The Complexity of Data-Driven in Engineer-To-Order Enterprise Supply-Chains

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Abstract. The complexity of data-driven engineer-to-order manufacturing enterprise supply-chains for effective and efficient decision making has received a lot of attention both within the original equipment manufacturing industrial research and development circle and supply-chains operations research and management circles. However, despite these complexities, most of the published supply-chains research in operations research and management have neglected the 'engineer-to-order perspective within the original equipment manufacturing supply-chains sector. This research employs a comprehensive study of complex supply-chains management activities to attempt to propose feasible and measurable essential propositions and/or framework for "best practices" in data-driven engineer-to-order supply-chains. There seems to be no specific comprehensive study on the complexity of data-driven engineer-to-order supply-chains within the original equipment manufacturing sectors for complex products such as the aerospace, marine, and/or power plant industries, etc. However, because this area of complexity of data-driven engineer-to-order within enterprise supply-chains have not been much researched or explored; there is an expected challenge of finding enough available literature to draw-on or makes an inference to. Hence, this study will take solace from mostly real-life industrial case(s) and/or activities, etc. Therefore, this paper presents a comprehensive study of the complexity of data-driven engineer-to-order enterprise supply-chains as well as outlining essential propositions and/or framework to enhance effective and efficient resilient complex engineer-to-order supply-chains. This paper will thus, contribute to the development of a more robust and resilient framework when dealing with the complexity of data-driven engineer-to-order enterprise supply-chains.

Keywords: Complexity · Engineer-to-Order · Supply-chains · Original-equipment-manufacturer · Bigdata

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1 Introduction

Engineer-to-Order (ETO) design of original equipment manufacturer (OEM) products includes design for large or huge products; such as aircraft, large electric machine, huge centrifugal pumps, diesel/natural fuel power plant engines, steam turbine, huge boilers, ship power engines, etc. [1]. ETO is a product development process, which starts with a product specification and finishes with engineering design as its final deliverable mostly excluding the actual manufacturing processes of the complex product. One of the notable problems associated with ETO complex products design and delivery is excessive lead-time. Thus, a data-driven ETO enterprise supply chain network is seen as a supply chain (SC) network system where the 'decoupling point' is located at the design stage, so that, customers' orders extends beyond the engineering design phase of a complex/new product [2] where these actives are enhanced by information, communication, and technology (ICT) enablers. Hence, an ETO process is associated with huge or large, complex project environments in sectors including the construction and capital-intensive OEM investment initiatives all generating huge/big data concurrently. This is the era where big data is constantly being generated within industrial settings; because of the huge acceptance of information, communication, and technology (ICT) enablers as the main embodiment of enterprise SCs. This has now been coined in many different terms such as internet of things (IoT); artificial intelligence (AI) aided by smart systems (SS) or internet of services (IoS). All these maps-up to what is now known as "Cloud/Virtual Manufacturing"; etc. Hence, complexity within data-driven ETO SC is rarely researched on or used in existing or trending research in this area: Thus a confusion exists as to the appropriate definitions for this specific type of industrial operation and the appropriate "best practices" employed to enhance competitiveness and resilience within a complex data-driven ETO enterprise supply chain network activities. Therefore, the purpose of this paper is to study the complexity of OEM data-driven ETO enterprise supply chain activities and attempt to introduce an optimum "best practice" framework by outlining effective and efficient operational propositions for a competitive and resilient ETO enterprise supply chain management (SCM).

SC is a complex network of industrial entities networked into the upstream, intermediate-stream and finally downstream flows of products processes and/or services, along with the related finances and information [3, 4]. Supply chain management (SCM) involves the systemic and strategic activity network of these flows both within and across OEM industries' SC intending to reduce costs; improve customer satisfaction and gain a competitive advantage as well as enhance the resilience within both the entity industries and the SC as a whole [3, 4]. The voluminous amount of data along with the dynamic and uncertain or volatile network environment of OEM SCs contributes to their complex nature. Thus, these complexities are inherent in SCs and are observed in different forms and origins, including static complexity, which is related to the interconnectivity and structure of subsystems with the network involved in a specific SC. However, dynamic complexity, on the other hand, consists of results from the operational behaviour of the systems and subsystems within an SC network and its environment. Decision-making form of SCM complexity is that which involves both static and dynamic aspects of complexity [5]. According to [5], the complex nature of SC contributes to the complexity in effectively managing OEM SCs, to the extent that it has almost become literal to say

SCM is about managing the complexity of the SC network. Over a decade and beyond now there have been series of studies or research on complexity in the SC to achieving effective and efficient SC performances [6–15].

