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, lesser automation, 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).

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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 (Ōno, 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) (Ōno, 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 work force , 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 1 BECKER'S 7 STEP CRITERION FOR MATURITY MODELS

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

Becker's 8 step procedural model is covered for our proposed model in the following matrix.

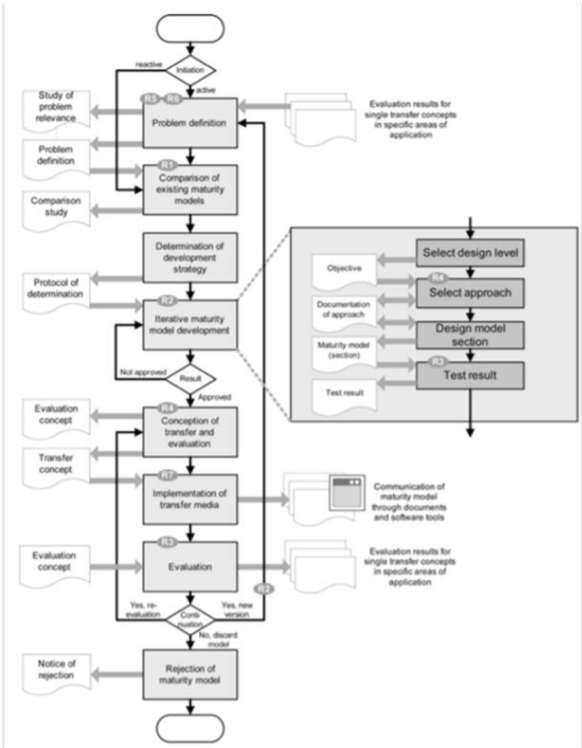

FIGURE 1 BECKER'S PROCEDURAL MODEL FOR MATURITY MODEL PREPARATION

TABLE 2 EXISTING MATURITY MODELS FOR IOT

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

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

Identifying 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.

Table 3: Independence of Constructs

CONSTRUCTS	IoT Enabled Asset	IoT Enabled Product	IoT Technology Maturity	IoT Compatible IT	IoT Skilled People	IoT compliant Process	IoT oriented Strategy	IoT Data	IoT Financial Feasibility
IoT Enabled Asset	X	Can happen independently	Can happen independently, accuracy matters	IT needed for storage, compute but independent	Independent	Independent	Can be independent if its part of OEM offering and not our demand	Asset Enablement and use of that data can still be exclusive	Feasibility may/ may not be dependent if mandated
IoT Enabled Product		X	Dependent , however if ignore accuracy then can be independent	Independent	Independent Totally	Independent totally	Dependent but can be a follower adoption	Can be exclusive	May not be dependent if mandated by law
IoT Technology Maturity			X	Independent	Independent	Independent	Can go for strategy even without maturity as early adopters	Independent	Independent
IoT compliant IT landscape				X	Independent	Independent	Independent may be because of natural IT progression	If data needs not be analyzed then IT may not be required	Independent if part of all IT offerings by vendors
IoT Skilled People					X	People and Process may be dependent but people not trained may still follow process	Skilling people may be part of strategy but not vice versa	Independent	Independent
IoT compliant Process						X	Overlap possible but strategy is more encompassing	Independent	Independent , process may be mandated by third parties , audits
IoT oriented Strategy							X	While data and analytics may be part of strategy but not vice versa	Strategy may be driven by finances
IoT Data								X	Independent
IoT Financial Feasibility									X

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.

Table 4: Expert Opinion on Contructs

Expert/ Participant	People	Process	Data	Assets	Product	Strategy	Financial	IT	Sensor Technology
1	Y	Y	Y	Y	Y	Y	Y	Y	Y
2	Y	Y	Y	Y	Y	Y	Y	Y	Y
3	N	Y	Y	Y	Y	Y	Y	Y	Y
4	Y	Y	Y	Y	Y	Y	Y	Y	Y
5	N	Y	Y	Y	Y	Y	Y	Y	N
6	Y	Y	Y	Y	Y	Y	Y	Y	Y
7	Y	Y	Y	Y	Y	Y	Y	Y	Y
8	Y	Y	Y	Y	Y	Y	Y	Y	Y
9	N	Y	Y	Y	N	Y	Y	Y	Y
10	Y	Y	Y	Y	Y	Y	Y	Y	Y

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 5: Coding of Variable of Constructs

