Industry 4.0 Research: Information and Communication Technology Capability Index for Supply Chain Management

Prashant R. Nair, S. P. Anbuudayasankar, R. Kishore, and R. Pradeep

Abstract **Purpose**—The objective of this paper is to suggest methods to compute an effective Information and Communication Technology (ICT), Capability Index for Supply Chain Management (SCM) as part of assessment framework on ICT impact on SCM. The other part of this assessment framework is an empirical model based on SCOR level I performance indicators. This framework can be seamlessly dovetailed into the universally accepted and popular APICS Supply Chain Operations Reference (SCOR) model as its constructs are based on SCOR. The assessment framework will be a welcome addition to the Industry 4.0 research underway. **Design/methodology/approach**—Survey questionnaire was administered and collected from 200 + SCM professionals in sectors such as manufacturing, services, MSMEs, international companies as well as SCM/ERP professionals working as domain experts in IT and service companies. Snowball sampling was primarily used with the support of various industrial associations and professional body chapters. This questionnaire combines quantitative and qualitative inputs with adequate provision for open-ended questions with user input as a means of eliciting case interviews. After Confirmatory Factor Analysis (CFA) using SEM was employed to validate the empirical model, its performance indicators are ranked using AHP and the weights are ascertained. Computing the ICT Capability Index for SCM from the metrics of the assessment model is done using tools such as Balanced Scorecard (BSC) and Snorm De Boer standardized normalization (SNORM) method. **Findings**—An ICT capability index for SCM is computed based on user input with respect to the impact of ICT on the supply chain performance indicator as part of this framework using the methods of BSC & SNORM. 2 industry case studies are used

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for the computation and analysis of this index. **Research limitations/implications**—Discussion with an enterprise is needed to take input on the impact of ICT on each supply chain performance indicator in our calculation for the index. This investigation considers ICT deployment as the variable which encompasses the entire gamut of ICT tools and technologies. There could be different granular approaches to ICT as a variable. A scoring system, scale, and rubric are proposed to be evolved based on multiple case studies of various enterprises as an extension to this research work. There is tremendous scope to extend the investigation into SCOR level II metrics which are diagnostics of strategic metrics and level III metrics which are context or sector-specific and also considering various geographies. **Originality/value**–The managerial implications of this ICT Capability Index for SCM assumes greater significance as a result of the present situation due to Covid-19 pandemic, which has accelerated the need for Industry 4.0, digitalization and embracing of ICT not only for supply chain but also all aspects of the enterprise. There is also an identified lacuna in terms of performance scoring and assessment framework with respect to impact of ICT in SCM. The advantages of this index are that it is universal and can be used by any enterprise irrespective of the geography or country, vertical or domain, manufacturing or services. This index will provide insights to enterprises on their ICT capabilities and help them to further leverage ICT so as to adapt their organizations, digitize their operations and also benchmark with their peers and competitors. A scoring system and rubric is proposed to be evolved based on multiple case studies of various enterprises as an extension to this research work.

Keywords Supply Chain Management (SCM) · Information and Communication Technology (ICT) · Industry 4.0 · Capability Index · Balanced Scorecard (BSC) · Snorm De Boer standardized normalization (SNORM)

1 Introduction

Speedy technology advancements and ever-changing market dynamics have altered the enterprise landscape as fundamentally translated current business models. Information and Communication Technology (ICT) applications and deployment have unlocked the flood gates for all enterprises to compete in any marketplace. Enterprises from all geographies and verticals, manufacturing and services, profit and non-profit are exposed to the current-day challenges of larger competition, pricing pressures and global marketplace. These challenging settings are popularly referred to as VUCA short for *Volatility, Uncertainty, Complexity* and *Ambiguity* [1] *and have been further complicated by the worldwide web and* Information Superhighway. The following examples illustrate the power of innovation enabled through ICT:

- The largest car company globally is Uber, but fascinatingly Uber does not own any cars.
- The largest media company globally is Facebook, but interestingly Facebook does not create any content.

- The largest retailer globally is Alibaba, but amusingly, Alibaba does not own any malls or superstore

The deployment of cutting-edge ICT tools such as big data analytics, Internet of things (IoT), Cyber-Physical Systems (CPS), mobile apps, and the like are revolutionizing automation in enterprises. This wave dubbed Industry 4.0 is fast emerging as an inflection point in manufacturing and is being touted as the fourth industrial revolution. Interestingly, in today's interconnected world, it is not the companies that are competing, but their supply chains and stakeholder networks.

2 Industry 4.0

Industry 4.0 is the latest wave of computerization in manufacturing. This comprises cutting-edge ICT tools and technologies such as robotics, IoT, CPS, Artificial Intelligence (AI), machine learning, mobile apps, and cloud computing. This fosters what has been popularly referred to as a smart factory, fourth industrial revolution, and Industrial IoT (IIoT). Within modular smart factories, CPS monitor physical processes in all aspects such as manufacturing, supply chain, and logistics, creating a digital twin of the physical world and making distributed decisions. Over the IoT connectivity of physical assets, CPS collaborate and engage in dialogue with one other and with humans in real time. Both internal and cross-organizational services are provided and employed by various stakeholders [2]. Industry 4.0 seamlessly transforms the supply chain into a value chain (Fig. 1).

