Developing Internet of Things Maturity Model (IoT-MM) for Manufacturing

Loveleen Gaur, Ravi Ramakrishnan

Abstract: The Manufacturing sector in India is still not globally competitive (Deloitte, 2018) due to over emphasis on labour based production, legacy manufacturing assets and production plants, energy inefficient systems, usage of Information Technology to integrate the physical and cyber world for potential benefits which other countries have adopted (Rockstorm, 2018) is almost non-existent. According to sources adoption of IoT enabled Industry 4.0 can lead to decrease of production costs by up to 30%, logistics costs by 30% and quality management costs by up to 20% (Thomas, 2016).

This study starts with a literature review of the factors that determine the manufacturing competitiveness index of India and how other developed countries are proceeding in these as compared to India. The study proceeds with identification of key determinants or constructs (abstract dimensions) of measuring the IoT maturity of any organization along with their relative weights and then identify the key factors (measurable) inside each construct. These constructs are hypothesized to be the building blocks of any IoT strategy to be adopted by Indian manufacturing concerns. By using these constructs definition, along with factors and possible measurable states, in which the factors can exist, an excel based IoT Maturity Self-Assessment tool has been developed which can be used by target Indian manufacturing organizations to identify their current state of preparedness.

The objective of this study is to define an Internet of Things Maturity Model (IoT-MM) which can be used by organizations to assess their current status. Indian manufacturing has started adopting IoT but in a disoriented manner, with adoption being guided more by technology consideration than a holistic business drive and consideration encompassing the benefits of productivity, energy conservation and environmental management.

Keywords: Internet of Things, Internet of Things Maturity Model, IoT, Manufacturing, Industry 4.0

I. INTRODUCTION

There have been rapid and profound advancements in industry, technology and applications, as a result of which many concepts have emerged in manufacturing prominently, Industry 4.0 which is a new revolution. These technological developments will alter our lifestyle, workstyle and will bring in unprecedented transformation in the way companies conduct business. This fourth revolution is not considered an extension to the earlier ICT revolution, because of its exponential evolution as compared to previous linear trends observed earlier and the velocity, scope and impact in systems and processes. The achievement criteria of Industry 4.0 is still uncertain in Indian context including the technology roadmap.

Businesses in India are still struggling to get a full overview of what Internet of Things and Industry 4.0 is (Kumaran, 2015) and how it can really deliver business value in a country like India where penetration of Information Technology is limited to transactional and compliance systems only (Berhert, 2016). Industry 4.0 is primarily driven by the adoption of IoT technologies in difference facets such as assets, products or for customer facing operations.

Diety, Ministry of Information Technology, Government of India has drafted a master plan for IoT adoption and introduction in the Indian context and develop IoT based industries. As per the report IoT industry is expected to evolve to USD 15 billion by 2020 in all possible business domains with focus in areas of Smart cities and supply chain. “Industrial IoT” as compared to “consumer IoT” has its own set of unique challenges including the volume of data generated from machines, heterogeneity of objects and their data interactions required between the machines in the supply chain, further the environment experienced by Industrial deployments are highly corrosive, submerged in liquids, explosive and combustible. Industrial IoT systems must be scalable for hundreds of endpoints and midpoints and are spread over thousands of meters thereby they require hardware that can perform analytics and device level and transfer aggregated information more than raw data.

This research work contributes to existing literature in IoT adoption both in theory and practice and provides insights to manufacturing concerns relating to adoption of IoT technologies in their business processes.

Objectives

1. To identify the factors that determine the manufacturing competitiveness index of India.
2. To identify the key determinants or constructs (abstract dimensions) of measuring the IoT maturity of any organization along with their relative weights and then identify the key factors (measurable) inside each construct.
3. The main objective of this study is to define an Internet of Things Maturity Model (IoT-MM) which can be used by organizations to assess their current status.

II. REVIEW CRITERIA

Industry 4.0 will be marked by several major digital innovations sensors, cloud, robotics, AI, sensors, cloud, 3d printing embedding all in a interoperable supply chain which can be used in a shared services model (Reinhard, 2017).
This isolated development will only result in some companies who can invest in technology having extremely efficient supply chains while their vendors and customers in the supply chain will have inefficiency and delays (Christopher, 1998) (Pettersson, 2008).

