Szent István University

Doctoral School of Economic and Regional Sciences

THE IMPACT OF INDUSTRY 4.0 ON SUPPLY CHAIN INTEGRATION AND PERFORMANCE: AN EMPIRICAL INVESTIGATION IN AN EMERGING MARKET

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1. INTRODUCTION

1.1.Research Background

The industry is a significant part of an economy that enables productivity and industrial growth (Lasi et al., 2014, p.239; Rüßmann et al., 2015, p.1). Since the start of industrialisation, technological advances have led to fundamental changes that today are called "industrial revolutions (Lasi et al., 2014, p.239). Industrial revolutions have initiated with the transformation from craft production to mass production, involving division of employees and standardisation (Brettel et al., 2014, p.37). The convergence of industrial production and information and communication technologies (ICTs), known as "Industry 4.0", commits the manifold potentials such as increasing operational effectiveness and improvements of new business models, products and services (Hermann et al., 2016, p.3928).

The introduction of Industry 4.0 into industrial production and manufacturing has also had many influences on the structure of supply chains (SCs) (Tjahjono et al., 2017, p. 1176) in particular real-time tracking of material flows (Hofmann and Rüsch, 2017, p. 24), adaptive decisions to be made in a timely manner (Zhong et al., 2017, p. 616), administrate predictive maintenance and preclude asset breakdowns (Ghobakhloo, 2018, p.920) and achievements in organisational-economic level such as lean management (Schumacher et al., 2016, p.161) with the integration of Cyber-Physical Systems (CPS) and Internet of Things (IoT). Furthermore, Industry 4.0 enables analytical capabilities for decision making through forecasting demand, Just in Time (JIT) and flexible manufacturing processes optimise performance in SCs (Lin et al., 2018, p. 593; thus, improving overall performance in SCs (Vaidya et al., 2018, p. 234).

Despite the potential benefits of Industry 4.0 on supply chain management (SCM), there is a deficiency of the literature in terms of practices of smart manufacturing and their influences on the performance, especially in developing countries (Lin et al., 2018, p. 590). Industry 4.0 has triggered in developed countries that may be able to take advantage of a higher level for automation due to their high skilled employees (Rüßmann et al., 2015, p. 11). However, many developing countries might also obtain the opportunities of automation due to their young and technology shrewd workforce (Rüßmann et al., 2015, p. 11).

Given the above considerations, the main motivation of this research is to examine the current Industry 4.0 concept in an emerging market, in Turkey, and its impacts on SCM, specifically on supply chain integration (SCI) and supply chain performance (SCP).

1.2. Research Questions and Hypotheses

This research attempts to identify whether the practices of Industry 4.0 have positive impacts on the concepts of SCM, in particular SCI and SCP. In addition, the study aims to observe the relevance between SCI and SCP since different perspectives are taken in the literature. For this reason, in this research, the definitions, directions and elements of these three concepts have been analysed and in the end, the linkages have been tested empirically. The arguments regarding the study lead to improved research questions, as follows:

Research Question 1: *How does Industry 4.0 affect SCI?*

Using IT and advanced digital technologies the partners in a supply chain need to undergo system alterations to enrich the relationships between them (Birasnav and Bienstock, 2019, p. 150; Vickery et al., 2003). Thus, it is expected that advanced technological solutions drive manufacturing processes to integrate the partners in a supply chain with their production systems. Although the research is ambiguous yet related to assessment models on

Industry 4.0, this study seeks to answer whether there is an impact of Industry 4.0 on SCI.

Research Question 2: *How does SCI affect SCP?*

SCI can be seen as a key success of organisations and their SCs (Huo, 2012; Fabbe Costes and Jahre, 2008; Flynn et al., 2010). For many years, the scholars (Narasimhan and Kim, 2002, p.303; Sezen, 2008, p. 233; Vickery et al., 2003, p.533) argue whether the capabilities of SCI are always beneficial for SCP. However, the effects of SCI on SCP are still unknown (Zhao et al., 2015, p.162). Thus, this research investigates whether SCI has an impact on SCP.

