Role Of Industry 4.0 In Supplier Selection

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Abstract

Industry 4.0, Industrie 4.0, or I4.0 is revolutionising the working of systems and also enabling them to interact among themselves. Incorporating the new technologies will not bring about a complete realisation of benefits if done in a disaggregated manner or only a few elements of the supply chain. This study looks into the supplier side of manufacturers to support the development of integrated value chains. The study aims at providing a holistic framework to evaluate the maturity levels of Industry 4.0 across manufacturers and suppliers, which can then be used in the process of selection. The study also incorporates an Analytic Hierarchy Process (AHP) evaluation of the dimensions to define their priorities, which will provide the weightages to arrive at an overall maturity level of Industry 4.0 at these entities (Manufacturer and suppliers).

Keywords
Industry 4.0, Supplier selection

1. Problem Description
Industry 4.0 can be defined as a manufacturing system that is integrated, optimised, and inter-operable and utilises algorithms, big data, and other new technologies. Industry 4.0 involves the Internet of Things (IoT), Cyber-Physical System (CPS), information and communications technology, Enterprise Architecture, and Enterprise Integration. However, the effectiveness of Industry 4.0 cannot be seen only by the manufacturer. It must be developed across the supply chain with various business partners. One of them is the suppliers. The current process of supplier selection involves various factors such as costs, resiliene, sustainability, and the like, but a perspective of Industry 4.0 is lacking. A framework to evaluate the maturity levels of different aspects of Industry 4.0 can not only help evaluate any entity of its terms with Industry 4.0 but can also help in finding compatible business partners (in our case, suppliers). This is the area this paper wishes to delve into.

2. I4.0 Technologies
For a supplier to be considered Industry 4.0 compliant, according to Frank et al. (2009), Industry 4.0 technologies integration should be considered on the following dimensions:

i. Supply Chain
ii. Working
iii. Manufacturing
iv. Product

The details of each of these dimensions and their respective technologies and maturity levels are discussed in detail in the following sub-topics.

2.1 Smart Supply Chain

Smart Supply Chain alludes to the operational exercises involved and improving their efficiencies through Industry 4.0 usage. Angeles (2009) and James et al. (2010) visualise real-time correspondence of a firm's functions and their exchanges with Enterprise Resource Planning (ERP). An ERP system that overlooks the functional areas and information flows in a firm is called ERP I. When these ERP systems of firms are related to their counterparts in commercial partners, it is called ERP-II. Recently, ERP executions have taken on a hybrid quality related to supply chain-wide activities: Knowledge management, Supply Chain Management, vendor managed inventory (VMI), collaborative planning, forecasting, and replenishment (CPFR).

Smart Supply Chain has to be implemented with each of these three stakeholders viz. (i) Suppliers, (ii) Customers, and (iii) Other Company Units. The maturity for each can be gauged as per Table 1.

Table 1. Smart supply chain maturity levels

Smart Supply Chain		
Level	**Criteria**	**Papers Referred**
	1. Digital Platform with Suppliers	
1	ERP-I implemented at the supplier	Angeles (2009)
2	ERP-II implemented with supplier	
3	Hybrid qualities incorporated with supplier	
	2. Digital Platform with Customers	
1	ERP-I implemented at the customer	Angeles (2009)
2	ERP-II implemented with customer	
3	Hybrid qualities incorporated with customer	
	3. Digital Platform with Other Company Units	
1	ERP-I implemented at other company units	Angeles (2009)
2	ERP-II implemented with other company units	
3	Hybrid qualities incorporated with other company units	

2.2 Smart Working

Smart working refers to the improvement of productivity and visibility in internal operations of a plant or workshop by the implementation of relevant technologies.

i. Remote monitoring of production: Yue et al. (2019) say that monitoring is a significant part of the operation, scheduling, and maintenance of the I4.0 manufacturing system. The use of different sensors has made smart monitoring conceivable. Smart monitoring gives a graphical perception of the information as well as alarms when an anomaly happens in machines or instruments. The levels are defined in Table 2.

ii. Remote operation of production: Traditionally, operators stood in assembly lines and manually worked on each unit that had to be manufactured, but with improved machines and robotic manoeuvres, the job of an operator is mostly cognitive. When it is limited to cognition, the job can also be remotely controlled. The maturity can be tracked, as seen in Table 2.

iii. Collaborative Robots: Du et al. (2012) say that, if an assignment is convoluted for an Autonomous Robot to complete, human insight is vital to control the robot. Besides, when the robot is in an imperilling situation, the teleoperation of the robot might be required. Such teleoperation can be of different levels, as in Table 2.

