong></td>
<td>Strategic Sourcing, Design and Part Reuse, Operation effectiveness,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internal standardization and External differentiation</td>
</tr>
<tr>
<td></td>
<td><strong>Lack of Part Rationalization</strong></td>
<td>Strategic Sourcing, Design and Part Reuse, operation effectiveness</td>
</tr>
<tr>
<td><strong>Process Complexity</strong></td>
<td></td>
<td><strong>Ineffective Process design</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Localized Work Instructions, Expansions, M&amp;A</td>
</tr>
<tr>
<td></td>
<td><strong>Ineffective Process performance measurement</strong></td>
<td>Shift in business models, M&amp;A, Divestures</td>
</tr>
<tr>
<td></td>
<td><strong>Ineffective Decision Making</strong></td>
<td>Organization structure re alignment, Metrics driven organization</td>
</tr>
<tr>
<td><strong>Data &amp; System</strong></td>
<td></td>
<td><strong>Data and system duplication</strong></td>
</tr>
<tr>
<td>Complexity**</td>
<td></td>
<td>Enterprise wide optimization initiatives, Operational efficiency</td>
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<td></td>
<td></td>
<td>initiatives</td>
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<td></td>
<td><strong>Master Data Inadequacy</strong></td>
<td>Major Enterprise wide IT initiatives, M&amp;A, supplier / vendor</td>
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<td></td>
<td></td>
<td>consolidation, Customer prioritization</td>
</tr>
</tbody>
</table>

Table 1: Types of complexities in the manufacturing industry and their drivers

The journey to simplification: Following a three-step process

Simplification is best achieved as a continuous process that requires businesses to lay a robust foundation and implement the right sequence of steps. The process includes:

**Step 1 - Identifying the larger objective behind simplification:** Simplification provides implicit benefits to organizations, and is rarely delivered as a stand-alone initiative. For example, organizations often find it hard to justify a business case to adopt parts classification as an enterprise-wide strategy. However, when it comes to executing corporate initiatives such as an enterprise-wide Product Lifecycle Management (PLM) initiative, classification becomes a foundational part of the exercise. It is, therefore, crucial to first define and agree on the key objective behind simplification.

**Step 2 - Identifying areas of complexity to address:** Although complexity might be evident in some organizations, in most organizations, complexity is either camouflaged or shows up in the form of symptoms. In addition, different types of complexities are interlinked, making it difficult to examine one type of complexity in isolation. Industry 4.0 and connected products further increase this interlinkage. Figure 3 illustrates how product and part complexities become apparent in different forms across the value chain.

![Figure 3: Product and part complexities show up in various forms across the value chain](image-url)
It is important to identify these areas of complexity before an organization embarks on a transformation program or a strategy shift. Closely analyzing shop floors or design centers where value is created, to identify the people involved, the processes governing them, and the technologies supporting them, can help organizations zero in on such areas.

**Step 3 - Determining the sequence of actions to realize simplification:**
Implementing product or part simplification is ideally sequenced in the following manner (see Figure 4):

- **Classification:** Classification is the foundation for any simplification initiative. It includes identification, analysis, and assigning of logical groups and classes.
- **Standardization:** Standardization improves the operational readiness of parts or products by reducing lifecycle costs and promoting the use of common, available, cost effective, and reliable parts.
- **Rationalization:** Rationalization involves de-duplicating or eliminating redundant parts.
- **Consolidation:** Consolidation involves either design integration, the design or fabrication of multiple discrete parts into a single part or reduction in the number of parts through consolidation of design, and the use of innovative materials.

Although, following this sequence helps maximize benefits, manufacturing organizations in different types of industries have the liberty to change the scope of - standardization, rationalization and consolidation - based on their unique business priorities. Typically, business units emphasize classification and rationalization most often in their simplification strategies while corporate teams focus on standardization, resulting in longer time to realization.
Simplification delivers remarkable benefits at the process, program, organization and technology levels

While evolving through a process of Digital Reimagination\(^T\)\(^M\), an organization’s simplification strategy can act as the differentiator, helping it achieve market leadership. It provides remarkable benefits at the process, program, organization and technology levels, enhancing the organization’s top and bottom line. An extrapolation of these benefits helps determine the true value delivered. Table 2 maps typical simplification drivers to the direct benefits they deliver. The length of the bars representing BOM definition, process standardization, product and parts classification, and product and parts standardization, reveal the relative importance of these activities in driving the benefits.