Research Question 3: *How does Industry 4.0 affect SCP?*

As briefly mentioned in Section 1.1., Industry 4.0 stimulates production processes through integrating them horizontally and vertically, as a consequence of this, it is estimated that the concept will increase both firm performance and SCP (Dalenogare et al., 2018, p. 383; Buer et al., 2018, p. 2934; Frank et al., 2019, p. 20). Accordingly, this study explores the effects of Industry 4.0 on SCP. In addition to the arguments mentioned above, some authors believe that there is a mediating role of SCI between Industry 4.0 and SCP (Delic et al., 2019; Yu, 2015, p.955; Bruque-Cámara et al., 2016, p.149). Since the role of integration in supply chains has been taken lack of importance in the literature because the relationship is generally observed between digital technologies and performance aspects; this thesis also seeks the impact of SCI between Industry 4.0 and SCP.

Research Question 4: *How should organisations prioritise the indicators of Industry 4.0 and SCI strategically to achieve higher performance in the context of the supply chain?*

The study also deepens the nature of links between three constructs by analysing the prioritisation items of Industry 4.0 and SCI, which lead to higher performance. It is significant to investigate which items are important for SCP and how companies perform on these items based on the analysis of the Importance-Performance Matrix. Ghobakhloo (2018, p. 911) suggested that organisations require to formulate accurate plans and designing principles because the directions of Industry 4.0 are still challenging and uncertain. Akdil et al. (2018, p. 62) argued that the outcomes of Industry 4.0 are still ambiguous because organisations do not have expertise on the concept. Therefore, the current state and route for the assessment of Industry 4.0 are necessary.

In the lights of the research questions discussed above, the following hypotheses are formulated in the present study:

H1: Industry 4.0 positively affects Supply Chain Integration.

H2: Supply Chain Integration positively affects Supply Chain Performance.

H3: Industry 4.0 positively affects Supply Chain Performance.

H4: Supply Chain Integration mediates the relationship between Industry 4.0 and Supply Chain Performance.

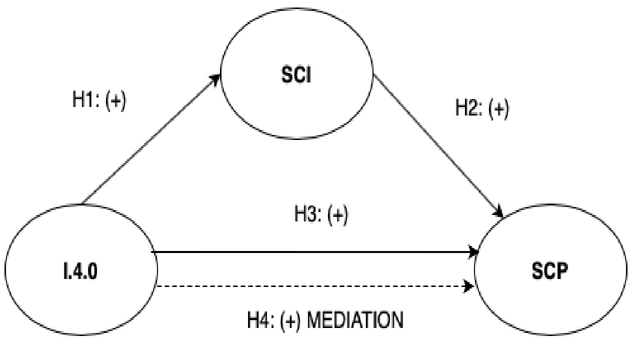

Figure 1. The Proposed Conceptual Model
Source: Author's own figure

Addressing the research questions, more specifically, the research model examines whether *"Industry 4.0 affects SCI"*, *"SCI affects SCP", "Industry 4.0 affects SCP"* and *"SCI mediates the relationship between Industry 4.0 and SCP".* Figure 1 indicates the research model which outlines the relationship between Industry 4.0, SCI and SCP.

2. MATERIALS AND METHODS

2.1. Research Method and Questionnaire Design

This research employs the questionnaire method to investigate the research questions and hypotheses formulated with the analysis of the data from primary sources. Although the quantitative method was selected for this research, the background of the thesis was also based on qualitative and exploratory research to explore issues in a particular subject and develop alternative methodological methods coupled with higher reflexivity of the process of study. Therefore, the research employed semi-structured interviews with some companies before developing the items of the questionnaire. In total, 70 randomly selected companies in the leading cities (Istanbul, Ankara and Izmir) of Turkey were identified by checking their websites, initiatives on their activities in both Industry 4.0 and the supply chain. Later e-mails were sent to their production, operations, planning or supply chain managers, in addition to executives of these companies; 14 respondents were invited to attend semi-structured interviews. Of the 14 companies, nine of them were large companies with more than 250 employees and their annual turnover was higher than 20 million dollars. Five of them were medium-sized companies with more than 50 and less than 250 employees and their annual turnover was more than 4 million dollars and less than 20 million dollars.