iv. Augmented and Virtual reality for Product Development: According to work cited by Elia et al. (2016), Augmented Reality (AR) systems have been used to speed up designing: Also, AR technologies could intuitively interact physically with products while making changes only virtually. The maturity of AR/VR systems can be determined by Table 2.

v. Augmented reality for maintenance: According to work cited by Elia et al. (2016), AR frameworks bolster effective maintenance techniques in harsh situations, such as low visibility and unsafe settings. The levels are outlined in Table 2.

vi. Virtual reality (VR) for workers' training: Gorecky et al. (2017) says, before the workers can perform assembly in the production system, they rehearse the actions using hardware prototypes which have many shortcomings and can be overcome by VR training.

Table 2. Smart Working maturity levels

Smart Working		
Level	**Criteria**	**Papers Referred**
	4. Remote Monitoring of Production	
1	Sensors tracking machine status are installed and can be viewed centrally	Yue et al. (2019)
2	Sensors tracking machine status are installed and can be viewed centrally in a graphical manner	
3	Graphical status reports of machines can be viewed remotely by anyone with access	
	5. Remote Operation of Production	
1	Machines run autonomously while being controlled by PLC interfaces	Song et al. (2017)
2	PLCs connected to the local network allows the operation of machines without a physical presence near them	
3	A central cloud collects all data from PLC and allows manipulation remotely	
	6. Collaborative Robots	
1	Enables robot control through non-intuitive methods such as keyboards, buttons	Du et al. (2012)
2	Enables robot control through intuitive methods such as gloves and other wearables	
3	Enables robot control through a visual system which detects human movement	
	7. AR and VR for Product Development	
1	The facilities for AR/VR based visualisation and inspection of product designs are available	Elia et al. (2016)
2	AR/VR based modification of designs is possible, and the company has a champion skilled at the same	
3	Collaborative designing is possible across locations or partners	
	8. AR and VR for Maintenance	
1	AR-enabled viewing and diagnosis is possible	Elia et al. (2016)
2	Remote access and maintenance are possible without any cycle time improvement	
3	Remote access and maintenance are possible with the cycle time improvement	
	9. VR for Workers Training	
1	The VR based system provides the ability only to view the scenario	Gorecky et al. (2017)
2	The VR based system enables interaction through non-intuitive methods (such as keyboards, remotes)	
3	The VR based system enables interaction through intuitive methods (such as VR enabled tools)	

2.3 Smart Manufacturing

Smart Manufacturing refers to the internal operational activities enhanced through technologies. While Smart Working aids the visibility and decision making of workers, smart manufacturing provides an enhancement to the product processing (production system).

i. Programmable Logic Controller: Work cited Song et al. says that, in current automation frameworks, the controller is executed freely and not with the actuators/sensors. They can collect feedback from sensors and control various actuators, which is known as a Programmable Logic Controller (PLC). Levels in Table 3.

ii. Enterprise Resource Planning: As discussed in the previous section, vertical integration can be enabled for information via Enterprise Resource Planning (ERP). To ensure a complete integration, the ERP systems across the supply chain must be interlinked, and data such as orders or outbound receipts should be seamlessly transferred to ease visibility and tracking. Table 3 mentions the maturity levels.

iii. M2M Communication - Vertical Integration: Work cited Gilchrist (2016) says that Big Data enables M2M learning and artificial insight, the bigger the pool of data, the more dependable the gauges. Data scientists use their capabilities in data examination to decide groupings in the data, which is the crux of M2M correspondence. This can help pose queries to find insights a human can never manually gauge. Levels can be found in Table 3.

iv. Manufacturing Execution System: A manufacturing execution system tracks material from the pre-process state to the finished good state. As per work cited by Yue et al. (2019), the core activities are operations, quality operations, inventory operations, and maintenance operations. Levels in Table 3.