Some authors have tried to define a criterion for achieving Industry 4.0 along with the technology roadmap (Jian Qina, 2016) while some have proposed how it would be necessary to sustain and create out industrial value in products leading to sustainable manufacturing using the ubiquitous information and communication technology (ICT) infrastructure (T. Stock, 2016). Kolberh and Zuhelke (2015) have added the third most important dimension of bringing efficiency in supply chain and manufacturing operation using “Lean Automation” which is a combination of Lean Production (Ôno, 1988) and Production Automation techniques. Lean Production contributes faster reaction, on changing market demands, applying the concepts of smaller batches and transparent plus standardized processes to mass and batch production (Womack, 2007) (Ôno, 1988).

As per a Grant Thornton (Grant Thornton and CII, 2017) report India ranks a poor 91 in the Networked Readiness Index 2016 (World Economic Forum) despite political and regulation framework improvements. This is because other countries are moving ahead faster and lack of infrastructure, low skill levels has created a deeper divide.

Ducker Worldwide ( DUCKER Worldwide, 2014) in its report titled “Manufacturing in India” shows that India is now starting to move away from Agro based traditional manufacturing to high precision-tools aided by the increasing sophistication of the workforce , embracing new technologies , adopting automated and intelligent machines and the advent of foreign technology and investments in India.

As per Ministry of Economics (2015), Indian Manufacturing sector could grow to $1 trillion by 2025 or a six fold growth from present, however today as per Academic Foundation report (Academic Foundation, January 2008) 45 million jobs or 80% of the workforce is employed in the unorganized sector or small enterprises. The share of micro and small enterprises in manufacturing employment is 84% for India versus 27.5% for Malaysia and 24.8% for China (Exim Bank, 2013).

Adoption of IoT in Indian context challenges has been discussed comprehensively using MCDM techniques in an earlier literature (Luthra, 2018). Predominant are high project cost issues (Granjal, 2015), talent issues (Bedekar, 2017 ), issues with security (Gubbi, 2014) and privacy (Whitmore, 2015), business model challenges (Whitmore, 2015) , infrastructure challenges (Botta, 2016) , lack of standards (Al-Fuqaha, 2015) and internet connectivity issues (Bedekar, 2017 ).

There are two distinct applications of IoT namely in domestic and industrial usage. Industrial internet of things refers to the following four dimensions: Connected Manufacturing, IoT enabled products, robotics-controlled operations and monitoring and control systems for non-core operations. Powered by ubiquitous computing and connectivity, heterogeneous devices with proprietary protocols are getting integrated using common set of standards to provide automated solutions. Initially RFID based solutions were deployed as part of IoT solutions but they faced inherent challenges in terms of range and data transmission capability (Atzori L, 2010) (Miorandi D, 2012). Industrial IoT has significant benefits such as improving employee’s safety, increasing productivity and enhancing efficiency of operations (Hung, 2017).

Application of IIoT must be prefaced by proper understanding of the business domain problem, agreement on business objectives, creation of a roadmap and having strategic vision and intent.

### III. METHODOLOGY

The support for this research methodology comes from Becker’s step by step model (Becker, 2009) which shows a procedural model for the design of maturity models. Our aim is to improve the Manufacturing competitiveness of Indian manufacturing organizations and innovative IoT (IT systems) offer good opportunities to improve a company’s competitiveness (Henderson JC, 1993).

<table>
<thead>
<tr>
<th>Becker’s Criterion</th>
<th>New IoT-Maturity Model for Indian Manufacturing organizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1- Comparison</td>
<td>Analysis of existing but limitation-prone IoT Maturity Models</td>
</tr>
<tr>
<td>R2- Iterative</td>
<td>Stage1 − Constructs , Stage 2 − Variables , Stage 3 − Observation</td>
</tr>
<tr>
<td>R3- Evaluation</td>
<td>Validation of major constructs from industrial data</td>
</tr>
<tr>
<td>R4- Multi Method</td>
<td>AHP , Interviews and Observations, Delphi Method Expert Survey</td>
</tr>
<tr>
<td>R5- Relevance</td>
<td>Needed to improve the Manufacturing Competitiveness Index − India</td>
</tr>
<tr>
<td>R6- Defined Problem</td>
<td>Classification of Indian Manufacturers based on IoT maturity</td>
</tr>
<tr>
<td>R7- Target</td>
<td>Web Page for tool based self-assessment</td>
</tr>
</tbody>
</table>

Becker’s 8 step procedural model is covered for our proposed model in the following matrix.
Table 2: Existing Maturity Models for IoT

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Promoted By</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPULS – Industries 4.0 Readiness (2015)</td>
<td>VDMA, RWTH Aachen, IW Consult</td>
<td>6 Dimensions, 18 Items , 5 Levels</td>
</tr>
<tr>
<td>Empowered and Implementation Strategy for Industry 4.0 (G. Lanza, 2016)</td>
<td>Lanza et al.</td>
<td>Process Model for Industry 4.0</td>
</tr>
<tr>
<td>Industry 4.0 / Digital Operations Self-Assessment (2016)</td>
<td>PricewaterhouseCoopers</td>
<td>6 Dimensions , 4 Levels</td>
</tr>
<tr>
<td>The Connected Enterprise Maturity Model (2014)</td>
<td>Rockwell Automation</td>
<td>5 Stage Approach , 4 Dimensions</td>
</tr>
</tbody>
</table>

Step 1: Identifying the determinants of manufacturing competitiveness and the factors affecting IoT adoption in an enterprise using existing models.