<table>
<thead>
<tr>
<th>Business goals/strategies</th>
<th>Value Levers</th>
<th>Operating Levers</th>
<th>BOM Definition</th>
<th>Process standardization</th>
<th>Prod and Parts Classification</th>
<th>Prod / Parts standardization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase Revenues</td>
<td>Improve Proposal Turnaround</td>
<td>Improve Estimation accuracy, Expedite product innovation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meet Product Development Time &amp; Cost Targets</td>
<td>Improve Product Integration</td>
<td>Reduce Prototyping costs, time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce Product/Project cost</td>
<td>Improve Engg. cycle Efficiency</td>
<td>Improve Engg. collaboration</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Reduce CAPEX</td>
<td>Improve Spend</td>
<td>Integrate Processes &amp; automate information flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce Inventory costs</td>
<td>Reduce Inventory costs</td>
<td>Improve Supplier collaboration</td>
<td></td>
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<tr>
<td>Reduce OPEX</td>
<td>Improve Asset Efficiency</td>
<td>Improve Asset availability</td>
<td></td>
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<tr>
<td>Increase Plant Efficiency</td>
<td>Improve sustainability</td>
<td></td>
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<tr>
<td>Improve Operations Efficiency</td>
<td>Optimize production &amp; operating parameters</td>
<td></td>
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<tr>
<td>Reduce Risks</td>
<td>Improve Change Management</td>
<td>Better traceability of part information</td>
<td></td>
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<tr>
<td>Improve Reliability</td>
<td>Improve RUL (Predictive Analytics, simulation &amp; Reliability)</td>
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<tr>
<td>Improve Compliance</td>
<td>Reduce Emergency Repair costs; Engg feedback loop</td>
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</table>

Table 2: Product and Part simplification: Mapping the value to activities

Synchronizing simplification initiatives with those in the area of PLM or ERP makes the development of business cases relatively easy because meticulous defined Bill of Materials (BOM) increases the accuracy of estimates and enables process standardization.

Developing a blueprint for simplification: Leveraging digital accelerators

Figure 5 provides a blueprint for a simplification approach, with advanced simplification capabilities supporting the organization’s evolution into a digital enterprise. The size of the bubbles in Figure 5 indicates the relative amount of time and effort needed to achieve the benefits. The actual benefits and efforts will depend on the context and nature of the organization’s business model.

Moving up the graph and to the right can take an organization closer to its simplification and digitization goals, while improving ROI. Foundational elements such as classification are typically technology-agnostic activities owned by core business departments such as engineering or procurement. These departments, along with CRM, stand to gain the most from simplification at the foundational and intermediate levels. Leveraging digitally enabled accelerators can help fast-track the simplification process and the resulting benefits. These accelerators are critical to the success of a simplification initiative as they reduce the time and efforts needed to progress from the foundational to advanced levels:

- **Automation**: Increasingly tools are being introduced with off-the-shelf capabilities, built using international standards and procedures, for ease of deployment and adoption.
Big Data and analytics: Data is at the heart of most foundational elements of the simplification journey and Big Data and analytics dramatically reduce the time to start a simplification journey and deliver higher ROI.

External differentiation through internal standardization: Postponement strategies and external differentiation play major roles in enhancing the top line, while internal standardizations of process, product, and systems improve the bottom line.

Simplification is poised to drive a deeper level of customer centricity: At a time when political trends such as Brexit, manufacturing regulations such as global emission norms, and emerging technologies such as social, mobile, analytics, cloud and Big Data are disrupting the manufacturing industry, the ability to adapt is critical to success. Product and Part simplification supported by sustainable governance helps achieve such adaptability. Simplification also enhances the effectiveness of digital twins that many organizations create for the physical products in their portfolio. By embedding real-time customer requirements into the product ideation stage, integrated and simplified product information leads to optimized decisions, in turn, leading to much higher levels of customer centricity.
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Configuration-driven BOM Management: Driving Agility in Global Manufacturing

The ability to provide a true digital experience to customers, from the time they configure and order their products up until product delivery, is key to modern manufacturing success. A foundational approach that effectively links the functional (product configuration) and physical (Bill of Materials) definitions of a product, provides a digital information thread that conveys a single source of truth for product information - across the manufacturing lifecycle. This digital thread ensures end-to-end traceability and synchronizes product development - from configuration to manufacturing, enabling the much-needed agility in a globalized business environment.