This section of the paper will continue with the following: an example of complexity in ETO – SC projects; the problem statement of this research. Then, the rest of the paper is structured as follows: Sect. 2 – Measuring complexity of data-driven ETO enterprise supply chains; Sect. 3 – Complexity in supply chain structures; Sect. 4 – Dynamic aspects of supply chain complexity; Sect. 5 – Product and system-related complexity and finally; Sect. 6 – Concludes the paper along with industrial implication and recommendations.

1.1 Examples of Complexities in Data-Driven ETO Enterprise SC Projects

ETO of OEM industries is characterized and described in terms of their markets, products, services, and the internal and external processes of their organization. The variety of SC activities in data-driven ETO projects are mainly customized and complex products due to the underlying uncertainties of characterizing the processes within the SC and their subsequent markets. Furthermore, complexity in OEMs ETO SC is also imminent in all data-driven ETO enterprise SC project procurements and marketing need in terms of information integration within the SCs as well as the other processes such as tendering and design. These characteristics put constraints and/or complexity on the application of established data-driven ETO enterprise supply chain management methods. Industrial ETO produce projects may require a detailed and specific set of the data-driven item, such as numbers, bills of material (BOM), and routings of scheduled manufacturing processes and activities. Thus, these details are usually complex with huge volumes of data or big data as well as long lead times. Therefore, customers are also normally heavily involved throughout the entire design process for specific ETO project products. They are usually limited to an engineering design process which involves the tasks of engineering analysis, concept design, architectural design, detailed design, and manufacturing process design. Hence, these processes do not include the manufacturing phase of materials acquisition, fabrication, and assembly. The product design process phase takes enormous time for the entire process lead-time. Thus, a new and improved data-driven ETO enterprise SC network effectively and efficiently coordinating the other aspects of the manufacturing phase not included in the traditional ETO process would attempt to reduce the long lead-time associated with ETO processes. This approach would enable all the partners on data-driven ETO enterprise SC to operate and function more effectively in terms of information communication and exchanging of essential ETO project product details on a common platform in near real-time if not in real-time.

The literature on SCM has begun addressing the inter-relationships SC network of suppliers as a supplier–to-supplier relationships [16, 17]. Although buyer–to-supplier networks have received sufficient attention in the literature [18, 19], supplier–to-supplier networks, these are also active in the supply chain networks, but are still trending actively in SCM research [20, 21]. For instance, when the network among suppliers, move beyond a dual-linked context (e.g., one supplier to another supplier) into a trio-linked context (e.g., two suppliers competing against each other to provide products to another supplier in the same industrial OEM); these dynamics become much more complex [21, 22]. For example, in the marine – ship power industry, groups of suppliers who used to compete against each another on a certain supply would now have to link themselves up to cooperate in a specific and/or single OEM ETO project. Thus, utilizing organizing themselves into a common effective and efficient ETO SC network to gain more leverage in their approach and activities, it enhances the effective use and analytics of the huge or big data generated among these data-driven ETO enterprise SC networks. This new improved approach as compared with the traditional ETO process will bring all the stakeholders on the ETO project together both internally within the OEM's SC and globally among their external ETO project suppliers. This interconnectivity could be facilitated and enhanced using information technology enablers. Thus, further to the exchange of product parts, exchange of information also occurs within supplier–to-supplier interaction. Therefore, a typical competitive supplier–to-supplier relationship may still lack certain objective information about the other supplier within the network (such as predictable demand, competitor's product features, and production capacity). This limitation could by means of technology enablers [6, 7, 16, 23, 24].

1.2 Research Problem Statement

Dynamism and volatility seem to have been increasingly dominant in recent times. Thus, globalization has made many industries to experience volatility within the industrial marketplace which has virtually prompted industries to have a rethink of the way business is conducted [25] and the huge data generated among the SCs are efficiently utilized. Hence, this has also led to certain vital trade-offs between for example labour costs, transportation costs, inventory costs and response time to the customer *(supply and/or delivery cost)* are becoming increasingly complex [26]. Therefore, it seems impossible to only focus on one's OEMs to gain a competitive advantage as far as resilience in their SC network activities is concerned. It has become obvious that the success of an individual OEM is dependent on the effective and efficient performance and reliability of its suppliers as well as the customers.

Based on the purpose and/or main objectives of this paper, the research question thus formulated is:

- How could "best practices" complexity be measured in a data-driven ETO enterprise SC network for it to be effectively assessed for competitiveness and resilience?