Step 2: Assigning weights and ranks to these factors using Analytical hierarchy Processing (AHP)

Identification of the factors which are necessary from the technology prospect and process prospect to adopt Industry 4.0 in the previous section need to be validated by experts. The AHP analysis by 10 experts aware of all the constructs helped rank them with percentage weight using pairwise comparison.

Step 3: Identifying the measurable variables inside each construct, the top five to form a tool for measurement of the maturity.

This was done using Delphi interviews surveys with 15 experts, an initial list of variables against each construct was shared with them and open questionnaire was given to help them add more variables they felt was relevant. They were required to give a one-line justification of why it was required. Once the replies were received the list was consolidated from all participants and send back to each participant to allow them to rank the top 5 variables. Once the ranked variables were received a group ranking was derived and a consolidated list was shared with each respondent showing his ranking and the group ranking allowing them to revise their individual rankings to suit the group rankings. This iteration was done three times till the final list of to 5 variables were prepared.

Table 3: Independence of Constructs

Table 4: Expert Opinion on Constructs

Table 5: Coding of Variable of Constructs

Step 1: Identifying the constructs or abstracts listed above which influence IoT adoption in any organization. This is done from existing models and highlights a set of 9 constructs namely Strategy, Machine Data, Assets, Products, Process, IT Landscape, People and Financial feasibility.

The study was done by sending an online AHP Template for pairwise factor comparison to experts (Haller, 1996). Ratings from 1 (Equal) to 9 was done by the experts on the online template. Mean was calculated based on equal weights for all the experts and the mean value was entered in the AHP template (Saaty, 2008). Had shown that a consistency ratio (Jiří, 2014) of 0.10 or less is acceptable to continue the AHP analysis.
Developing Internet of Things Maturity Model (IoT-MM) for Manufacturing

Table 6: Variable wise construct wise rank and total score

<table>
<thead>
<tr>
<th>Construct</th>
<th>IoT Enabled Assets</th>
<th>IoT Enabled Products</th>
<th>IoT Aware People</th>
<th>Financial Feasibility of IoT Products</th>
<th>IoT Technology Maturity</th>
<th>IoT Oriented Strategy</th>
<th>IoT Capable Process</th>
<th>IoT Compatible IT Systems Maturity</th>
<th>IoT Machine Data Capable Analytics and Use Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Score</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

The above has identified that the different measures so obtained using Delphi methods are now ranked using experts, these ranks and total scores will be used later in the calculations to arrive at the maturity rating of an organization and incorporated in the excel tool.

Step 4: Validation and Reliability of Tool

It is pertinent to understand here that being a direct collection of data some conditions have been ensured to provide authentic research. Especially important is the term validity and reliability. Validity refers to what extent the study is a reflection of the actual reality (Bloor & Wood, 2006) and it is of utmost importance to ensure validity and reliability (Voss, Tsikriktsis, & Frohlich, 2002). Validity has to be ensured also during the time or participant selection and interview and observations (Patel & Davidson, 2011). Internal Validity of research which deals with whether the results are answering the original question (Quinton et al, 2006:126 127), whether interviews are conducted in the right way (Gibbert, Ruigrok, & Wicki, 2008) and external validity relating to the applicability of the results in other context or situation (Voss, Tsikriktsis, & Frohlich, 2002). The reliability of the research comes by the ability to repeat the research process and results. In our research reliability and validity is ensured by having authentic data sources, ensuring data collection quality and using multiple data sources such as surveys and questionnaires.

To ensure further validity of study a Triangulation method has been applied using three methods to gather data namely – Interviews, Observations and system production data. Observations exclude personal bias of the interviewees (Yin, 2013) and system data is accurate since it is used for MIS and is internally audited by the company. The Interviews and Observations have been held on different days and different times and with multiple set of participants.

Step 5: Preparation and Testing of the excel tool and preparing the Maturity Model

Finally at the end of the earlier process of gathering inputs form experts including construct identification affecting IoT maturity, the key 5 variables inside each construct and for each variable the 5 stages of possible existence obtained by case study method we have developed an excel tool using the above three factors.