Today's trend of catering to emerging customer demands through a service-as-a-product model that complements core offerings, is resulting in spiraling product complexity - a key manufacturing challenge that must be tackled immediately. This paper critically evaluates the challenges of product configuration and Bill of Materials (BOM) management for modular products, and presents solution approaches to tackling them through innovative practices in product definition and configuration management. A context-based approach to BOM, for instance, can help reduce product complexity, ensuring sustained growth and profitability.
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Edzil Gonsalves is a lead consultant with the New Product Innovation (NPI) services value engine of the Manufacturing Innovation and Transformation Group (ITG) at TCS. Edzil has over 26 years of experience across areas such as product development, supply chain management, customer experience management, and program management. He has closely partnered with leading manufacturing organizations on many transformational programs. Edzil holds a Bachelor of Engineering degree - Production Engineering from Victoria Jubilee Technical Institute in 1990 and noteworthy professional certifications namely NPDP, Six Sigma, PMP, CSCP.

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The need to rethink product information management across the product lifecycle

The global manufacturing industry is under tremendous pressure to overhaul product lines, and offer innovative and differentiated products, to meet emerging customer needs and market demands.

Today, manufacturers are transforming their offerings using the ‘Service-as-a-Product’ model to complement their core offerings. The result: increasing product complexity and burgeoning product information management challenges. Gaps in product definition and order delivery, inefficiencies in change management processes, and errors resulting from the lack of a robust cross-enterprise configuration management solution, pose high risks to global manufacturer growth and profitability. Addressing these risks requires manufacturers to rethink their product information management approach across different product lifecycle phases, spanning multiple work streams owned by disparate business functions.

Table 3 describes the product configuration and BOM management challenges faced by global manufacturers.

<table>
<thead>
<tr>
<th>Category</th>
<th>Business Challenge</th>
<th>Degree of Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business model and/or Business environment</td>
<td>1. Increased risk of delay in new product and variant launches, parts proliferation, and cost intensive rework as the number of variants grow</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>2. Inaccuracies in translating original requirements from customers into engineering intent and final products</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>3. Lack of agility in responding to new customer requirements for new features or custom features</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>4. Time consuming Configure-Price-Quote (CPQ) process depending on industry, product complexity, and variety</td>
<td>High</td>
</tr>
<tr>
<td>Business process and methods, enterprise data and information maturity</td>
<td>5. Inability to rationalize large product portfolio (e.g. ineffective platform sharing)</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>6. Changing demand patterns and regulatory requirements across different markets, resulting in cascading impact</td>
<td>High</td>
</tr>
<tr>
<td>Enterprise data and information maturity</td>
<td>7. Absence of a centralized view of available or feasible product variant information, leading to duplication of development efforts</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>8. Inability to perform timely “what-if analysis” of cross-functional product information, resulting in delayed decision making and poor planning</td>
<td>Medium</td>
</tr>
</tbody>
</table>

*Table 3: Business challenges and the severity of their impact on business processes*

The impact of these challenges demands a holistic solution approach. For discrete manufacturing organizations, a configuration-driven Bill of Materials (BOM) management approach presents a radically different method to address the challenges.
How order fulfillment methods influence product information management

Before considering a solution approach to the product information and BOM management challenges, it’s worth appraising the contemporary product configuration management practices across various business models.

The extent of customer involvement in order definition varies. For instance, the order fulfillment method used by a manufacturer could be: Make to Stock (MTS), Assemble to Order (ATO), Configure to Order (CTO), or Engineer to Order (ETO) - based on the customer order decoupling point as shown in Figure 6.

**Make to Stock:** With increasing product complexity, modular design has emerged as the common approach in industries that use MTS for order fulfillment. The key product configuration management practices include maintaining common master data of configurable features, and defining commercial and technical constraints to orchestrate configuration.

**Configure to Order:** Manufacturing companies that use CTO rely on the accelerated and accurate transfer of knowledge from engineering to sales and manufacturing, with major emphasis on standardization.