After the interview process, the next stage is to identify the items used in the questionnaire. The scale items were derived from previous studies; however, the most appropriate scale was selected based on the results of the interviews and conceptualisations of the constructs in the literature. Based on this, the most appropriate items were selected from the research of Bibby and Dehe (2018), Jajja et al. (2018) and Beamon (1999) to measure the elements of Industry 4.0, SCI and SCP respectively. The guideline of the questionnaire is comprised of four sections; (1) the questions related to company information and profiles of the respondents, including the position of the respondents in the company, employee numbers in the company, annual revenue turnover of the company and sector of the company. (2) the questions related to Industry 4.0, including the extent to implement of Industry 4.0 strategy of companies, extent to assess the employee and culture in the activities of Industry 4.0 and extent to assess Industry 4.0 technologies. (3) the questions related to Supply Chain Integration, including the extent to integrate with suppliers, extent to integrate internally, extent to integrate with customers. (4) the questions related to Supply Chain Performance, including the extent to perform in resource items, the extent to perform in output items and the extent to perform in flexibility items of organisations.

The first main construct measures the assessment of Industry 4.0; including three elements: “strategy and organisation”, “employee and culture”, and “technology”. A total of 24 items were selected to evaluate these elements. The scale items for the elements were improved considering the definition of Industry 4.0 and the findings of the semi-structured interviews. Based on this, the most appropriate items were selected from the research of Bibby and Dehe (2018) to measure the elements of Industry 4.0. Through this study, the first construct “strategy and organisation (S&O)” was evaluated using four items; “Availability of roadmap (S&O1)”, “Infrastructure (S&O2)”, “Customising products (S&O3)”, and “external collaborations (S&O4)”. The second construct “Employee and Culture (E&C)” was measured using four items; “employee familiarity (E&C1)”, “employee training (E&C2)”, “openness to innovation (E&C3)” and “continuous culture (E&C4)”. The third construct “Technology (T)” was evaluated using sixteen items; advanced technology (T1), supplier technology (T2), data access (T3), data analysis (T4), sensor1 (T5), cloud (T6) track and trace (T7), autonomous machines (T8), customer access (T9), CAD (T10), 3D (T11), hard-soft resources (T12), digital media (T13), embracement of digitalisation (T14), sensor2 (T15) and high automation (T16). All of the items were evaluated on a 5 point Likert scale; where (1) represents 'not at all'; (2) represents 'slightly'; (3) represents 'moderately'; (4) represents 'very' and finally, (5) represents 'extremely'. Figure 2 shows the measurement model of Industry 4.0.