Industrial organizations engage in value-adding activities in their industrial businesses such as purchasing and supply of products and services mainly from a group of suppliers within their supply chain network [27, 28]. The group of suppliers is thus referred to as "supplier network" of the SC and the manufacturing industry that purchases from this supplier network are referred to as the "original equipment manufacturer – OEM." Operationally, the OEM is seen to be at the centre or have an oversight view of all suppliers in the supply chain network, thus, coordinating and controlling all the supply chain management activities. Therefore, OEMs producing engineered products on a data-driven engineer-to-order (ETO) concurrent engineering approach (i.e. partners from various divisions in the organizations) have traditionally maintained some level of business competitiveness. Through the design and product development expertise and could respond to demands for customization with improved product performance as customers are increasingly seeking for just-in-time (JIT) and affordable products. These competitiveness, responsiveness, or resilience in operational data-driven ETO enterprise SCs could be best achieved through improved OEM manufacturing systems' efficiencies. Thus, these OEMs require manufacturing ETO SC network system that is driven by the improved integration of the huge data generated from industrial designs, manufacturing and production processes and procurement functions of a data-driven ETO enterprise SCM system [29]. This facilitates the improvement of effective and efficient integration of the various stakeholders involved in an ETO SC project. Furthermore, it improves the overall product development lead-time, along with enhanced and better-defined product documentation a concurrent engineering process provides. Concurrent engineering process thus operates in the same vein as a collaborative or simultaneous engineering process. It is a process in which the appropriate partner organizations are committed to integrating their various manufacturing system to work interactively. Concurrent engineering in this sense is a moderate collaborative engineering approach that is much more focused on the engineering product design process of its concurrent cross-functional partner organizations. They come together to create products that are much better, much affordable and with a much-reduced lead-time [1].

2 Measuring the Complexity of Data-Driven ETO SCs

SC complexity fundamentally varies conceptually based on nature or operations processes of OEMs, thus, influencing the absolute direct control of an ETO SC project. This is due to the seeming integration among the stakeholders on the SC network, hence, posing some level of complexity or performance measurement within the organizational operations [30]. Measuring complexity within the SC, where the network coordination is no longer a concern of the SC ownership only, but instead on networking across various partners and stakeholders; the complexity within measurement system may be reflected as an engineering system of measuring the unmeasurable or uncertainties. SC network activities not under the direct coordination of an individual OEM company (i.e. a manufacturer) have to be measured and coordinated (by the manufacturer and its supply chain partners), making the supply chain more transparent, to a level not experienced before and leading the way for performance improvements [23, 30, 31]. According to the [32], there are two kinds of complexity in any industry: the good complexity and bad complexity. Thus, implying that, industries may employ one kind of complexity to their advantage while they seek to eliminate the other. So, what does complexity mean in this context? Some may think that complexity is merely the opposite of simplicity; others may think that complexity is synonymous for complicacy. However, both definitions are said to be incorrect, especially the second one [12]. In that, according to [12] "Complicated" and "complex" both come from Latin words, but the first one originally means "of things knotted, entwined with each other", while the second one means "of things which interact among each other". Complexity is the fusion of three things, which includes: The number and variety of components *(information or data about things, objects, machines or equipment)*, systems and people within an industry and across its entire value-chain as well as the interrelationships among all of them and also the pace at which they vary.

Therefore, complexity could be said to continue to increase exponentially more components, systems and/or people to the value-chain interrelationship [12]. Thus, culminating in a huge voluminous generation of industrial "big data."

As yet, there is no agreed or one definition of industrial big data. Hence, many enterprises industrial SCM network stakeholders and experts predict that big data will have a positive impact on their industrial ETO SC operations and activities [23]. Thus, enabling them to make more strategic data-driven and informed decisions. This then enables industrial big data generated for from industrial operation, product development activities as well as services of data-driven ETO SCs to effectively and efficiently utilize these data to coordinate their network activities in an IoT perspective. Big data generated in the form of data-driven ETO SC network on an enterprise SC platform, operates in the form of IoT which only becomes useful when it is analysed and processed for value-adding. According to [23] findings, IoT came to the forefront as an enabling driver of high growth of data both in terms of quantity and category in industrial data-driven ETO SCs perspective. Thus, providing the opportunity for the application and development of big data for effective and efficient industrial operations management activities. On the other hand, the application of data-driven ETO enterprise SC networks as big data platform to IoT also accelerates the research advances and business models of IoT in industries [33]. Furthermore, IoT can also enable improvement of product development activities as well as services. Also, data analytics for customer experience, security, etc., if it is properly filtered and authenticated and harnessed for such industrial or service purposes. IoT also has the potential to transform traditional business-to-customer interactions in a way previously not thought of [34] when networking sensors such as RFIDs are embedded in a variety of electronic devices and/or machines to communicate and exchange data or information in real-time and in a real-world activity [35]. Data-analytics (e.g. machine learning) and data-driven decision making are an essential part ETO SC projects and processes because of the enormous amount of data. This data can be utilized in several ways to provide extended value for ETO SC. Data can be analysed based on data content, which can be for example, with text, audio, video, or other content. Data analytics always knowledge extraction from the dataset as Fig. 1 is illustrating.