CPS consists of collaborating computational elements controlling physical objects, whose processes are seamlessly monitored, coordinated, controlled, and integrated. The resultant value chain thereby becomes more agile, collaborative, visible,

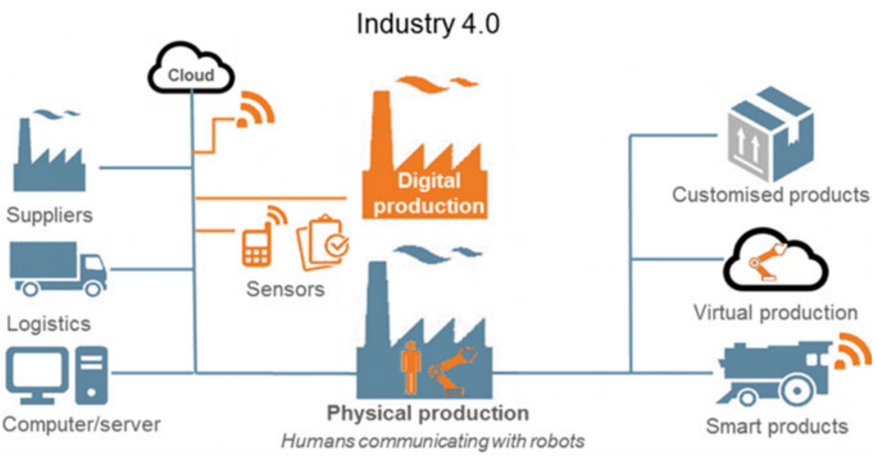

Fig. 1 Industry 4.0 constituents

and responsive. An example would be a totally connected and retooled supply chain, which can reconfigure itself on receipt of any new data point. If a weather delay ties up a shipment, a connected system can proactively adjust itself and modify manufacturing priorities bringing about perfect alignment between supply chain planning and execution. Digital technologies are transforming supply chain management from linear to circular models. This trend of transformation and reorganization of SCM due to the digital technologies of Industry 4.0 is also cited as Supply Chain 4.0 [3]. Industry 4.0 has rendered supply chains to be more transparent, visible, resilient, adaptable, and pro-active in decision-making. This is in terms of effective access to timely and actionable information as also communication, collaboration, and dialogue with various stakeholders. And this benefit has percolated to their partners and suppliers, who are connected to the enterprise through an extranet.

Adoption of Industry 4.0 technologies has become all the more relevant considering the fact that annual global supply chain losses run into billions of dollars. Cargo theft has resulted in loss of $ 23 billion dollars as per BSI in 2015. Three out of 4 companies have seen disruptions in their supply chains in 2015. A couple of years ago supply chain disruptions resulted in closure of almost 65% of 900 Kentucky Fried Chicken restaurants in England [3].

Industry 4.0 adoption and deployment are gathering steam. German manufacturing powerhouse, Siemens is executing an Industry 4.0 application in biomedical engineering for artificial knee and hip joints, which are standardized products needing high level of customization for patients. With industry 4.0 software tools, Siemens can produce an implant within 3–4 h. Predix, the Operating System for the Industrial IoT is the engine for enterprises in the new knowledge economy. Predix-based apps are unleashing new levels of performance for General Electric (GE) [3].

3 Motivation, Background and Relevance of the Research

This effectual investigation assumes greater significance as a result of the present situation due to Covid-19 pandemic, which has accelerated the need for Industry 4.0, digitalization and embracing of ICT not only for supply chain but also all aspects of the enterprise. Indices and metrics for measurement of ICT at an enterprise level or even at a national level are dime a dozen. The International Telecommunications Union (ITU), which is part of the United Nations has taken leadership and emerged as the primary source of global ICT and telecom statistics. One of the major metrics developed by ITU is ICT Development Index (IDI) used for ranking nations based on ICT readiness and digital divide with knowledge, social, or economic dimensions. Consequent to this, there are now 20 similar indices like ICT Diffusion Index by UNCTAD, Global Innovation Index by WIPO, and Networked Readiness Index by INSEAD-World Economic Forum (WEF) [4, 5]. On similar lines, there are metrics developed for industry. McKinsey Global Institute (MGI) has developed MGI India Firm Digitization Index, which shows how digitally advanced firms are pulling ahead of their peers and Country Digital Adoption Index [6]. The firm digitization index for India is built on digital strategies, organization, and capabilities and is a variant of the indices developed by MGI for US and European companies. Interesting insights from these indices and studies are that digital adoption by India's businesses has so farbeen uneven. Rather, ICT adoption is uneven not only across firms, but sectors and countries.