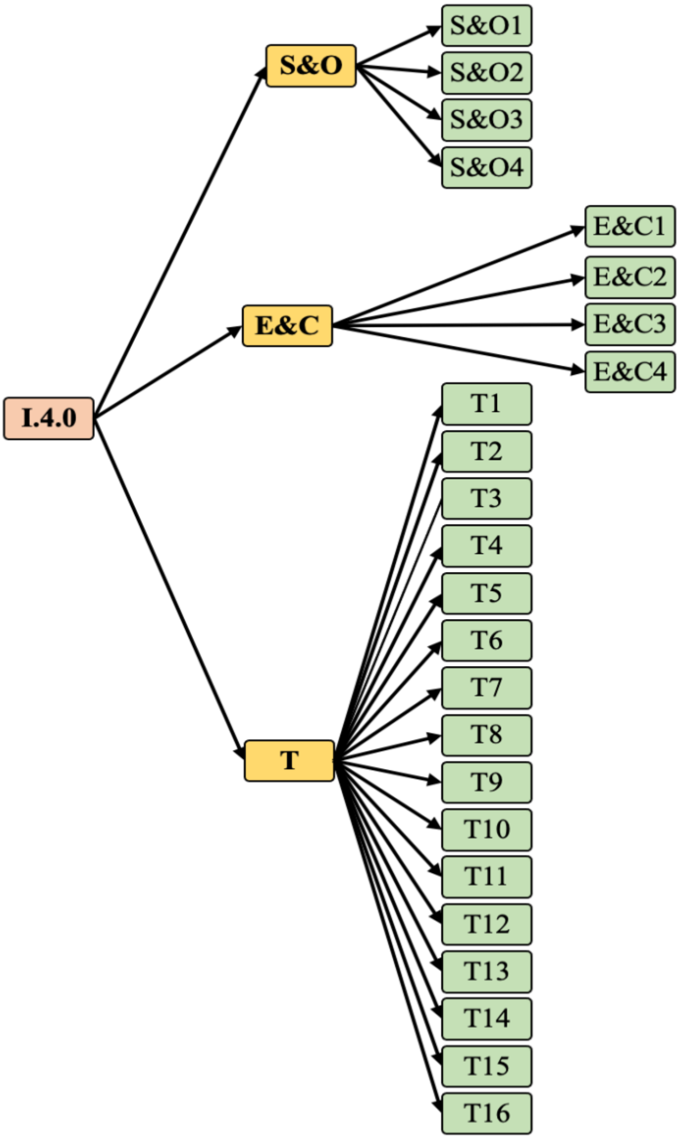

Figure 2. Measurement Model of Industry 4.0
Source: Author's own figure

The second main construct, SCI, was measured using three constructs: “supplier integration (SInt)”, “internal integration (IInt)” and “customer integration (CInt)”. A total of 12 items were created to measure these elements. The scale items used previously conducted by Jajja et al. (2018); which is close to the items provided by the interviews and the literature. “Supplier Integration” was measured using four items; “information sharing with main suppliers (SInt1)”, “collaboration with main suppliers (SInt2)”, “decision making with main suppliers (SInt3)” and “system development with main suppliers (SInt4)”. “Internal Integration” was evaluated with four items; “information sharing with purchasing department (IInt1)”, “decision making with purchasing department (IInt2)”, “information sharing with sales department (IInt3)”, and “decision making with sales department (IInt4)”. Finally, “Customer Integration” was measured using four items; “information sharing with main customers (CInt1)”, “collaboration with main customers (CInt2)”, “decision making with main customers (CInt3)”, and “system development with main customers (CInt4)”. All of the items were evaluated using a 5 point Likert scale; where (1) represents ‘very low’; (2) presents ‘low’; (3) represents ‘moderate’; (4) presents ‘high’ and finally, (5) represents ‘very high’. Figure 3 indicates the measurement model of SCI.

The third main construct, SCP, was evaluated with three constructs: “resources (RPERF)”, “output (OPERF)” and “flexibility (FPERF)”. A total of 17 items were created to measure SCP. The scale items used previously conducted by Beamon (1999) which is a well-known model in performance measurement. The element of “Resources” was evaluated with five items: “total cost of resources used (RPERF1)”, “total cost of distribution (RPERF2)”, “total cost of manufacturing (RPERF3)”, “inventory costs (RPERF4)” and “return on investments (RPERF5)”.