v. Supervisory Control and Data Acquisition (SCADA): Work cited Song et al. (2018) speaks about SCADA arriving at new levels to offer both monetary and safety benefits. Their levels can be gauged in Table 3.
vi. Virtual Commissioning (VC): Per reference cited Mortensen and Madsen (2018), VC is a virtual manufacturing environment with real controls, allowing the recreation of the scenario for commissioning. The design for VC has the levels as per Table 3.
vii. Process Simulation: Work cited Song et al. (2018) says that simulation is valuable in the process modelling stage when it is utilised to test and check the specifications. There are multiple levels, as shown in Table 3.
viii. AI for predictive maintenance: Predictive maintenance is a method where the ongoing states of machines or tools are monitored, and the failure is predicted. With AI, the learning curves to understand possibilities of breakdown are much higher and can become accurate over time. Lee et al. (2019) give insights into the increasing research. Refer to Table 3.
ix. AI for the planning of production: Lazansky et al. (1995) says that production planners plan "by hand" using various tables, which may be extremely difficult and hard to carry out without errors. Implementation of an AI system ensures that the planning system can learn by itself and correct or avoid mistakes. Refer to Table 3.
x. M2M Communication — Automation: Refer to point 3 under Smart Manufacturing.
xi. Robots: Gilchrist (2016) says that modern robots are set up to work vigorously on mundane, dirty, hazardous, or challenging tasks leaving humans to cognition and supervision tasks. This removes strenuous or repeated tasks off human hands providing benefits. Refer to Table 3.
xii. Auto identification of non-conformities: Quality is one of the most significant Key Point Indicators (KPI) of a manufacturing company. From the onset of I4.0, various improvements can be made for non-conformities detection. However, the basic idea lies in the poka-yoke concept. It has three levels, as shown in Table 3.
xiii. Traceability of raw material &
xiv. Traceability of product: Work cited Angeles (2009), includes that RFID can be used in inventory management, tracking goods shipped, auto-replenishment, and many other cases. This has to be done for raw material and products separately. Maturity levels can be gauged for both as per Table 3.
xv. Additive Manufacturing: Weller, Kleer, and Piller (2014) say that the critical capability of additive manufacturing (AM) is the operation of manufacturing from virtual models by joining materials, generally by layer one after one. The advantage of AM is that it empowers the flexible creation of items without the cost losses of manufacturing. Refer to Table 3.
xvi. Autonomous lines: Balogun and Popplewell (1999) say that interest in and establishment of an FMS is exceptionally capital concentrated. Hence, the possible benefits have to be understood, which are improvement of (i)lead time, (ii)throughput, (iii)inventory, (iv) utilisation, (v)setup times, (vi)quality, and (vii)responsiveness. Levels in Table 3.
xvii. Energy efficiency monitoring &
xviii. Energy efficiency improvement: Song et al. (2018) say that energy efficiency is essential and suggests strategies required in MES to acquire an energy-effective process. The maturity levels are as given in Table 3.

Table 3. Smart Manufacturing maturity levels

Smart Manufacturing		
Level	**Criteria**	**Papers Referred**
	1. Programmable Logic Controller	
1	PLCs centrally collect input from sensors to control	Song et al. (2017)
2	PLCs are connected to the local network via LAN/WAN & can be accessed locally	
3	PLCs are connected to the network & can be accessed remotely	
	2. Enterprise Resource Planning	
1	ERP-I implemented at supplier & customer	Angeles (2009)
2	ERP-II implemented with supplier & customer	
3	Hybrid qualities incorporated with supplier & customer	
	3. M2M Communication - Vertical Integration	
1	Communications enabled by wired networks	Gilchrist (2016)
2	Communications enabled by local wireless	
3	Communications enabled by wireless remote networks	
	4. Manufacturing Execution System	
1	MES covers the activity of operations	Yue et al.