**Engineer to Order:** In industries that use ETO, the product configurator essentially includes integrated technical, cost, and schedule requirements, traceability of requirements across the product lifecycle, and virtual verification of unit level and system integration requirements.

Regardless of the type of order fulfillment model used, an integrated approach to product information management across business functions and product lifecycle is fundamental to bridging the gaps in traditional BOM practices.
Making the case for context-based, configuration-driven product information management

Let us now explore how a configuration-driven BOM management approach addresses the typical gaps in conventional BOM management practices. Any disparity between different BOMs such as engineering or service BOMs can lead to delays in new product introduction. This delay might be due to incongruent BOM definitions or last minute resolutions at the assembly line that affect product quality and result in cost escalations. It could also be due to incorrect replacement parts that cause product failures and safety risks. In addition, factors such as multi-disciplinary nature of data, large number of product variants, disparate context-based BOM views, and frequent product introductions, lead to enhanced BOM complexity.

A configuration-driven BOM management approach brings significant agility to the process. The configuration thread interlinks various parts with each other, as well as parts with features and features with variants, based on configuration rules and product structure. It connects equivalent elements of content across the different BOM views, ensuring synchronization. All changes to parts are tagged with effectivity dates. This means BOM definitions can be aligned with relevant rules to ensure consistency with parts applicable to a specific context and defined point in time.

Figure 7 shows how a configuration management thread orchestrates context-based BOM definition. Based on the business context such as sales, engineering, or production, business users can execute tasks against the relevant BOM structure. Meanwhile, the common configuration thread leverages relational logic to ensure that product representation in the context-based BOM is consistent and synchronized across all product data. For example, components of a sales configuration model can be mapped to equivalent components in an engineering configuration model.

Figure 7: Context-based BOM definition orchestrated by an enterprise-wide configuration management thread
The configuration management approach supports product and order realization processes by acting as a single unified platform. It provides each organizational function and role with the contextual view necessary to efficiently execute their processes. Also, it establishes the much-needed forward and backward traceability.

The next step is to digitize this process using a configurator solution that can eventually support business processes across the enterprise. Figure 8 shows the reference architecture for implementing a digital configuration thread for integrated product information management and explains the scope of the elements of an enterprise configurator needed to implement such a thread. It also provides a snapshot of various business roles and their interactions with an enterprise configurator solution.

Figure 8: Reference architecture for implementing a digital configuration thread

Evolving a configuration thread solution: A roadmap

Organizations need to meet certain prerequisites before deploying the configuration thread approach such as:

a. **Common product structure definition**: Establish a uniform approach to product definition and taxonomy across the enterprise.

b. **Governing rules for managing context through relationships and constraints**: Define product build up through a set of rules that are easy to author and interpret. The rules help maintain the dynamic aspects of the configuration thread across functions such as sales or engineering, using different configuration models. The configuration thread approach ensures that the different configuration models are synchronized and product definition remains immutable even as the context changes.

c. **Process and data ownership**: Build a comprehensive model that reflects various organizational roles and defines the ownership of distinct processes and associated data across the value chain.
Beyond these foundational elements, a robust product data integration architecture is also required for effective configuration interplay across business units, functions, and regions. Organizations could continue to manage data using multiple applications and technologies. Quality of integration, ease of usability, and adherence to governance are therefore fundamental to the success and maturity of this model. As the configurator solution advances in maturity, additional functionalities such as ‘what-if’ models can be included at each level. This helps stakeholders understand the potential impact of changes to product configuration within their functions as well as in the downstream stage, driving timely, objective decisions.

Potential benefits of the approach

The configuration-led BOM management approach offers manifold benefits including:

- **Optimizes product portfolio:** Product portfolio optimization enables differentiation for the customer and helps maintain a high level of internal standardization, leading to better positioning, higher revenues, and improved margins. Also, it enables rationalization of product portfolios by supporting a platform sharing strategy through the configuration management process.

- **Supports agile customer response:** The integration of product configuration processes, with pricing and quotation in the upstream stage and with BOM management in the downstream stage, significantly improves customer response time by eliminating duplication of efforts. Such integration also supports an agile response to changing demand patterns and regulatory requirements.