The following equation states the maturity assessment function implemented by the tool:

\[ f(\text{maturity}) = f(\text{constructs}, \text{variables}, \text{current state of variables}) \]

Where

- Maturity is the index of maturity or value,
- constructs refer to the 9 constructs identified,
- While the state of variables are the 5 possible stages of each variables.

\[ f(\text{constructs}) = f(\text{adaptation}) \ast f(\text{weights}) \]

- Adoption is 0- No adoption, 1 – Work in Progress and 2 is successful implementation and results.
- Constructs are IoT enabled Assets, IoT enabled Products, IoT aware people, financial feasibility of IoT products, IoT Technology maturity, and IoT oriented strategy, IoT capable process, IoT compatible IT systems maturity, IoT Machine Data capable analytics and use cases.
- Weights are the ones derived for each construct from earlier AHP study

\[ f(\text{variables}) = f(\text{current state}) \ast f(\text{weights var}) \]

- Variables are the 5 identified for each construct
- Weights are dependent on the possible states of each variable

The sample excel prototype is attached below: -

![Figure 2 IoT Maturity Model Assessment tool in excel](image-url)
- IoT Financial Feasibility Score- The financial use case and incentive for an organization to adopt IoT.
- IoT Product Score- The IoT enablement score of end products.
- IoT Technology Maturity Score- The extent of maturity of the IoT technology stack as explained by successful pilot and field trials and production runs.
- IoT Take-up Score- The weighted mean of taking up IoT products in all the constructs taken together.

c. Field Test of Maturity Assessment Tool

The IoT-Maturity Model can be done for any organization across 9 constructs – Assets(IoT enablement), Products(IoT enablement), Financial Feasibility (IoT enablement) , Process Improvement (IoT enablement), IT Landscape(existing), Machine Data (generated by IoT enablement),People (IoT Skill Sets) , Strategy (IoT adoption), Technology (IoT related). Any organization can be ranked on above constructs in 5 tiers – Startup, Traditional Maturity, IoT Stable, IoT Evolving, and IoT Champions.

<table>
<thead>
<tr>
<th>Organization Profile</th>
<th>IoT MM values and observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leading Agro Manufacturing company</td>
<td>The company has yet to move towards stability in the traditional aspects be it traditional IT – ERP/CRM/ DMS/ HCM and has not yet started any projects in IoT. The IoT take-up score was hence zero. In terms of Maturity the ratings were more or less 1 in all the measurable variables and hence the firm was given a rank of “L1” or “Starter”. This is the lowest slab which can be achieved under the IoT-MM tool.</td>
</tr>
<tr>
<td>Leading Telecom equipment manufacturing company</td>
<td>The telecom organization has developed state of the art connected equipment’s which are entirely digital and the physical value share is less than the digital value. The high end products are IoT enabled for fault sensing and reporting while the manufacturing lines are also highly connected assets. People are well versed with latest technology trends while the financial model is justified with revenue share from digital. However the Machine data usage is limited to reporting and not analytics. Process are well defined to incorporate machines in between people. The firm has got a rank of “L4” or “IoT-Advanced” which is the fourth highest level.</td>
</tr>
<tr>
<td>Tea Coffee and other vending machine assembler</td>
<td>The firm though smaller in size but has advanced its end product capabilities by incorporating IoT to transmit data from its product in terms of usage and performance parameters , providing digital value add like online billing and error reporting. The financial feasibility is ensured while the assembly line assets also have IoT enablement. The firm has got a rank of “L3” or “IoT- Stable”.</td>
</tr>
<tr>
<td>Leading chemical manufacturer</td>
<td>The firm has reached maturity in traditional IT, has assets and products which can be IoT enabled and have robust upgrade roadmap. The people and management have shown keenness in adopting IoT in the long term and also a financial feasibility exists. Process such as learn manufacturing, supply chain planning are in place but primarily human driven. The firm has been given a rating of “L2” or “Traditionally Mature” which is the second rating in the chain.</td>
</tr>
<tr>
<td>Leading engineering products manufacturer</td>
<td>The firm produces engineered machines with a high degree of IoT components inbuilt. The asset lines are also IoT enabled with ongoing upgrade work happening. The people are IoT aware, the financial profitability comes from the IoT enabled business model and process are tailor made to include man and machine. The ratings are of “L4” or “IoT – Advanced”.</td>
</tr>
<tr>
<td>Leading IT Hardware manufacturer</td>
<td>This high end developer of network switches and components has a strong automated asset like with high degree of cohesion and connectivity for data transmission. The assembly lines are driven by highly coordinated and digitally driven , synchronized robotic arms with minimal human intervention , even quality checks are performed digitally, products are sensor enabled to check for optimum operating environments. The people and strategy is fully IoT focused and candidate has been adopted in a big way successfully. The firm has a rating of “L5” or “IoT Mature”</td>
</tr>
</tbody>
</table>