2	MES covers the activities of operations and inventory	(2019)
3	MES covers all the four core activities	
	5. SCADA	
1	SCADA is implemented & real-time data is gathered	Song et al. (2017)
2	SCADA can perform detailed condition monitoring	
3	SCADA can perform situation-based system reconfiguration or automated debugging	
	6. Virtual Commissioning	
1	Can perform virtual process planning & mapping	Morten & Madsen (2018)
2	Can include geometrical dimensions & create visual structure virtually	
3	Can include logical modelling & perform simulations	
	7. Process Simulation	
1	Simulation is done based on the hardware components	Song et al. (2017)
2	Simulation is done based on the partly available hardware components	
3	Simulation is done on virtual hardware models and later used to design hardware components	
	8. AI for predictive maintenance	
1	The AI can track the conditions of the machine	Lee et al. (2019)
2	The AI can predict breakdown and warn the operator	
3	The AI can help to provide schedules for maintenance	
	9. AI for the planning of production	
1	AI can identify issues causing the inability to meet targets	Lazansky et al. (1994)
2	AI can identify mistakes & suggest optimised changes	
3	AI autonomously runs the production planning activity	
	10. M2M Communication — Automation	
1	Communications enabled by wired networks	Gilchrist (2016)
2	Communications enabled by local wireless	
3	Communications enabled by wireless remote networks	
	11. Robots	
1	Robots are involved in basic heavy lifting & work separately	Gilchrist (2016)
2	Robots & humans are both involved in the production line	
3	Robots autonomously complete production end-to-end	
	12. Auto identification of non-conformities	
1	Detection of non-conformities is automatic	Wang (2014)
2	Detection of non-conformities leads to simplistic action taken to stop it from moving forward	
3	Non-conformities are detected & prevented	
	13. Traceability of raw material	
1	RFID enabled management of inventories	Angeles (2009)
2	RFID enabled notification of depleting levels	
3	Auto-replenishment using ERP or other tools	
	14. Traceability of product	
1	RFID enabled management of stock	Angeles (2009)
2	RFID enabled notification of depleting levels	
3	Auto-replenishment using ERP or other tools	
	15. Additive Manufacturing	
1	AM is limited to the production of prototypes	Weller et al. (2015)
2	AM is used to produce sub-components only	
3	AM is used to produce final products	
	16. Autonomous lines	
1	When the line achieves at least 3/7 benefits mentioned	Balogun and Popplewell (1999)
2	When the line achieves at least 5/7 benefits mentioned	
3	When the line achieves all 7/7 benefits mentioned	
	17. Energy efficiency monitoring	
1	The machines have energy meters for gauging usage	Song et al.

2	A central monitor can provide a view of all machines	(2017)
3	Consumption rates are incorporated into the ERP	
	18. Energy efficiency improvement	
1	Manual planning is done considering the energy factor	Song et al. (2017)
2	Sort rules are used to support production planning	
3	Optimised algorithms are used for production planning	

2.4 Smart Product

Smart product refers to the capability of producing a product that can be considered smart. Porter and Heppelman (2016) mention the aspects of Smart Products as (i) Connectivity, (ii) Monitoring, (iii) Control, (iv) Optimisation, and (v) Autonomy. Maturity levels can be determined using Table 4.

Table 4. Smart Product maturity levels

Smart Product		
Level	**Criteria**	**Papers Referred**
	1. Product Connectivity	
1	One-to-One connectivity feature	Porter & Heppelmann (2014)
2	One-to-Many connectivity feature	
3	Many-To-Many connectivity feature	
	2. Product Monitoring	
1	Can monitor anyone out of the product's condition/external environment/usage	Porter & Heppelmann (2014)
2	Can monitor any two out of the product's condition/external environment/usage	
3	Can monitor the product's condition, external environment, and the usage	
	3. Product Control	
1	Allow product function control through software	Porter & Heppelmann (2014)
2	Remote control without contacting the product enabled	
3	Can also allow customisation of UI	
	4. Product Optimisation	
1	The product can self-monitor if it is performing below maximum optimisation	Porter & Heppelmann (2014)
2	The product can suggest the reason for low performance	
3	Product autonomously optimises itself	
	5. Product Autonomy	
1	Automatic Product operation	Porter & Heppelmann (2014)
2	Self-coordination with other entities in the system	
3	Self-diagnosis and service	

3. Analysis

Industry 4.0 can be broadly classified into four aspects or dimensions. Each dimension of Industry 4.0 is divided into multiple technologies as seen in Section 2, and Tables 1, 2, 3, 4. There are 3 maturity levels provided for each of these technologies based on the literature found in papers cited.

To achieve any level of technology, the requirements for the previous maturity levels of the same technology must be fulfilled in order. This can be used to evaluate any company based on each of these technologies. An average of maturity levels of all technologies under a particular dimension can be calculated to find the score on that particular dimension.

4. Numerical Illustration

For a numerical illustration purpose for the proposed framework, an automobile manufacturer (OEM). Kindly note that this is a simulation scenario for the demonstration of concept and not an actual study. The OEM considered is looking to source a new-age electronic control unit (ECU) and has received quotations from two suppliers. The OEM can now conduct an audit of the two suppliers (S1 & S2), and itself (OEM) regarding the enabling technologies of I4.0 to understand the maturity levels. The results of this evaluation can be seen in Table 5 to 8, where each of the technologies is rated between maturity levels 0 to 3. After that, the averages are calculated.