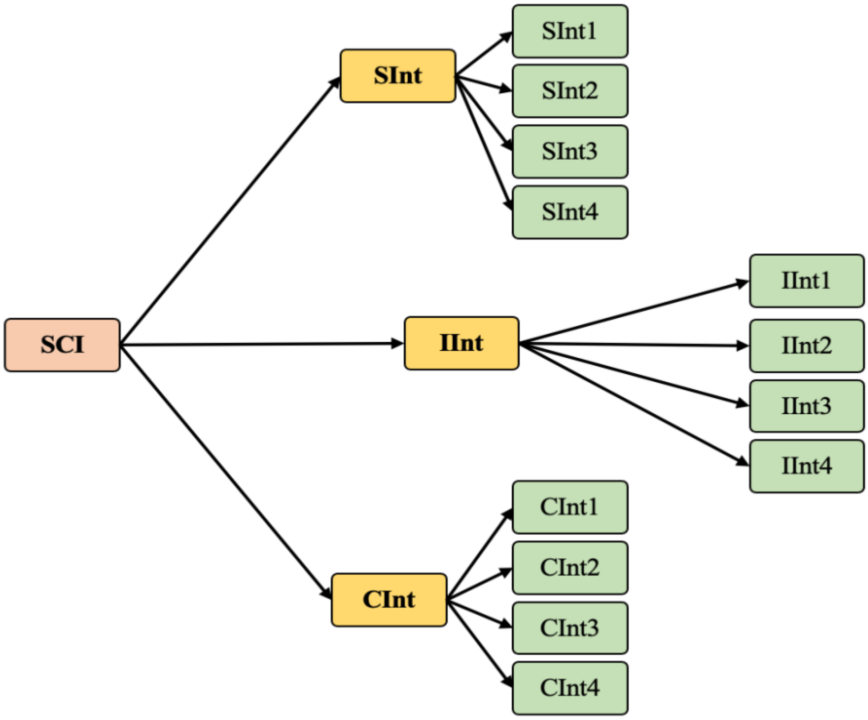

Figure 3. Measurement Model of SCI
Source: Author's own figure

"Output (OPERF)" was measured using seven items: "sales (OPERF1)", "order fill rate (OPERF2)", "on-time deliveries (OPERF3)", "customer response time (OPERF4)", "shipping errors (OPERF5)", "manufacturing lead time (OPERF6)" and "customer complaints (OPERF7)". Finally, "flexibility (FPERF)" was measured using five items: "ability to respond to demand changes (FPERF1)", "ability to respond to periods of low manufacturing performance (FPERF2)", "ability to respond to periods of low supplier performance (FPERF3)", "ability to respond to periods of low delivery performance (FPERF4)" and "ability to respond to new products, new markets and new competitors (FPERF5)". All of the items were evaluated using a 5 point Likert scale; where (1) represents 'very low'; (2) represents 'low'; (3) represents 'moderate'; (4) represents 'high' and finally, (5) represents 'excellent'. Figure 4 displays the measurement model of SCP.