While most supply chain professionals from both academia and industry are in complete agreement of the reality that ICT conclusively impacts performance and fulfillment of the supply chain with many frameworks having been suggested, there is an identified lacuna in terms of performance scoring and assessment framework with respect to the impact of ICT in SCM [7]. Various factors that contribute to this gap in measurement include intangibility of measures in the knowledge economy [8, 9]; the dynamic nature of supply chains [10] and multiplicity of performance metrics [11]. In the latest release of SCOR Process Reference model version 11 by APICS [12], a new process addition is 'enable' processes largely concerned with collaboration and dialogue amongst various stakeholders like suppliers and partners in the enterprise, which are now primarily through ICT. But APICS does not have list any ICT metric. Nor does other SCM models like GSCF, balanced scorecard and benchmarking [7]. There is only a casual mention of ICT as a KPA in OPQR framework [13]. A recent study reinforces this position that a coherent picture or metric of ICT impact on SCM performance is not available [14, 15]. It is also observed that there is asymmetry and variability in ICT adoption for SCM across various sectors and companies [7].

The motivation of this investigation is to append an original addition to the existing knowledge archive in providing enterprises with a universal benchmark in form of an assessment framework on their ICT deployment in SCM and its dovetailing into Supply Chain Operations Reference (SCOR) model of the APICS professional body, which has 45,000 members. SCOR model is very popular and the de facto benchmark for process enhancement for SCM [3] with over 200 process elements, 550 measures, and 500 good practices [16, 17]. This assessment framework includes an empirical model and ICT capability index for SCM derived from performance constructs of the empirical model, which is built on SCOR Level I metrics. The managerial implications and benefits of the assessment framework will be discussed in later sections.

4 Research Methodology

To address this research problem, which is exploratory in nature, an assorted research method consisting of both descriptive and numerical means seemed appropriate considering the scope and nature of the research problem. A detailed survey questionnaire combines quantitative and qualitative inputs with adequate provision for open-ended questions with user input as a means of eliciting case interviews of ICT deployment for SCM in the enterprises as well as the quantitative inputs.

In a pilot phase, the survey questionnaire was administered to a cross section of supply chain professionals from industry and experts from academia. This includes both supply chain managers in manufacturing and services directly dealing in supply chain planning and execution as also professionals working on the automation side in ERP and software solutions for SCM. Initial feedback and respondents' point of view included insights such as respondent needs to be very well-versed in supply chain concepts and that almost 20 min are needed to fill the questionnaire. These inputs were factored in with the pilot phase contributing to face validity for the research instrument. Snowball sampling was employed and support for the survey was enlisted from industry associations and professional body chapters such as Indian Institute of Materials Management, MSME Development Institute (DI), CIO Forum of Computer Society of India (CSI), Institute for Supply Chain Management (ISM), Coimbatore District Small and Medium Scale industries association (CODISSIA) and Coimbatore Management Association (CMA), all of whom, have a large member and subscriber base. More than a thousand e-mails were sent using these good offices and networks.

An empirical model which is the first part of the assessment framework on impact of ICT in SCM is propounded based on the SCOR performance indicators details of which are provided in the next section. After getting a turnaround of 200 respondents, analysis using Structural Equation Modeling (SEM) method was used. These respondents were SCM professionals in sectors such as manufacturing, services, MSMEs, international companies as well as SCM/ERP professionals working as domain experts in IT and service companies. Confirmatory Factor Analysis (CFA) was used to validate this empirical model and the proposed supply chain performance constructs. After validation, using these supply chain performance indicators, the second part of the assessment framework, i.e., the ICT capability index for SCM is computed using 2methods, namely, Snorm De Boer standardized normalization (SNORM), Balanced Scorecard (BSC), and ranking of these constructs done using Analytic Hierarchy Process (AHP).

5 Empirical Model on ICT for SCM

The first part of the assessment framework is an empirical model for measurement of ICT impact in SCM based on SCOR model, which has been proposed and validated using Structural Equation Modeling (SEM). This model is based on exogenous latent variable & endogenous and latent & measured variables. Exogenous variables are independent and this investigation uses ICT Deployment, which refers to the entire gamut of ICT tools and technologies as the exogenous variable. In the next stage of research, different granular approaches to ICT deployment variable are proposed. Endogenous variables are dependent variables and are adopted from SCOR Level I metrics. As given below in Tables 1 and 5 latent endogenous factors and its 13 measurable endogenous factors are taken from SCOR to develop the empirical model of supply chain. These factors or variables are based on theoretical foundation [12]

Table 1 Endogenous latent and measured variables [12]

Endogenous latent variable	Endogenous measured variables
Reliability	Complete Delivery (CD) On-time Delivery (OD) Accurate Documentation (AD) No Damage (ND)
Responsiveness	Order Fulfillment Cycle Time (OCT)
Agility	Upside Supply Chain Flexibility (UPCA) Upside Supply Chain Adaptability (UPSA) Downside Supply Chain Adaptability (DSCA) Overall Value at Risk (Risk)
Costs	Total Cost to Serve (Cost)
Asset management efficiency	Cash to Cash Cycle Time (CCR) Return on Supply Chain Assets (RFA) Return on Working Capital (ROW)

and validated through expert opinion [7]. Variables list are given above in Table 1 and the validated empirical models are shown in Fig. 2. Here all λ are factor loadings, € & δ are measurement errors and γ are regression weights.