Table 5. Smart Supply Chain Maturity Evaluation

SN	Technology	OEM	S1	S2
1.1	Supplier Management	3	2	2
1.2	Customer Management	3	2	3
1.3	Other Stakeholders	2	0	1
	Average	2.67	1.33	2

Table 6. Smart Working Maturity Evaluation

SN	Technology	OEM	S1	S2
2.1	Remote Monitoring of Production	2	1	1
2.2	Remote Operation of Production	1	0	0
2.3	Collaborative Robots	0	0	0
2.4	AR and VR for Product Dev	1	0	1
2.5	AR for Maintenance	0	0	0
2.6	VR for working training	1	1	0
	Average	0.83	0.33	0.33

Table 7. Smart Manufacturing Maturity Evaluation

SN	Technology	OEM	S1	S2
3.1	PLC Control	3	2	2
3.2	ERP	2	2	2
3.3	M2M – Vertical Integration	0	0	0
3.4	Manufacturing Execution System	2	1	1
3.5	Supervisory Control (SCADA)	0	0	0
3.6	Virtual Commissioning	1	0	1
3.7	Process Simulation	2	1	1
3.8	AI for Predictive Maintenance	1	0	1
3.9	AI for Planning of Production	2	1	0
3.10	M2M – Automation	0	1	0
3.11	Robots	1	2	1
3.12	Auto nonconformities identification	3	3	3
3.13	Traceability of Raw Materials	2	1	1
3.14	Traceability of Final Products	0	2	1
3.15	Additive Manufacturing	0	0	0
3.16	Autonomous lines	3	2	1
3.17	Energy efficiency monitoring	2	0	0
3.18	Energy efficiency improvement	1	0	0
	Average	1.39	1	0.83

Table 8. Smart Product Maturity Evaluation

SN	Technology	OEM	S1	S2
4.1	Product Connectivity	1	0	0
4.2	Product Monitoring	2	1	1
4.3	Product Control	3	1	1
4.4	Product Optimisation	2	1	1
4.5	Product Autonomy	0	0	0
	Average	1.6	0.6	0.6

Further Analytical Hierarchy Process (AHP) is conducted with the four criteria being Smart Supply Chain (SSC), Smart Working (SW), Smart Manufacturing (SM) and Smart Product (SP) to find a consolidated score. The pairwise comparison is shown in Table 9. The resulting priorities & decision matrix are shown in Tables 10 & 11.

Table 9. Pairwise Comparison

Criteria 1	Criteria 2	AHP Scale
SSC	SW	3
SSC	SM	1/3
SSC	SP	9
SW	SM.	1/3
SW	SP	7
SM.	SP	9

Table 10. Priorities

	Priority	Rank
SSC	29.4%	2
SW	15.8%	3
SM	51.4%	1
SP	3.5%	4

Table 11. Decision Matrix

	SSC	SW	SM	SP
SSC	1	3	0.33	9
SW	0.33	1	0.33	7
SM	3	3	1	9
SP	0.11	0.14	0.11	1

The Consistency Ratio is 9%, which is acceptable (<10%).

Table 10 provides the weightage for each Industry 4.0 driver based on the pairwise comparison. This needs to be multiplied by the respective driver-wise averages of each entity in Tables 5, 6, 7, 8. By adding the multiplied products, we can calculate an overall score. This final step is seen in Table 12.

Overall Industry 4.0 Maturity Score = (Average maturity level of SSC Dimension * SSC Priority)
+ (Average maturity level of SW Dimension * SW Priority)
+ (Average maturity level of SM Dimension * SM Priority)
+ (Average maturity level of SP Dimension * SP Priority)

Table 12. Overall Maturity Level

	Weightage	OEM	S1	S2
Smart Supply Chain	0.294	0.785	0.391	0.588
Smart Working	0.158	0.131	0.052	0.052
Smart Manufacturing	0.514	0.714	0.514	0.427
Smart Product	0.035	0.056	0.021	0.021
Total	**1**	**1.687**	**0.978**	**1.088**

6. Discussion and Conclusion

It can be observed that supplier S2 has a higher maturity level as compared to S1, which can help the manufacturer in selecting S2 if they require a supplier with a higher I4.0 maturity level.

The proposed framework is useful to determine the implementation level of Industry 4.0 across all partners of the supply chain. It enables a holistic evaluation across the dimensions viz. smart supply chain, smart working, smart manufacturing, and smart product. Besides, AHP is used for the prioritisation of the identified dimensions, which helps in arriving at a final score. This framework not only helps in the calculation of maturity of Industry 4.0 implementation at supply chain partners but also for the selection of suppliers with the optimum maturity in Industry 4.0.

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