- **Ensures enhanced collaboration for better decision making:** The approach ensures that the entire organization understands the configuration thread and its implications to their respective functions. What-if analysis capability significantly improves decision-making, especially in terms of cross-organizational impact.

- **Improves time to market:** By enhancing product lifecycle management, the approach leads to shorter product and variant development cycle times, and enables more on-time and first time right launches.

- **Eliminates order translation errors:** Supply chain and manufacturing-related errors at the time of order execution lead to costly line stoppages and poor capacity utilization, which can be eliminated with the synchronization of product configuration and various BOM views.

- **Ensures lower warranty and recall costs:** By streamlining configuration with the physical build, the approach enables effective forward and backward traceability. The integration of product information and the reduction of process complexity helps avoid or reduce recalls and costly warranty issues.

Product configuration thread helps OEMs stay agile and competitive

An enterprise-wide configuration thread that ensures the synchronization of product information - horizontally across business functions and vertically through the product lifecycle - is a smart solution approach. It helps OEMs increase the agility and accuracy of BOM management by considering all key value chain aspects in the context of configuration management. This allows OEMs to better plan for their future with error-free translation of customer functional intent into a product’s physical definition (BOM), thereby introducing greater agility and responsiveness into the product information management system.
Reimagining Systems Engineering for Product Development in the Digital, Sustainability Era

To meet the needs of today’s customer, organizations are transitioning from having a product focus to providing services and elevated user experience. On the regulatory and end usage front for industrial products, the demands for efficiency, safety and sustainability are constantly on the rise. Building highly personalized, complex, and sustainability-driven multi-domain products is imperative to meeting these goals.

While organizations transform the nature of their products and services, it is equally essential to transform the organization itself with relevant process and technology enhancements, to generate greater value. Systems engineering is an interdisciplinary methodical approach to develop complex products that focuses on the ‘how to’ aspect of product development and management across the lifecycle. Leveraging digital technologies such as the IoT, analytics, augmented reality (AR), and virtual reality (VR), manufacturers can create a robust knowledge base that underpins the digital thread and digital twin. This, in turn, lays the foundation for enabling model-based systems engineering and developing next-gen, connected products.
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Increasing product intricacies are leading to complexities in product development. Today’s connected products not only generate but also consume the information produced over their lifecycle. Integrated systems and embedded technologies are the essence of such products. Products that are essentially taking the form of ‘System of Systems’ in which multiple domains and disciplines converge, place unique demands on information integration, making system boundary definition and interface engineering critical. Each system boundary needs to be defined by carefully considering the dimensions of domains, disciplines, and the functional requirements in each space. In addition, each system requires interface definitions that establish specifications for integration with other systems. Organizations also have to establish which domains and disciplines fulfill the required functionalities. Multi-layered dependency maps need to be developed to provide a visual representation of the information required to support critical decisions that impact the reliability and scalability of the core product architecture (see Figure 9).

Finally, product systems and subsystems need to be developed concurrently, creating system boundaries that interface with each other in the development process. With robust planning, integration touch points in the development process can be defined for all stakeholders, to ensure collaboration and information flow across multiple groups.

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Jimish Shah is a Consultant for New Product Introduction (NPI) and lifecycle processes in the Manufacturing Innovation and Transformation Group at TCS. He has extensive business and technology consulting experience, covering the entire product development spectrum - from strategy definition to implementation. Shah is a certified New Product Development Professional from the Product Development and Management Association (PDMA). He holds a Master’s Degree in Business Management from Great Lakes Institute of Management in India.

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Redefining Systems Engineering for increasingly complex products

Traditionally, the mechanical and electrical processes of product development have existed in silos. But today, systems engineering plays a critical role in decomposing the product requirements into the different product domains such as mechanical, electrical, and software, to deliver a robust and complex product. It establishes inter-linkages and touchpoints at critical milestones throughout the product development process - from requirements through retirement - at a granular level. Information visibility and traceability is maintained to enable collaboration across cross-domain and cross-functional teams.

Figure 10: Redefined systems engineering

Although the foundational elements remain the same, advanced systems engineering is critical to enabling lifecycle virtualization and traceability, model-based design and engineering, and collaboration across engineering domains and organizational teams. In essence, systems engineering is critical to: achieving agile design and development processes to deliver demand-led functional requirements for individual systems, managing interface requirements for integrated products, and handling data and workflows across the product lifecycle and extended organizational boundaries.