6 Computation of ICT Capability Index for SCM

The second part of the assessment framework, i.e., the ICT capability index for SCM is computed using the supply chain performance indicators from the validated empirical model and questionnaire responses. ICT Capability Index for SCM has the potential to serve as a universal benchmark for measuring of the impact, effectiveness, and benefits of ICT enablement in SCM. Based on the multiple indicators of ICT impact on SCM, this ICT Capability Index is one that requires Multi-Criteria Decision-Making (MCDM).

MCDM is used in addressing the real-world decision problems by using both qualitative and quantitative information. This is peeled down into a ranking of alternatives. Building on this, a tool that will help us rank the attributes would be helpful [18]. MCDM can also be used as an approach to pick the best alternative from the list of available alternatives [19]. Techniques to address MCDM include PCA, Data Envelopment Analysis (DEA), fuzzy methods, non-linear programming, ISM, TOPSIS, and Analytic Hierarchy Process (AHP) [20]. This research investigation has used two methods to compute the ICT Capability Index for SCM, namely, Snorm De Boer standardized normalization (SNORM), Balanced Scorecard (BSC), and ranking of these indicators is done using AHP.

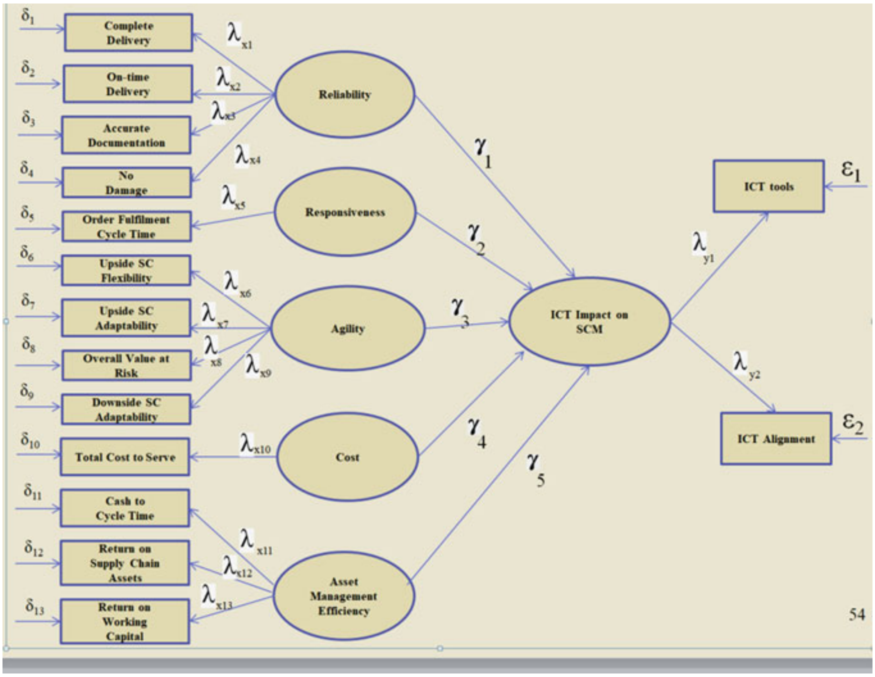

Fig. 2 Empirical model on benefits of ICT for SCM

6.1 *AHP Method for Ranking Indicators to Compute ICT Capability Index for SCM*

AHP is a structured tool for analyzing complicated and multifarious courses of action. AHP helps managers ascertain the alternative that is best suited to fulfill their aims. It provides a logical and coherent framework for providing a hierarchy to a decision problem, for constituting its elements, linking them to overall goals, and for assess alternative courses of action. The problem is broken down to elements, which are easy to understand and a hierarchy is built as also independent analysis of each element and the inter-relationships between these elements [21]. AHP is well-suited for MCDM as it is possible to determine the relative ranking of alternatives or attributes [22], which in this case is supply chain performance indicators impacted by ICT. This led to the selection of AHP and its extensions as the tool that ranks and quantifies the attributes in the order of importance and preference.

170 valid responses from the 200 respondents of the survey questionnaire are converted from Likert scale translated to Saaty Scale and the following methodology is used as shown in Fig. 3 and supported by Table 2 which is the AHP importance scale and Table 3 which is the pair-wise comparison matrix so as to get the AHP ranks and weights of the supply chain performance indicators reproduced in Table 4. These weights in Table 4 are utilized in the computation of the ICT Capability Index.