Figure 3: IoT Maturity Model with Constructs

Now that the IoT Maturity Assessment model in excel is prepared it was put to test in 10 different organizations with the following results:
Developing Internet of Things Maturity Model (IoT-MM) for Manufacturing

<table>
<thead>
<tr>
<th>Leading Polyester manufacturer</th>
<th>The firm has a strong traditional IT, is process driven but primarily physical product driven profitability is there. The IoT technology seems immature to enable the products though at asset level IoT upgrade is feasible but requires investment. The firm is placed at L2 since the projects are yet to succeed.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leading manufacturer of wood and pulp/paper</td>
<td>The firm again is in between the L1 and L2 stage, however given the shorter and aggressive roadmap for Industry 4 adoption and ongoing modernization plans, they have been kept in the “L2” slab after thorough analysis.</td>
</tr>
</tbody>
</table>

**FIGURE 4 IOT PROGRESSION ROADMAP WITH ATTRIBUTES**

IV. CONCLUSION

IoT in the Manufacturing sector can be a huge boon in India where scarcity of resources and infrastructure problems are resulting in low competitiveness when it comes to global standards. With growing concerns on energy management, environmental safety and compliances and productivity concerns, use of IoT in manufacturing has been increasing in the last few years. However there are challenges since manufacturing systems have been solely designed with the aim of increasing production and not keeping data storage, transfer or processing design considerations, as a result they have low memory footprints, closed protocols and proprietary data formats with no built in error-detection, correction or deduplication checks built in. The lower level of Manufacturing Competitiveness index of India can be improved with the adoption of IoT and move towards Industry 4 adoption. This Model is not company or sector specific and organization can first assess their current position construct wise and proceed from that point onwards.

V. REFERENCES

AUTHORS PROFILE

Dr Loveleen Gaur, PhD, M.Phil, MCA, PGDCA. Authored “Internet of Things: Approach and Applicability in Manufacturing” with Taylor and Francis. Prof. Gaur has significantly contributed to enhancing scientific understanding by participating in over three hundred scientific conferences, symposia and seminars, by chairing technical sessions and delivering plenary and invited talks. She has specialized in the fields of Information Sciences IoT, Data Analytics, E-commerce and E-Business, Data Mining, and Business Intelligence. Prof. Gaur pursued research in truly inter-disciplinary areas and published about 6 Books and more than 60 research papers in referred Journals. Prof. Gaur holds various prestigious positions in India and Abroad as a member of Area Advisory Board of Various Business Institutions in India and Abroad, Board of Studies (BOS) and IQAC (Quality) team and member of Student Research Committee (SRC) and Department Research Committee (DRC).

Ravi Ramakrishnan is an MBA from Faculty of Management Studies Delhi University and has further done a Post Graduate Diploma from AIMA in IT systems ,DOEACC A level certified and a Post Graduate Diploma in Operations Management from IGNOU after a Bachelors in Science. He is a Prince 2 certified professional, Microsoft Certified Professional and a Oracle Certified professional and has 20+ years of global experience and is an award winning Global CIO with a strong technical and managerial background and has done numerous global rollouts of Enterprise Information Systems – ERP/CRM/BI and M2M/Mobility and IoT solutions which have been widely acknowledged and awarded in different forums. He is currently pursuing his Doctorate in Information Technology Management with focus on IoT strategies and technologies and has published papers on IoT in Springer and IEEEXplore and book chapter on IoT in IGI Global. He is a Senior IEEE member and has implemented projects in US/Europe/Asia/Africa/Middle East across multiple cultures , industry domain verticals and technologies. His global awards include Computerworld Global 100 CIO honoree (Florida), IDG – CIO 100 India Award winner consecutively 2011,2013,2014,2015 , IDC – CIO 100 award winner 2014,2015 , Dataquest CIO award winner in Mobility and IoT categories ,Chief Information Security award winner CISO 2013,2014 , Oracle Best Implementation award winner 2016 , Innovative CIO award winner 2015,2016 , C-Change Awards CIOL 2015 ,Business World CIO 3.0 award winner 2016 , Information Week CIO and Business Impact Leader award 2015 and Information Week Edge Award 2014.