Construct	Variable	Variable	Variable	Variable	Variable
Strategy	New Business Models (SNBM)	Regulatory Compliances (SRCM)	Innovation Management (SINM)	Collaborative development (SCOD)	Digital Market & Access channels (SDMA)
Data	Economic Value (DEVA)	Data Driven Services (DDDS)	Data Share of Revenues (DDSR)	Share of Data getting used (DSDU)	Analytics for predictive and preventive (DAPP)
IT	Team Skills , Quality , Timelines (ITSQ)	IT Integration with other value chain participants (IIVP)	IoT ready IT and Data architecture (IITD)	IT systems , applications , network traditional maturity (IAPN)	Extent of digitsation – vertical and horizontal (IDVH)
Process	Existing process maturity (PEPM)	Productivity improvement (PPRM)	Process driven innovation (PPDI)	Autonomous Process (PAUP)	Ratio of Man – Machine as co actors (PRMM)
People	Perceived Usefulness (PPU)	Ease of use (PEU)	Employee skill sets (PESS)	Employee skill acquisition (P ESQ)	Senior Management vision and support and expertise (PSMV)
Assets	Nature of Assets (ANS)	Real Time track and trace (ARTT)	Real time accurate information (ARTA)	Identification and sensing capabilities (AISC)	Autonomous capabilities (AAC)
Products	Extent of customization ideal state desired lot size 1 (PECU)	Product Life cycle digitized – Idea to engineering (PPLC)	Digital to Physical services in product portfolio (PDTP)	Real time accurate information on usage , diagnostics (PRTI)	Capable of AI, Robotics and design advancements incorporation (PCAI)
Technology	Standardization (TSTD)	Sensing Layer – Cost , deployment , efficiency (TSLC)	Network layer – Management , energy , QoS (TNLM)	Service Layer – Discovery , API , Trust (TSLD)	IoT Design , Architecture and implementation (TIDA)
Financial	Cost Saving Potential (FCST)	Perceived Benefits- Profit , Sales , Service time (FPB)	Cash Flows – Profitability , Sales Value (FCFL)	Return on investment (FROI)	Investment Protection (FIP)

Table 6: Variable wise construct wise rank and total score

Construct	Var /Score/ Rank			Var /Score/ Rank			Var /Score/ Rank			Var /Score/ Rank			Var /Score/ Rank		
Strategy	SNBM	60	1	SRCM	18	5	SINM	27	3	SCOD	24	4	SDMA	30	2
Data	DEVA	33	2	DDDS	30	3	DDSR	27	4	DSDU	9	5	DAPP	36	1
IT	ITSQ	30	3	IIVP	24	4	IITD	36	1	IAPN	12	5	IDVH	33	2
Process	PEPM	36	1	PPRM	18	5	PPDI	27	3	PAUP	24	4	PRMM	30	2
People	PPU	39	2	PEU	15	5	PESS	42	1	PESQ	21	3	PSMV	18	4
Assets	ANS	18	5	ARTT	30	2	ARTA	39	1	AISC	21	4	AAC	27	3
Products	PECU	45	1	PPLC	27	3	PDTP	30	2	PRTI	15	5	PCAI	18	4
Technology	TSTD	27	3	TSLC	24	4	TNLM	30	2	TSLD	21	5	TIDA	33	1
Financial	FCST	42	1	FPB	36	2	FCFL	30	3	FROI	15	4	FIP	12	5

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

a. Maturity Assessment Tool

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:

$$f(maturity) = f(constructs, variables, current\ state\ of\ variables)$$

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.

$$f(constructs) = f(adoption) * f(weights)$$

- 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

$$f(variables) = f(current\ state) * f(weights\_var)$$

- 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:-

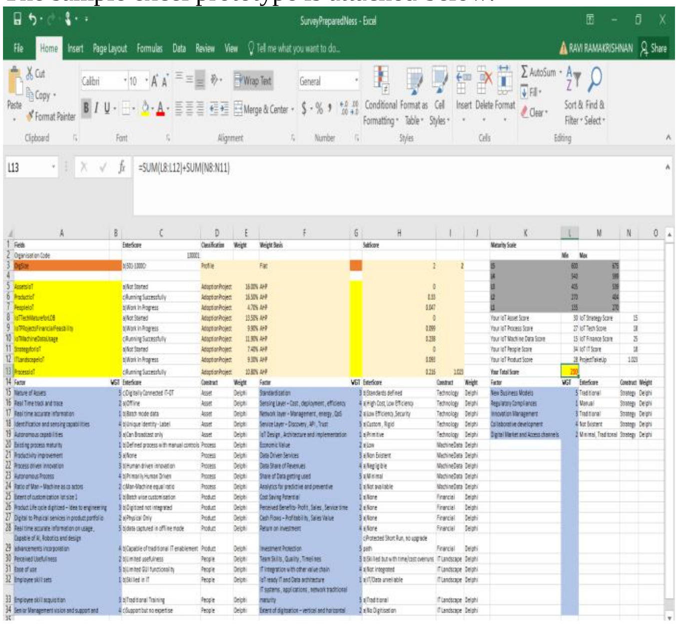

Figure 2 IoT Maturity Model Assessment tool in excel

b. The IoT maturity model has the following scores

- IoT Asset Score – This is the rating for adopting IoT enablement in production assets.
- IoT Process Score- This is the rating for implementing IoT enablement in process bringing efficiency or productivity with man –machine coexistence.
- IoT Strategy Score – This is the organizations overall IoT focused strategy score
- IoT Machine Data Score- This is the Machine data generated by IoT which is used for further analytics
- IoT People Score- The extent of awareness and skill of people
- IoT IT Score- The maturity of IT systems to take up IoT adoption

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- 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.

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:

Organization Profile	IoT MM values and observation
Leading Agro Manufacturing company	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.
Leading Telecom equipment manufacturing company	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.
Tea Coffee and other vending machine assembler	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".**
Leading chemical manufacturer	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.
Leading engineering products manufacturer	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".**
Leading IT Hardware manufacturer	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 I4 has been adopted in a big way successfully. The firm has a rating of "**L5" or "IoT Mature"**

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Leading Polyester manufacturer	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.
Leading manufacturer of wood and pulp/ paper	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.

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

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