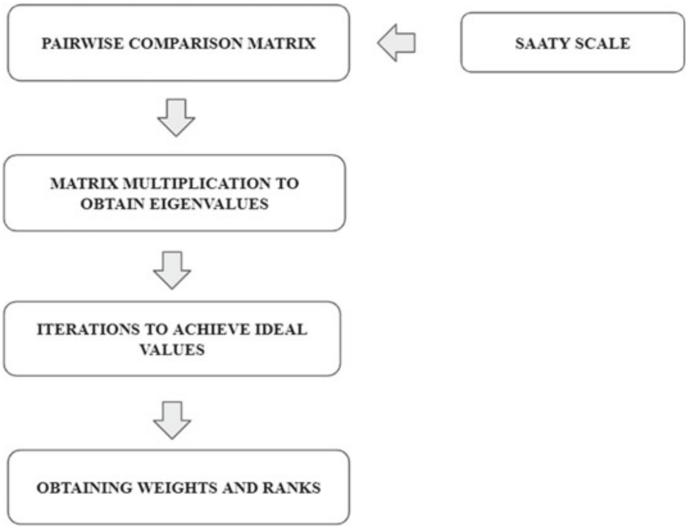

Fig. 3 AHP ranking methodology

Table 2 AHP importance scale

Importance scale	Definition of importance scale
1	Equally important
2	Equally to moderately important
3	Moderately important
4	Moderately to strongly important
5	Strongly important
6	Strongly to very strongly important
7	Very strongly important
8	Very strongly to extremely important
9	Extremely important

6.2 SNORM Method for Computing ICT Capability Index for SCM

Snorm De Boer standardized normalization (SNORM) method is used to normalize supply chain performance constructs and used in conjunction with SCOR as a method for measuring business performance. Companies can use this tool to assess and gauge each business practice and also find out the ones that need improvements to be made [23]. This method is used to calculate the ICT Capability Index for SCM.

Weight of each construct is obtained by AHP from the values in Table 4. SNORM method is defined as follows [24]:

If large value of a performance indicator or construct is better:

Table 3 AHP pair-wise comparison matrix from questionnaire responses in likert scale translated to saaty scale

ICT impact on	Accurate Documentation	Complete Delivery	Cost	No Damage	On-time Delivery	Order Fulfillment Cycle Time	Upside Supply Chain Adaptability	Downside Supply Chain Adaptability	Cash to Cash cycle time	Risk	Return on Supply Chain Fixed Assets	Upside Supply Chain Flexibility	Return on Working Capital
Accurate Documentation	1/1	2/1	3/1	4/1	5/1	6/1	7/1	7/1	8/1	8/1	8/1	9/1	9/1
Complete Delivery	1/2	1/1	3/1	3/1	3/1	3/1	3/1	4/1	5/1	6/1	6/1	7/1	8/1
Cost	1/3	1/3	1/1	3/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	9/1	9/1
No Damage	1/4	1/3	1/3	1/1	4/1	4/1	5/1	6/1	7/1	8/1	8/1	9/1	9/1
On-time Delivery	1/5	1/3	1/3	1/4	1/1	5/1	5/1	6/1	6/1	7/1	8/1	9/1	9/1
Order Fulfillment Cycle Time	1/6	1/3	1/4	1/4	1/5	1/1	6/1	6/1	7/1	8/1	9/1	9/1	9/1
Upside Supply Chain Adaptability	1/7	1/3	1/5	1/5	1/5	1/6	1/1	7/1	7/1	8/1	8/1	9/1	9/1
Downside Supply Chain Adaptability	1/7	1/4	1/6	1/6	1/6	1/6	1/7	1/1	8/1	8/1	9/1	9/1	9/1
Cash to Cash cycle time	1/8	1/5	1/7	1/7	1/6	1/7	1/7	1/8	1/1	7/1	8/1	9/1	9/1
Risk	1/8	1/6	1/8	1/8	1/7	1/8	1/8		1/7	1/1	9/1	9/1	9/1
Return on Supply Chain Fixed Assets	1/8	1/6	1/9	1/8	1/8	1/9	1/8	1/9	1/8	1/9	1/1	8/1	9/1
Upside Supply Chain Flexibility	1/9	1/7	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/8	1/1	9/1
Return on Working Capital	1/9	1/8	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/1

Table 4 AHP ranks and weights

ICT impact on	Weights	Ranks
Accurate documentation	0.217861815	1
Complete delivery	0.137556089	3
Cost	0.141317992	2
No damage	0.126162194	4
On-time delivery	0.104515685	5
Order fulfillment cycle time	0.085308167	6
Upside supply chain adaptability	0.062960113	7
Downside supply chain adaptability	0.044615283	8
Cash to cash cycle time	0.02854347	9
Risk	0.020812043	10
Return on supply chain fixed assets	0.014019403	11
Upside supply chain flexibility	0.009737723	12
Return on working capital	0.006590024	13

$$\text{SNORM is } ((\text{Si} - \text{Smin})/(\text{Smax} - \text{Smin})) * 100$$

If smaller value of a performance indicator or construct is better:

$$\text{SNORM is } ((\text{Smax} - \text{Si})/(\text{Smax} - \text{Smin})) * 100$$

where

- Si is Actual performance value of the indicator/construct.
- Smax is Maximum value of the indicator/construct.
- Smin is Minimum value of the indicator/construct.