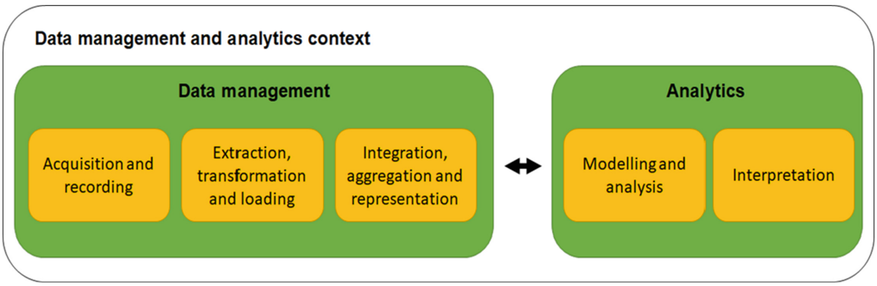


Fig. 1. Processes of knowledge extraction from the data ([36] [adapted])

Process of knowledge extraction from the data can be distributed in data management and analytics processes as Fig. 1 is proposing. First, the data is collected using different methods and devices (e.g. sensors). Data is extracted, transformed, and loaded (ETL) to an appropriate data store where it is integrated, aggregated, and represented in a certain format. After these preparatory processes data is already useful but it can be analysed more with data modelling with machine learning and other analytics. Data analytics does not provide any value without appropriate interpretation which can be done in several formats. Thus, from a manufacturing industry's system engineering point of view, "complexity" surfaces most often when there is variety existing within the boundaries of its SC network. These entities of various existing within the boundaries of these varieties are connected and interlinked with many others: for example, selecting a specific finished product on the global market among a plethora variety of many others may require different and but equally demanding industrial technologies; to control and exploit the variety of different sales channels. Furthermore, the same effort would be required to deliver and/or transport same to a large number of logistic customers; to be able to effectively manage any large variety of different subgroups, components and raw materials connected or interlinked within or among the SC network. Substantial research work has been carried out discussing how the variety of products, of distribution channels, of suppliers, of components, etc. can enhance the competitive strength on one side, but increase coordination and management costs on the other, up to the point of more than counterbalancing those benefits [12].

3 Complexity in Enterprise Supply Chains and Enterprise Structures

Manufacturing systems configuration has extensively been used to effectively address the OEM manufacturing system's specific operations responsiveness by a series of companies dealing with mass ETO project products (mass customization). Several applied types of research have yielded feasible solutions to some of these operational process issues by way of proposing frameworks. These have since been introduced to enable their systematic planning, analyses, development, and implementation data-driven ETO enterprise SC processes. Traditional research has thereby either focused on defining modelling techniques for the configuration model of stable products, on improved configuration algorithms, or the impact of configurators on specific OEM project operations [37]. However, not much focus has been placed on complex issues within data-driven ETO enterprise SC projects in terms of research. Therefore, this paper attempts to outline the critical "best practice" propositions to assess and facilitate these proposals effectively and efficiently. The categorisation of SCs according to specific networks, features and/or clusters that have been widely researched on in previous SC literature and still trending. Therefore, this section of the paper will seek to touch on most of the widely used and adopted manufacturing systems processes and sometimes referred to as 'SC structures.' These SC structures turn to make sense of the diverse range of SC operational processes by outlining how different sections of a data-driven ETO enterprise SC interact with customer purchasing orders, etc. Many research literature within this research area have not adequately addressed the full range of enterprise manufacturing SC or manufacturing systems structures but have, however, focus on just one of these domains or just a selected of these specific structures outlined in Table 1 below. Many of the structures for thinking about effectively connecting ETO SCs to the appropriate marketplace have been organized around the concept of the 'decoupling point' [2].