Figure 10 showcases the redefined systems engineering. Here, information and lifecycle management systems and Model Based Systems Engineering (MBSE) supported by digital technologies such as the IoT, AR, VR, and advanced analytics, significantly enhance product development processes.

Information and lifecycle management systems help reduce complexity

Industry 4.0 and the IoT have resulted in an exponential rise in product creation and usage data that are immensely valuable in enhancing decision making during product development. However, highly evolved information and lifecycle management systems are required to manage voluminous, complex data sets and realize their full potential by providing holistic views that link data across the production value chain.

Information schema definition helps support integrated views and drive simplicity at the workgroup level and provide value at the enterprise level. While Product lifecycle management (PLM) and application lifecycle management (ALM) systems have traditionally existed in silos, combining ALM and PLM capabilities into a unified platform enables seamless, integrated product development by globally distributed multi-domain teams. However, significant differences in hardware and software nomenclature, processes, and data formats, can hamper the integration of PLM and ALM into a single system. Enabling integration across the product lifecycle by ensuring meaningful relationships that provide contextual information reduces complexity and improves user experience for engineering teams.

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Realizing Model Based Systems Engineering

Computer-aided product development has matured by leaps and bounds, but the ultimate product development goal is to leverage completely virtual models, better known as, digital twins, for product definition. Engineers can use AR and VR to interact with digital twins, which are 3D annotated models of products used to capture all product data elements. Defined during the concept stage, digital twins mature throughout the product lifecycle. Equally important is realizing the digital thread for the product value chain which digitizes the processes and data throughout the lifecycle creating a product information pipeline. Different functions can access the digital thread to extract the contextual information that is required for effective task completion.

A relatively new paradigm, MBSE supports the design and development of products optimized for the entire value chain in terms of sustainability, cost, performance, and maintenance, to drive higher value. MBSE enables the design and development of systems across all domains, leveraging the digital twin and the digital thread. As the product moves across the lifecycle - from concept to support - the digital twin is enriched with product information and information from knowledge management systems for environment and system boundary definitions. Target setting, analysis-led design, behavior modeling, verification and validation testing can all be conducted virtually to reduce complexity, while saving time and cost with the help of digital technologies. Figure 11 depicts the role of MBSE in realizing this vision.

Figure 11: Realizing model-based systems engineering
Adopting sustainability as a core product quality: An MBSE use case

Certain limitations pertaining to processes, technology, and information availability stand in the way of organizations trying to adopt sustainability as a core product quality. One way to address this challenge is to leverage a four dimensional (4D) sustainability model that introduces a sustainability layer on top of product design. The model considers factors such as compliance, purpose and use, impact, and consumer behavior to enhance sustainability:

- **Compliance**: Designing for compliance is a must-have requirement of product design that takes into account current as well as possible future regulations.
- **Purpose and use**: Design components are optimized for end use and purpose in terms of material efficiency, adaptive technology, and reduction of accessory-driven ‘good to have’ design components.
- **Impact**: Designing for impact requires evaluating the impact of a product and using the results of the evaluation to enhance design.
- **Behavior**: Designing for behavior leverages consumer behavior information and related analytics to drive sustainable design.

Figure 12 explains how systems engineering can be used to drive sustainability.

**Figure 12: Using systems engineering to drive sustainability**

The digital twin or model-based product definition can be based on the 4D sustainability model. Social product development (SPD) feeds the models, providing customer requirements and enabling collaboration. An IoT platform enables reverse correlation to feed information from the entire product value chain into the design and development cycle. The model helps designers conduct lifecycle assessment (LCA) upfront, during the product design stage, with intelligent insights to evaluate tradeoff scenarios, technology, and material options, while providing an optimal design solution.
Developing a structured roadmap for digital technology adoption

While the concepts discussed earlier can help transform the current approaches and practices in product development, organizations cannot realize them without adopting the enabling digital technologies. Figure 13 shows how organizations can move up the product development value chain through technology adoption.

Two factors are critical to the creation of a structured roadmap that is tailored to an organization's product strategies, business model, and processes: the pace of technology adoption and appetite for organizational change. A structured adoption roadmap provides higher returns through increased product innovation, reduced development cycle time, faster product launches, and high uptime.