Actual performance value of the indicator/construct is given by a company based on the maximum and minimum value of the construct. Actual value of a particular indicator is given by the enterprise as company value. Finally by multiplying the weights of the factors and the SNORM value, the performance score for the five performance attribute is obtained and adding these gives the overall performance score which is converted to an ICT Capability index for SCM.

6.3 Balanced Scorecard (BSC) Method for Computing ICT Capability Index for SCM

Balanced Scorecard (BSC) is a comprehensive business performance measure to measure overall performance in diverse aspects of an enterprise. Using this tool, an organization is viewed from the following four important perspectives which cover both operational and financial aspects.

- Customer.
- Internal business.
- Innovation and learning.
- Financial.

Each perspective is constituted of objectives and metrics [25]. This is again an application of MCDM. BSC impacts decision-makers with insights on whether enhancements in one perspective are attained at the cost of the other. In our investigation, BSC is applied in conjunction with matrix goals and interpolation formula method. Weights are taken from AHP for each indicator in the same method employed in SNORM method from Table 4. Target and stretch are defined as lower and upper threshold values for each indicator in the attainment of performance. The actual company value of a particular indicator is obtained for the enterprise. The attainment value for each indicator is calculated using the following interpolation formula [26]:

$$y_2 = \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1$$

x_1, x_2 and x_3 are target, actual, and stretch values of the indicator.

y_1 and y_3 are lower and upper threshold values of the indicator.

From the attainment value, the score is computed by multiplying weight of indicator with the attainment value of indicator. And total score is the sum of all performance scores, which is our index [26]. Enterprise case studies are hereby explored based on selected respondents which contained both quantitative data points and qualitative data points with provision for some open-ended responses as well.

6.3.1 Industry Case Study # 1: Manufacturing Company # 1

The first case study is of a manufacturing company headquartered at Coimbatore with the following details:

- Respondent: Senior Vice-President.
- Total Number of Employees: 3000.
- Name of Business Vertical/SBU/Description: Horn/Industrial Cleaning Equipment's/Die Casting/Plastic components/Medical Equipment, etc.
- Total Turnover (In Indian Rupees): Rs. 700 crores.
- Years of Operating experience of enterprise: 40 Years.
- ICT Deployment.
    - ERP Package.
    - Bar Code.
    - DSS.
    - Software Agents.
    - Cloud Computing.
    - Business Analytics.
    - High Performance Computing.
    - Mobile Apps.
    - Social Media.
    - CRM package.
    - E-business software suite.
    - IoT.
- ICT Deployment benefits described by respondent
    - Visibility of order status.
    - Visibility of shipping and transportation details.
    - Accuracy of demand forecasts.
    - Decrease of manual work.
- ICT Capability Index computed and shown in Tables 5 and 6 using:
    - SNORM: 0.9172.
    - BSC: 0.947.

- Recommendations & Inference from the ICT Capability Index for SCM
  - o SNORM & BSC are different methods for computing the index and as such as the range of values and scale will show some variation between the two methods.
  - o This is an enterprise which has not only adopted high-end ERP software package but also cutting-edge ICT tools like analytics, mobile apps, etc. for their supply chain processes. More or less the enterprise has leveraged the power of ICT for all aspects of the SCM.
  - o As such the values of the index are high and this can be compared with other case studies.
  - o There is scope to maximize the ICT usage of internal process and financial measures as evidenced from scores from both methods.
  - o ICT tools have already been deployed and improvement of internal process like OCT, UPCA, UPSA can be done by maximizing the usage of these tools as also look for operational gaps in the ICT-enabled processes like poor communication between stakeholders, technology incompatibility, etc.
  - o There is scope for maximization of financial measures, but this requires management actions and audits.
  - o As and when required, the enterprise can upgrade their ICT tools.

6.3.2 Industry Case Study # 2: MSME # 1

The second case study is of a MSME headquartered at Coimbatore with the following details:

- Respondent: Senior General Manager.
- Total Number of Employees: 400.
- Name of Business Vertical/SBU/Description: Food processing.
- Total Turnover (In Indian Rupees): Rs. 15 crores.
- Years of Operating experience of enterprise: 15 Years.
- ICT Deployment
  - o Bar Code.
  - o Inventory management software package.
  - o Fleet.
  - o Management software package.
  - o Cloud Computing—ESDS.
  - o Mobile Apps—Local startup.
  - o Social Media.
  - o CRM software package—Salesforce.com.
  - o Management Information System (MIS) package—Tally for finance, Benny Impex.