According to [2], the customer order decoupling point (CODP) is a stockholding point that separates the part of the SC that responds directly to the customer from the part of the SC that uses forecast planning. The various manufacturing system decoupling point structures can act as operational strategies as a buffer against the variable system demand within the SC as well as efficiently schedule an effective way to standardize ETO projects whilst reacting to uncertain orders or complex issues within the SC network. Table 1 below outlines most of the popularly used manufacturing SC system structures. [38–40] identifies with most of the conceptual foundations for SC structures in the different logistics and SC structures for the various decoupling points:

Table 1. Manufacturing SC system structures

#	Manufacturing systems and/or processes	Acronym	System/Process definitions
1	Engineer-to-order	ETO	The decoupling point is located at the end of the detailed engineering design phase with the project SC. Hence, the deliverable for the data-driven ETO enterprise SC is a detailed engineering design of an ETO project
2	Make and ship-to-stock	M/STS	The decoupling point is located at finished goods in a national organization
3	Make to stock	MTS	The decoupling point is located at finished goods in a supply centre
4	Assemble to order	ATO	The decoupling point is located at subassemblies within the assembly process
5	Make to order	MTO	The decoupling point is located at purchased goods
6	Purchase and make to order	P/MTO	The decoupling point is located at the supplier

4 Dynamic Aspects of Data-Driven ETO Supply Chain Complexity

Industrial organizations into data-driven ETO SC projects are facing various challenges in terms of competitiveness and pressures arising from new competitors and emerging competitions [42, 43]. Furthermore, customers are calling for higher flexibility and thereby challenging OEMs to make their ETO SC projects more accessibility in terms of global presence. Detailed engineering design is a core deliverable of the ETO SC project business, defining about 50–60% of the total ETO project life-cycle processes [44]. Figure 1 below, illustrates an optimal framework for ETO SC projects feasibly capable of transforming data-driven ETO SC network activities with the requisite ICT enablers into an improved data-driven ETO enterprise SCM network.

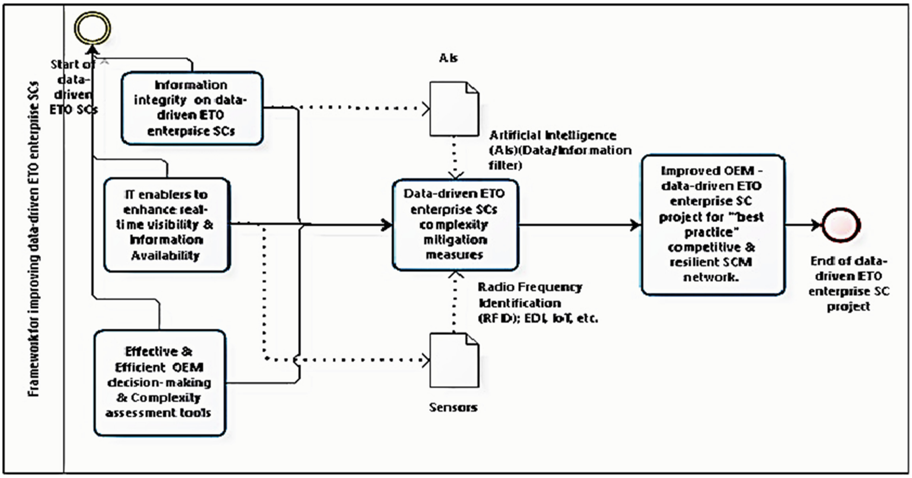


Fig. 2. Framework model for improved data-driven ETO enterprise SCs – *Bizagi Modeler*

5 Product and System-Related Complexities

Complexity in data-driven ETO enterprise SCs as hinted in previous sections of this paper as well as some past literature mainly has to do with ETO projects' product design lead-times which are the main issue of attention in manufacturing systems structure. Another area of attention is the design tools and/or system technologies applied in the product design processes and within other product design domains in terms of design integration or interfacing. Thus, in each of the product design domains, tools and/or technology employed causes some level of complexities which arises mainly due to the numerous data-driven elements within the multitude of relationships or networks involved. These include but not limited to the huge/big data generated between the components of an ETO product being designed as well as the activities or processes employed to design the products, and also among the enterprise SC network stockholders involved in these activities. According to [45] one of the very capable and feasible approaches in handling and/or managing complexity within data-driven ETO enterprise SC is to represent and analyse the various product design domains' structures or enterprise system architectures (ESA). The design structure matrix (DSM) has proved to be a very helpful tool for representing and analysing these complex enterprise system architecture of a specific enterprise SC such as a data-driven ETO enterprise SC [7, 45]. Below is an example of a typical automobile OEM data-driven manufacturing SC project illustrating the complexity of an OEM electrical wiring system (harness) for different customer cars. This electrical wiring system (harness) collects, communicates, and monitors in real-time various data/information inside and outside the car to enable the car functions appropriately for purpose. There are two types of customer products namely, KSK (these are customer-specified concepts/cars) and NKSK (non- customer-specified cars). KSK is made up of individual building blocks which are engine, cock-pit, body and basis whereas NKSK use of the same combination of electrical wires and these include roofs, seats, bumpers, and doors. Figure 3 below, shows a schematic picture showing a different position of harness in a car. JIT and FIFO principles are incorporated from the beginning of the manufacturing process until the harness reach the customer.