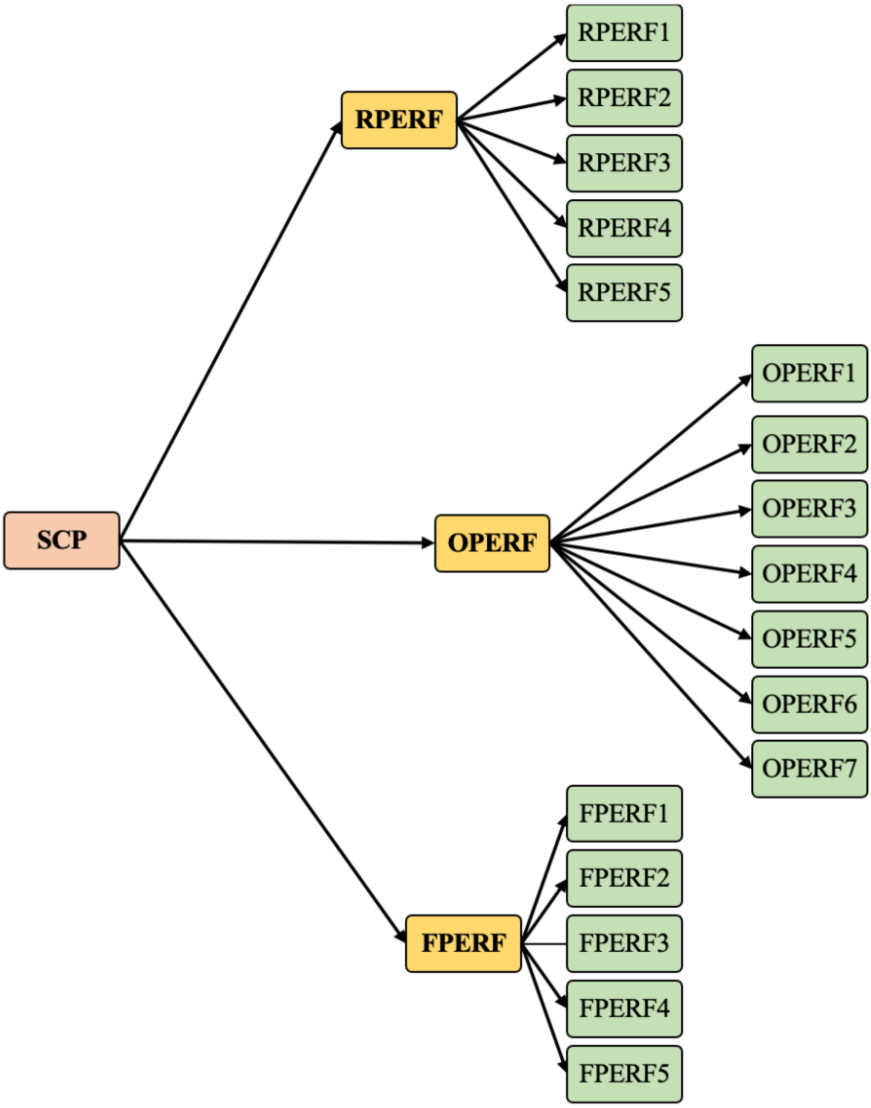

Figure 4. Measurement Model of SCP
Source: Author's own figure

Before data collection, the questions used in a questionnaire must be precise; therefore, firstly, each question was reviewed by supervisors in terms of phrases describing each item, length, readability and avoiding ambiguity of the questionnaire. Later, the survey instrument was also pre-tested by ten practitioners and six academics from the field of the supply chain, production and operations management to check if the indicators were susceptible for evaluating the models. After the results of the pre-test, small changes were made in the questionnaire. As for the scale of SCI and SCP, no questions were added to or removed from the questionnaire, only some explanations in brackets were added to the items to make the items more clear for the respondents. Only one question was removed from the Industry 4.0 scale, which was “the company’s 3D machines use metal alloys as its raw material”, as an item of technology element because it was found very technical and vague by 11 academics/practitioners. Instead of this item, the question which was added based on the recommendations of interviewees and the literature, was that “the company applies in Computer-Aided Design (CAD) software tools to design the 3D models of products”. Also, another question was added into the questionnaire as an item of “employee and culture element” in the Industry 4.0 scale, which was “my company supports the training of employees toward Industry 4.0”.

The original language of the questions derived from literature was English. Therefore, the questionnaire was translated into the Turkish language by a native speaker in the field of the supply chain; and later, it was checked by two other native speakers in the same field for its accuracy.

2.2. Sampling and Data Collection

For this thesis, the data for hypotheses testing were collected from the respondents who were involved in the operational, production-based, or supply chain activities of the companies. Data for this thesis were collected from Turkish manufacturing companies listed on the 1000 largest manufacturing companies operating in Turkey according to the Istanbul Chamber of Industry (ISO). The questionnaire was sent to the key informants via online channels such as emails, their profiles on Linkedin or via on-site visits made to some of the companies. After sending the questionnaire, it was followed up by email. Out of 1000 respondents, a total of 212 usable responses were returned. The response rate is 21.2% among the targeted sample. Accordingly, all reported analysis is based on a sample of 212 manufacturing companies.

2.3. Data Analysis

The partial least square technique (PLS-SEM) was chosen to analyse the data due to the small sample size and non-normal distributed data. Firstly, Confirmatory Factor Analysis (CFA) was applied in order to evaluate the measurement model assessments because it is used for verifying the factor structure of a set of latent variables used in previous studies. CFA was tested for the models of Industry 4.0, SCI and SCP separately. After measurement model assessment for each model, structural model assessment was evaluated by including all items.

Table 1. Rules of Thumb for Measurement Model Evaluation

Criterion	Measures	Acceptable Values
Internal Consistency Reliability	Cronbach's Alpha	Higher than 0.70
	Composite Reliability	Higher than 0.70
Indicator reliability	Outer loadings	Higher than 0.70
Convergent Validity	The average variance extracted (AVE)	Higher than 0.50
Discriminant Validity	Fornell-Larcker criterion	A latent construct has more variance with its assigned indicators than other latent variables
	Cross Loadings	Indicators' loadings are higher than all of its cross loadings
Multicollinearity	Variance Inflation Factor (VIF)	Less than 5

Source: Adopted from Hair et al. (2011, p. 145)

Table 1 and Table 2 show the procedures and rules of thumb followed in this thesis to evaluate measurement model assessment and structural model assessment respectively.