In many cases, it is important to fix or build foundational capabilities such as master data management (MDM) and business process management (BPM) before deploying MBSE. For certain organizations, legacy modernization programs to upgrade existing IT landscapes may also be a critical first step. While defining the roadmap and making investments, it is important to consider a building block approach providing two dimensional returns: immediate business value and increased capability maturity for future readiness.
Effective information management provides competitive advantage in a service-based economy

As organizations move from a product to a service-based economy, information management and utilization provide the necessary competitive edge to disrupt the status quo. Although some organizations have leapfrogged others in starting the digital journey for product development, many others are in the wait and watch mode, or are taking cautious first steps.

Enterprise-wide process change and transformation is essential to achieving servitization success. Pilot projects can help organizations analyze the economic efficiency of the changes and subsequently move to full blown MBSE implementations aimed at generating superior customer value and ROI.
Reducing Time to Market for Manufacturing Innovations through Social Product Development

Manufacturing markets are maneuvering from physical products to curated experiences, from tangible goods and services to intangible emotional connections, and from industrial economics to innovations. In the face of such disruptions, organizations have struggled to ramp up internal talent pools and knowledge systems linearly due to time constraints, talent scarcity, and cost inefficiencies. Organizations can work with the passionate crowd, who are intrinsically motivated to create business value across functions—to build better products and services, design frugal supply chains, improve brand advocacy and customer experience management, ensure sustainability, or generate leads for products and services. In this paper, we look at a plug-and-play social product development platform that harnesses the wisdom of the crowd from both within or outside the enterprise, to co-create value through crowdsourcing, social listening, gamification, collaboration, and analytics.
Reducing Time to Market for Manufacturing Innovations through Social Product Development

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Social Product Development: A comprehensive, result oriented approach based on crowdsourcing

Moving from 'piece meal to holistic view'

Crowdsourcing has been adopted occasionally, in silos in manufacturing organizations by enterprises focusing on innovation management to generate ideas from outside the enterprise. The current paper focuses on leveraging the platform for solving the relevant problems across the manufacturing value chain.

Moving from 'ideas to monetization'

Adopting enterprise contextual intelligence through analytics or machine learning components help to make informed decisions, aligning crowdsourcing with the enterprise business processes landscape to reap returns on investments. Examples include:

1. Targeting the right crowd for a crowdsourcing program by predicting the participant crowd profile through gamification and analytics to shorten the lead time of the crowdsourcing process.
2. Combining similar ideas from diverse crowd participants and identifying patterns in incoming ideas can improve the overall potential value of ideas in a crowdsourcing program.
3. Converting the ideas to products, features, or services by feeding them into market research and product planning processes.
4. Creating a ‘test bed’ to validate the ideas and assess the adoption rate or success of ideas before big bang implementation to optimize innovation investments.

Why Manufacturing Organizations Must Adopt Social Product Development

Here are five key trends that are bolstering the case for social product development platforms:

1. Organizations need a proactive approach, agility, and the ability to anticipate the future and ensure sustainable business growth. Yard Club¹, a California startup, created a peer to peer marketplace that helps customers earn income on idle construction equipment by renting it to verified club members, maximizing the financial returns companies receive on fleet investments. With no guarantee that an organization’s competitors might come only from within the industry, social product development platforms help manufacturers run a series of lean innovation experiments involving employees, start-up partners, suppliers, and customers across the globe to anticipate future business trends and validate it with their target markets.

About the Authors

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¹ https://www.yardclub.com
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2. Specialist expertise and seamless collaboration are critical to develop cross-disciplinary future products, processes, business models, and cost innovations. Such talent might not be available on the payroll of an organization, or even locally. Social product development enables seamless collaboration that leverages diverse expertise from beyond the boundaries of the manufacturing enterprise to help create compelling products, services, and processes.

3. Digital social collaboration platforms increasingly offer proven models of crowd engagement. On First Build, a crowdsourcing product development platform for the appliance industry built by GE, individuals design and submit ideas, and the community tests out these ideas and creates products using 3D printing. First Build then manufactures and delivers the next generation of major home appliances to customers.² Crowdsourcing, crowdfunding, and co-creation are proven models to engage with a larger ecosystem to create value.