Table 5 Index computation using SNORM method of industry case study # 1

ICT	Impact on construct	Abbreviation	Minimum (in %)	Maximum (in %)	Company value (in %)	AHP weights	SNORM	Score
ICT+	Complete delivery	CD	0	100	100	0.137556089	100	13.7556089
ICT+	On-time delivery	OD	0	100	100	0.104515685	100	10.4515685
ICT+	Accurate documentation	AD	0	100	100	0.217861815	100	21.7861815
ICT +	No damage	ND	0	100	100	0.126162194	100	12.6162194
ICT−	Order fulfillment cycle time	OCT	100	0	80	0.085308167	80	6.82465336
ICT+	Upside supply chain flexibility	UPCA	100	0	80	0.009737723	80	0.77901781
ICT+	Upside supply chain adaptability	UPSA	0	100	80	0.062960113	80	5.03680904
ICT+	Downside supply chain adaptability	DSCA	100	0	80	0.044615283	80	3.56922265
ICT−	Cash to cash cycle time	CCR	100	0	80	0.02854347	80	2.28347761
ICT+	Return on supply chain fixed assets	RFA	0	100	80	0.014019403	80	1.12155222
ICT+	Return on working capital	ROWC	0	100	80	0.006590024	80	0.52720189
ICT−	Cost	Cost	100	0	80	0.141317992	80	11.3054393
ICT−	Risk	Risk	100	0	80	0.020812043	80	1.66496347
							Score	91.7219156
							Index	0.9172

Table 6 Index computation using BSC method of industry case study # 1

Balanced score card	ICT impact on construct		Abbreviation	Target	Stretch	Actual	Weights	Score	Weight * score
Customer	ICT+	Complete delivery	CD	80	100	100	0.137556	100	13.75560885
	ICT+	On-time delivery	OD	80	100	100	0.104516	100	10.45156851
	ICT+	Accurate documentation	AD	90	100	100	0.217862	100	21.78618148
	ICT+	No damage	ND	90	100	100	0.126162	100	12.61621941
Internal process	ICT−	Order fulfillment cycle time	OCT	100	80	95	0.085308	85	7.251194195
	ICT+	Upside supply chain flexibility	UPCA	100	80	95	0.009738	85	0.827706428
	ICT+	Upside supply chain adaptability	UPSA	0	100	85	0.06296	97	6.107130958
	ICT+	Downside supply chain adaptability	DSCA	100	80	95	0.044615	85	3.792299066
Financial	ICT−	Cash to cash cycle time	CCR	100	80	95	0.028543	85	2.426194963
	ICT+	Return on supply chain fixed assets	RFA	0	100	85	0.014019	97	1.359882064
	ICT+	Return on working capital	ROWC	0	100	80	0.00659	96	0.632642266
	ICT−	Cost	Cost	100	80	95	0.141318	85	12.01202931
Learning and growth	ICT−	Risk	Risk	100	0	85	0.020812	83	1.727399601
								Score	94.7460571
								Index	0.947

- ICT Deployment benefits described by the respondent
  - o Better visibility of milk movements [both at procurement and distribution stages].
  - o Better Planning for milk and milk products sales and stocking.
  - o Better utilization of the production facilities.
  - o Effective manpower deployment.
  - o Reduction in the milk transaction and storage timings.
  - o Increase in the shelf life of milk and milk products.
- ICT Capability Index computed and shown in Tables 7 and 8 using:
  - o SNORM: 0.65
  - o BSC: 0.8571
- Recommendations and Inference from the ICT Capability Index for SCM
  - o SNORM and BSC are different methods for computing the index and as such as the range of values and scale will show some variation between the 2 methods.
  - o This enterprise is a progressive MSME in dairy and food processing with ICT deployed for various activities of the enterprise. Even though ERP has not been procured, MIS packages for operations, finance, etc. are available as also cutting-edge tools like mobile apps, cloud, etc.
  - o When this is compared with other case studies, it is clear that there is a tremendous room for improvement in ICT deployment. From stand-alone MIS, the MSME can explore a capital investment in procuring an ERP to integrate the enterprise operations.
  - o As evidenced from the scores, internal processes to a large extent have been improved by the stand-alone MIS packages and few cutting-edge tools.
  - o There is tremendous scope to improve customer, financial, and risk measures.
  - o If procuring an ERP is not possible, customer measures can be improved using web services for better dialogue and communication.
  - o Reducing risk will require more integration and this is best served by integrating all the MIS packages for various functional areas of the enterprise.

7 Managerial Implications and Future Research Directions

The managerial implications of this ICT Capability Index for SCM assume greater significance as a result of the present situation due to Covid-19 pandemic, which has accelerated the need for Industry 4.0, digitalization, and embracing of ICT not only for the supply chain but also all aspects of the enterprise. The index is derived from the empirical model which together constitutes assessment framework on impact of ICT for SCM. The advantages of this index are that it can be used by any enterprise irrespective of the geography or country, vertical or domain, manufacturing,