Table 2. Rule of Thumb for Structural Model Evaluation

Criterion	Acceptable Values
Coefficient of Determination (R^2)	R^2 values of 0.75, 0.50 and 0.25 for endogenous latent variables are described as substantial, moderate or weak respectively
Path Coefficients (β)	Use bootstrapping technique of PLS with the minimum number of bootstrap samples (5,000) to measure the path coefficients' significance. The critical t-values are 1.65 (significance level = 10 percent), 1.96 (significance level = 5 percent), and 2.58 (significance level = 1 percent) for a two tailed test.
Predictive Relevance (Q^2)	Use blindfolding technique of PLS to measure predictive relevance (Q^2) value of an endogenous construct which must be higher than zero

Source: Adopted from Hair et al. (2011, p. 145)

The measurement model and structural model assessments were measured using SMARTPLS 3 software programme, which is the latest version of SMARTPLS while data preparation tests such as normality, common method bias, collinearity tests and descriptive statistics of the data were conducted in IBM SPSS Statistics 25.0 software programme.

3. RESULTS & DISCUSSION

3.1. Common Method Bias and Normality Tests

Following the approach of Harman one factor analysis, all the constructs used in this study were observed in unrotated solution Exploratory Factor Analysis (EFA) to check common method bias. The findings reveal that several factors were extracted with an eigenvalue above 1 and they account for 70 percent of the total variance. Also, the first factor accounted for 37 percent of total variance which is less than the majority of the variance among measures. Therefore, common method bias is not a concern in this thesis.

The normality test is also carried out as applying in the Shapiro-Wilk test and Kolmogorov-Smirnov test. In both tests, as a rule of thumb, the null hypothesis is rejected when p-value is lower than 0.05. Since our findings show statistically significant results, it can be concluded that the data is non normal used in this thesis.

3.2. Demographic Profiles of the Respondents and Companies

In order to analyse the demographic profiles, four questions were formed in the questionnaire. These questions are about the position of the respondent in the company, tghenumber of employees working in the company, the annual revenue of the company and the related sector of the company. Table 3 displays the demographic profiles of the respondents and companies.

Of 212 respondents, only 5.7 percent (n=12) accounted for CEOs of the companies, while 26.4 percent of them (n=56) indicate general managers. Among the categories, the department heads hold the majority of the respondents, which accounted for 40.1 percent total (n=85). Finally, professional experts represent 27.8 percent of the respondents (n=59).

Table 3. The demographic profiles of the respondents and companies

Respondent Variable	Category	Frequency (n)	%	Cumulative (%)
Position	CEO	12	5.7	5.7
	General Manager	56	26.4	32.1
	Department Head	85	40.1	72.2
	Professional Expert	59	27.8	100.0
	Total	**212**	**100.0**	
Employee Numbers	10-49	30	14.2	14.2
	50-249	43	20.3	34.4
	250-499	34	16.0	50.5
	>500	105	49.5	100.0
	Total	**212**	**100.0**	
Revenue (Year)	<=3M TL	19	9.0	9.0
	3M> <=25M TL	36	17.0	25.9
	>25M <=125 M TL	42	19.8	45.8
	>125M TL	115	54.2	100.0
	Total	**212**	**100.0**	
Sector	Textile	48	22.6	22.6
	Automotive-Electronic	109	51.4	74.1
	Food and Beverage	29	13.7	87.7
	Chemicals-Pharmaceutical	26	12.3	100.0
	Total	**212**	**100.0**	

Source: Author's own analysis

14.2 percent of the companies employed higher than 10; but less than 50 employees (n=30), 20.3 percent had 50-249 employees (n=43). These companies also represent small and medium-sized companies according to employee numbers. 16 percent of the companies demonstrate that the companies which have a number of employees between 250-499 (n=34); and 49.5 percent represent the companies that have more than 500 employees (n=105).