4. Socially-savvy employees, partners, customers, and other stakeholders have embraced an open culture Generation Y, Generation Z, and millennial employees, partners, and stakeholders are socially savvy digital natives—comfortable with and accustomed to expressing themselves on digital collaboration platforms. By adopting social product development, manufacturers can ensure that their offerings resonate with that of their audiences’ persona and culture.

5. Technologies continue to become powerful, feature rich, accessible, and cost effective. A social product development platform that is scalable and replicable can be built using mostly open source technologies, reducing operational overheads and costs.

Social Product Development Platform: Use Cases

![Social Product Development Platform: Enterprise Schema](image)

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Unlocking Real Business Value

By using a social product development platform, organizations can achieve real business benefits including faster and first-time-right product development, stronger customer engagement, lower costs, higher revenues, and collaborative learning.

In September 2015, GE invited data scientists, analysts, and GIS specialists to develop a data science model to solve water scarcity. In two months, it received about 1000 ideas and the winner was granted a cash prize of $10,000. The idea owner was invited to participate in the development of GE’s algorithm for the solution.³

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Recognizing and Addressing Concerns Early

To ensure success, manufacturers that plan to adopt a social product development platform must address key concerns including:

- Willingness of the crowd to provide ideas or to consent to create value with an organization
- Ownership of intellectual property rights (IPR) of ideas in a crowdsourcing program
- Possibility of competitors misappropriating crowdsourced innovations

Key Attributes and Groundwork for Ensuring Success

Manufacturers need to inculcate cultural and technological attributes to ensure the success of a social product development platform such as creating an open culture, picking the right crowd, providing the right tools, and integrating crowdsourcing with existing processes.

Before embarking on creating a social product development platform, organizations need to:

- Understand the foundational units of practicing social product development and observe industry leaders.
- Plot the skills canvas and the innovation requirements for the enterprise ten years ahead.
- Identify or develop the relevant communities outside the enterprise for collaboration.
- Create a cross-functional team within the enterprise to drive the social product development journey.
- Pilot initiatives with themes aligned to business priorities and evangelize success stories in the organization.
- Repeat the initiatives for varied use cases and functions, learn from experience, and embed the culture in the organization’s DNA.

Conclusion

Today, collaborative consumption, globally dispersed diverse talent, and the maturity of social collaboration platforms, make it both essential and possible for manufacturers to tap the talent pool beyond their organizational boundaries, combine structured and unstructured data to anticipate the future, and know what existing and potential customers want at any given moment. Manufacturers must streamline processes to take advantage of crowdsourced social product development.
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Cloud hosting models allow organizations to build and leverage the social product development platform-as-a-service to reduce TCO. While considerable investments are required to manage the platform, there are significant returns in form of innovative business products, services and processes.

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About TCS’ Manufacturing Business Unit

TCS helps global manufacturers reduce operational expenditure, utilize capacity optimally, and increase efficiencies while meeting safety and regulatory norms. We are the preferred partner for a third of the Fortune 500 manufacturers, and have a record of enabling business innovation that helps them meet the objectives of global operations.

The core strength of our solutions lies in our rich experience across discrete (automotive, industrial manufacturing, and aerospace) and process industries (chemicals, cement, glass, and paper). Our vertical focused Centers of Excellence (CoE) leverage this rich database to cross-reference learning and drive innovation in business solutions for standardized processes, assets and templates, ERP implementation, and continued support services.

Our solutions and services portfolio spans IT-led business transformation; design, development, and support for IT solutions; and value-added services such as infrastructure management and consulting.

Contact

For more information about TCS’ Manufacturing Business Unit, visit:
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About Tata Consultancy Services Ltd (TCS)

Tata Consultancy Services is an IT services, consulting and business solutions organization that delivers real results to global business, ensuring a level of certainty no other firm can match. TCS offers a consulting-led, integrated portfolio of IT and IT-enabled, infrastructure, engineering and assurance services. This is delivered through its unique Global Network Delivery Model™, recognized as the benchmark of excellence in software development. A part of the Tata Group, India’s largest industrial conglomerate, TCS has a global footprint and is listed on the National Stock Exchange and Bombay Stock Exchange in India.

For more information, visit us at www.tcs.com

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