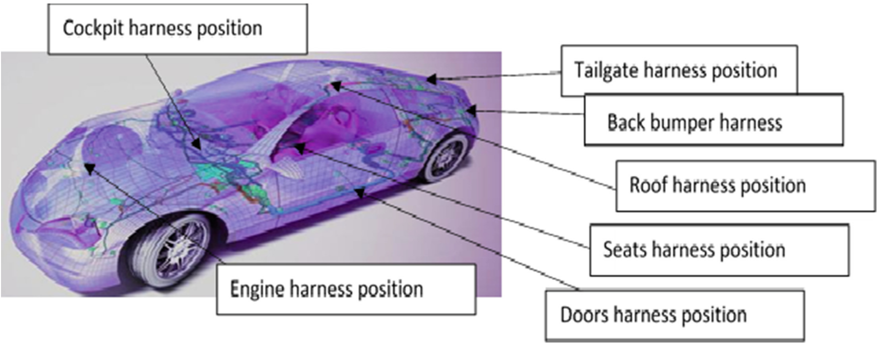


Fig. 3. Harness positions in a car

Figure 4 below, shows a typical example of a complete electrical wire harness and Fig. 5 below systematically illustrates the harness production or manufacturing process and stages. An electrical wire harness is made up of a different combination of wires and components; to mention a few, antennas, wire protectors, housings/connectors, seals, terminals, and grommets.

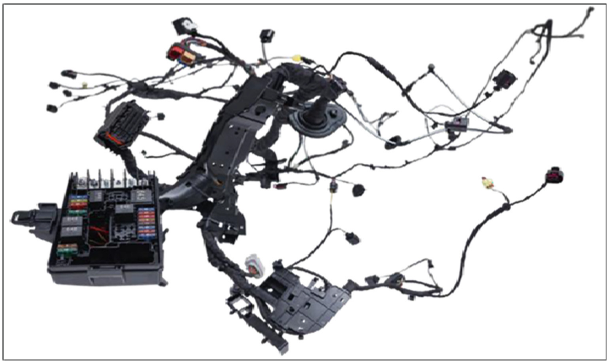


Fig. 4. Typical example of a manufacturing automobile OEM car wiring system harness

5.1 Piloted Real-Life Industrial Case Study Example

Industrial SCM networks are confronted with various challenges. Thus, most of them find themselves struggling to survive operationally. Therefore, most OEMs embarked on high data-driven ETO enterprise SCM activities in complex engineering design and delivery product development activities such as marine – SP engines, aviation – jet engines, automobile manufacturing, etc., are being compelled to improve their SCM network