Table 7 Index computation using SNORM method of industry case study # 2

ICT	Impact on construct	Abbreviation	Minimum (in %)	Maximum (in %)	Company value (in %)	AHP weights	SNORM	Score
ICT+	Complete delivery	CD	0	100	60	0.137556089	60	8.25336531
ICT+	On-time delivery	OD	0	100	60	0.104515685	60	6.2709411
ICT +	Accurate documentation	AD	0	100	60	0.217861815	60	13.0717089
ICT+	No damage	ND	0	100	60	0.126162194	60	7.56973165
ICT−	Order fulfillment cycle time	OCT	100	0	60	0.085308167	60	5.11849002
ICT+	Upside supply chain flexibility	UPCA	100	0	80	0.009737723	80	0.77901781
ICT+	Upside supply chain adaptability	UPSA	0	100	80	0.062960113	80	5.03680904
ICT+	Downside supply chain adaptability	DSCA	100	0	80	0.044615283	80	3.56922265
ICT−	Cash to cash cycle time	CCR	100	0	80	0.02854347	80	2.28347761
ICT+	Return on supply chain fixed assets	RFA	0	100	60	0.014019403	60	0.84116416
ICT+	Return on working capital	ROWC	0	100	20	0.006590024	20	0.13180047
ICT−	Cost	Cost	100	0	80	0.141317992	80	11.3054393
ICT−	Risk	Risk	100	0	40	0.020812043	40	0.83248174
							Score	65.0636498
							Index	0.65

Table 8 Index computation using BSC method of industry case study # 2

Balanced score card	ICT impact on construct		Abbreviation	Target	Stretch	Actual	Weights	Score	Weight * score
Customer	ICT+	Complete delivery	CD	80	100	90	0.137556	90	12.38004797
	ICT+	On-time delivery	OD	80	100	85	0.104516	85	8.88383323
	ICT+	Accurate documentation	AD	90	100	90	0.217862	80	17.42894518
	ICT+	No damage	ND	90	100	90	0.126162	80	10.09297553
Internal process	ICT−	Order fulfillment cycle time	OCT	100	80	95	0.085308	85	7.251194195
	ICT+	Upside supply chain flexibility	UPCA	100	80	85	0.009738	95	0.925083655
	ICT+	Upside supply chain adaptability	UPSA	0	100	95	0.06296	99	6.233051184
	ICT+	Downside supply chain adaptability	DSCA	100	80	85	0.044615	95	4.238451897
Financial	ICT−	Cash to cash cycle time	CCR	100	80	90	0.028543	90	2.568912314
	ICT+	Return on supply chain fixed assets	RFA	0	100	55	0.014019	91	1.275765648
	ICT+	Return on working capital	ROWC	0	100	25	0.00659	85	0.560152006
	ICT−	Cost	Cost	100	80	95	0.141318	85	12.01202931
Learning and growth	ICT−	Risk	Risk	100	0	50	0.020812	90	1.873083905
								Score	85.72352602
								Index	0.857

or services. This index not only provides insights to enterprises on their ICT capabilities for SCM but also assesses to what extent digital matters to them and how it might transform their business models and supply chains and affect financial performance and diagnostics. This will help them to adapt their organizations, leverage ICT, digitize their operations, and also benchmark with their peers and competitors. The index can also provide insights on selection of appropriate ICT tool after measurement of its impact on the supply chain paradigm and understanding success factors and operational challenges for adoption of various ICT tools [27].

This index calculation has been done using 2 methods, namely, SNORM and BSC. Discussion with an enterprise is needed to take input on the company value on the effect of ICT on each supply chain performance indicator in our calculation for the index. Two case studies are showcased with calculation of the index using the 2 methods. Inferences and recommendations are also provided to these respective companies.

A scoring system and rubric are proposed to be evolved based on multiple case studies of various enterprises as an extension to this research work. This will essentially involve not only providing the enterprise with an index but also a gradation model with specific recommendations on moving up the ladder in terms of ICT adoption. The investigation has focused primarily on strategic supply chain metrics or level I metrics as per the SCOR model. There is ample scope to extend the investigation into SCOR level II metrics which are diagnostics of strategic metrics and level III metrics which are context or sector-specific. A cluster-based or sector-based analysis approach with or without geographical limitations can also be considered as an extension to the research.

8 Conclusion

Industry 4.0 is the latest cutting-edge wave of ICT deployment in enterprises. The present situation due to Covid-19 pandemic has only accelerated the need for Industry 4.0, digitalization, and embracing of ICT not only for supply chain but also all aspects of the enterprise. While most supply chain professionals are in complete agreement of the fact that ICT conclusively impacts performance and fulfillment of the supply chain with many frameworks having been suggested, there is an identified lacunae in terms of performance scoring and assessment framework with respect to impact of ICT in SCM. This investigation proposes an ICT Capability Index for SCM as one part of an assessment framework on ICT impact on SCM. The other part is an empirical model based on SCOR level 1 performance constructs, which is validated using SEM from the survey questionnaire responses. These constructs are ranked using AHP and the weights are ascertained. Computing the ICT Capability Index for SCM from the metrics of the assessment model is done using tools such as Balanced Scorecard (BSC) and Snorm De Boer standardized normalization (SNORM) method. Enterprises irrespective of sector or vertical can use this index as a universal benchmark to assess to what extent digital technologies and ICT matters to them and how it might transform their supply chains and business models as also affect financial performance and diagnostics. A scoring system and rubric is proposed to be evolved based on multiple case studies of various enterprises as an extension to this research work. Enterprises may be provided with specific recommendations on moving up the ladder in terms of ICT adoption as also from a cluster or sector-based approach.

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