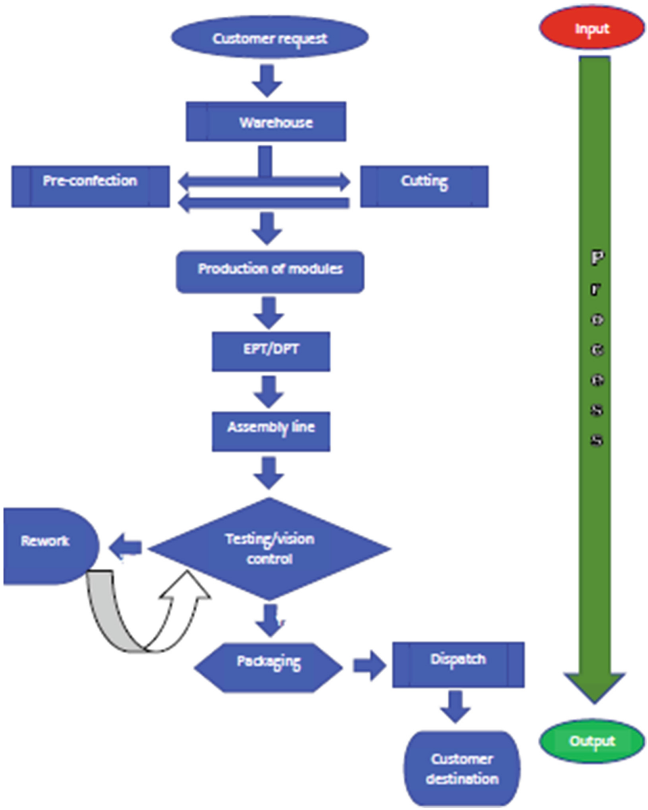


Fig. 5. Harness production process

activities [7]. In this globalized or digital era; most of the real-life challenges facing these OEMs include evolving data-driven actives such as customer demands, stiff global competition market research and the need to improve new or complex products' time to market [46–48]. These persisting operational challenges could be effectively dealt with when the multidisciplinary teams/partners on an enterprise SC network concurrently work together effectively and the information flow and exchange communication network among them are effective and efficient. The marine ship power OEM is one such industry with high data-driven ETO enterprise SCM network approach. Thus, a classical applied industrial case example from [7] on such industrial operation data-driven analysis approach has been adopted as a typical example to illustrate the feasibility and efficacy of the proposed framework in this research paper. In perspective relevance, the case OEM's logistics and the supply chain management division were used for this real-life pilot study. The OEM has over 280 major suppliers globally. The company aims at improving business process efficiency by integrating its industrial operational process with that of its suppliers and customers as well as sharing and exchanging real-time information within its SC network concurrently.

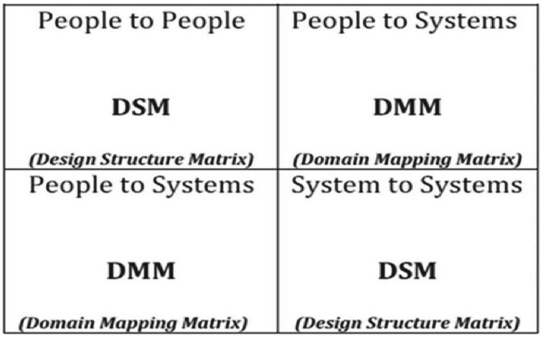
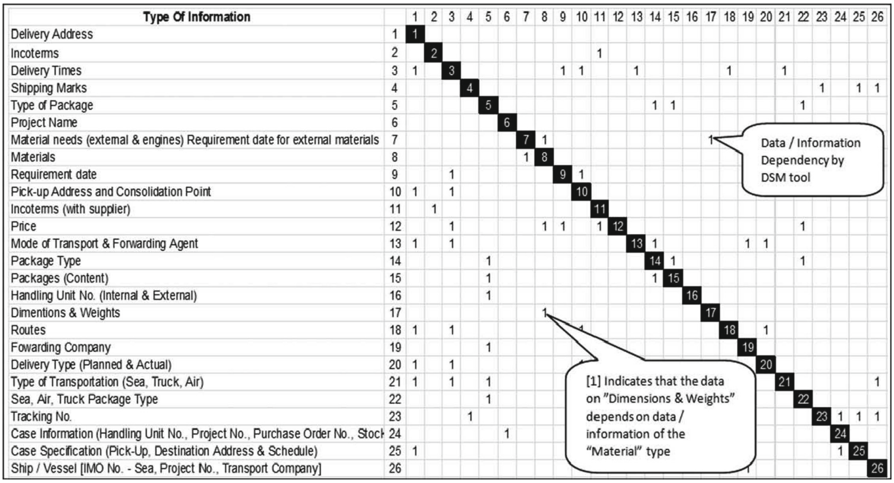


Fig. 6. DSM, DMM data analysis matrix (Source: [27])

According to [7] data-driven analysis matrix illustrated in Fig. 6 above; system-to-system analysis is also best affected by employing the same DSM simulation approach. However, when analysing people to systems, these are two domains that need to be effectively mapped or integrated or interfaced. Therefore, the approach employed is domain mapping matrix (DMM) [49].



Type Of Information		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Delivery Address	1	1																									
Incoterns	2		2									1															
Delivery Times	3	1		3						1	1			1					1			1					
Shipping Marks	4				4																			1		1	1
Type of Package	5					5									1	1							1				
Project Name	6						6																				
Material needs (external & engines) Requirement date for external materials	7							7	1									1									
Materials	8							1	8																		
Requirement date	9			1						9	1																
Pick-up Address and Consolidation Point	10	1		1							10																
Incoterns (with supplier)	11		1									11															
Price	12			1					1	1		1	12										1				
Mode of Transport & Forwarding Agent	13	1		1										13	1					1	1						
Package Type	14					1									14	1							1				
Packages (Content)	15					1									1	15											
Handling Unit No. (Internal & External)	16					1											16										
Dimentions & Weights	17								1									17									
Routes	18	1		1															18		1						
Fowarding Company	19					1														19							
Delivery Type (Planned & Actual)	20	1		1																	20						
Type of Transpotation (Sea, Truck, Air)	21	1		1		1																21					1
Sea, Air, Truck Package Type	22					1																	22				
Tracking No.	23				1																			23	1	1	1
Case Information (Handling Unit No., Project No., Purchase Order No., Stock	24						1																		24		
Case Specfication (Pick-Up, Destination Address & Schedule)	25	1																							1	25	
Ship / Vessel [IMO No. - Sea, Project No., Transport Company]	26																										26

Fig. 7. Design structure matrix (DSM) data/information types relationship entries. Source: [27].

Figures 7 above illustrate some of the graphics from the DSM simulation tool employed in [7] research on the concurrent enterprise: a conceptual framework for enterprise supply-chain network activities. Moreover, several other data-driven models and methods can be employed to support ETO SCM networks. For instance, machine learning provides several algorithms to manage the ETO SCM data which is illustrated in Fig. 5 below (Fig. 8).

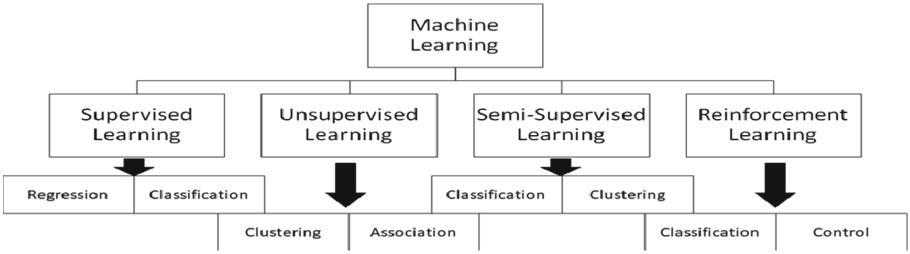


Fig. 8. Machine Learning algorithms. Source: ([50] adapted).

Machine learning can be utilized several ways is ETO SCM depending on the dataset available. Machine learning provides value searching patterns from the data and formulating models which can be utilized in different applications. Machine learning can be combined with vehicle routing systems as computation capacity increases [51]. Complex ETO SCM process can take major advantage of machine learning algorithms as complexity is increasing. Machine learning can be utilized, for instance, in modular structures in the process to estimate process length in a certain configuration. Moreover, digital twins can be utilized to support ETO SCM. Digital twins are replicas of physical objects, which will be developed in the future. Digital twins can be utilized to illustrate the new product in various ways. NASA, for example, is utilizing digital twins to support vehicle development in several ways [52].

6 Conclusions

SC network itself is a complex system. Moreover, integrating enterprise SC complexity management into the SCM system is a necessary action. Therefore, OEMs coming to terms the inherent complexity of their data-driven ETO enterprise SC and taking necessary actions to mitigate, manage and avert these complexities that arises from the voluminous data generated; enable them to perform better and also ensures customer satisfaction. Therefore, this paper defines data-driven ETO enterprise SC complexity in a more practical and system dynamics perspective. It also attempts to categorize the manufacturing system structures of enterprise SC complexity according to the type and origin of the complexity. Further to this, it studies, investigates, and outlines some "best practice" propositions on how data-driven ETO enterprise SCs could be assessed optimally, effectively, and efficiently for industrial competitive advantage in operational complexity. For a competitive, resilient, and successful data-driven ETO enterprise SC network, complexity must be effectively and efficiently managed and/or mitigated. Therefore, it is imperative to identify and understand the causes and drivers of the uncertainties and complexities that arise due to the voluminous amount of data generated during industrial operations within an organization. This paper thus proposes some feasible "best practice" solution strategies to deal with the complexities that arise within OEM – data-driven ETO enterprise SCs to enhance and promote effective and efficient SCM systems network activities [7, 53]. Therefore, below outlines the "best practice" propositions in addition to the framework model illustrated at Fig. 2 above, to enhance OMEs data-driven ETO enterprise SC operations in a more competitive and resilient approach in industrial SC complexities:

- Proposition 1. Data-driven ETO enterprise SC network complexity is positively associated with full information integrity from the various supplier and customer network systems.
- Proposition 2. When OEMs designing and/or developing data-driven ETO enterprise SC projects employs and effectively utilizes enterprise IT enablers to enhance the total visibility of the ETO SC projects and real-time availability of information on the SC network; this approach promotes competitiveness and resilience of a data-driven ETO enterprise SC network.
- Proposition 3. The effective and efficient use of OEM "best practice" operations management tools for decision-making as well as competitive and resilient ETO SC network are essential for data-driven ETO enterprise SC complexity assessment and mitigation measures.

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