The firms which have annual revenue turnover of less than 3 M TL accounted for 9 percent (n=19) while 17 percent (n=36) is with more than 3 M and less than 25 M TL. 19.8 percent of them (n=42) display more than 25 M TL and less than 125 M TL annual revenue. Finally, the companies with more than 125 M TL annual revenue turnover accounted for 54.2 percent (n=115) *(1 dollar is approximately 7.60 TL*). Considering the employee size and annual revenue turnover, this research involves predominantly large companies.

The majority of the companies are mainly from the automotive-electronic industry with 51.4 percent (n=109). The textile industry represents 22.6 percent of the companies (n=48), while 13.7 percent of the companies (n=29) are from the food and beverage industry. The chemicals/ pharmaceuticals industry only accounts for 12.3 percent (n=26).

3.3. Measurement Model Evaluation

To validate the specified model, confirmatory factor analysis was implemented with the observed variables. In our model, since the main endogenous variables were determined as Industry 4.0, SCI and SCP, reliability and validity tests must be evaluated for each variable. Therefore, the factor loadings, construct reliability and validity tests, discriminant validity tests, collinearity statistics (VIF) of the items for each element will be discussed as the reliability and validity tests.

3.3.1. Reliability and Validity Tests for the Items of Industry 4.0

Considering the factor loadings of each item of Industry 4.0, a total of 15 items show a value higher than 0.70. For this reason, a total of nine indicators were eliminated from the measurement model: "S&O3, T6, T8, T9, T10, T11, T12, T13, T15" because they have less than 0.70 outer loadings' value to explain their assigned variables. Although these indicators are extracted from the model one by one- starting from the lowest value -, none of them did exceed the sufficient threshold. The rest of the indicators retained in the model, "S&O1, S&O2, S&O4, E&C1, E&C2, E&C3, E&C4, T1, T2, T3, T4, T5, T7, T14, T16". Their outer loading values range from 0.737 to 0.939.

As for internal consistency reliability, the values of Cronbach's alpha and composite reliability have been employed while for convergent validity, AVE values are calculated for each construct of Industry 4.0. the element of “S&O” was measured with the values of 0.902 and 0.928 for Cronbach’s alpha and composite reliability consecutively; the element of “E&C” was observed with the values of 0.817 and 0.884 for Cronbach’s alpha and composite reliability respectively; and the element of “T” was measured with the values of 0.908 and 0.925 for Cronbach’s alpha and composite reliability consecutively. These values are well accepted for the measurement model. The values of AVE for the measurement model were observed as 0.829, 0.647 and 0.618 consecutively for the elements of ‘S&O’, ‘E&C’ and ‘T’, thereby satisfying the threshold.

Discriminant validity is also confirmed; this shows the level to which a variable is correctly distinguished from other variables. The findings of the Fornell-Larcker criterion indicated that the square root of AVE for the variables must be higher than other variables’ correlation value.

Variance Inflation Factor (VIF) values also must be conceived in order to identify the multicollinearity between the variables. The values of all of the items were determined at acceptable levels, below 5, ranging between 1.601 to 4.204.

3.3.2. Reliability and Validity Tests for the Items of SCI

The factor loadings for each item of SInt, IInt, and CInt, which are the elements of SCI are between 0.85 to 0.91; therefore, none of the indicators is extracted from the model because they have a higher value than the minimum threshold (0.70).

The values of Cronbach’s Alpha and Composite Reliability were calculated as 0.89 and 0.92 for SInt, 0.92 and 0.94 for IInt, and 0.91 and 0.94 for CInt respectively. Considering the accepted values, which must be higher than 0.70 for both tests, these measures are well accepted for the elements. Also, AVE values were observed as 0.75, 0.81 and 0.79 for SInt, IInt and CInt consecutively; therefore, all they are at a satisfactory level since the values are higher than 0.50.

The discriminant validity test -the Fornell Larcker Criterion- has been employed for the elements of SCI- SInt, IInt and CInt-. The results indicated that each element has higher values than the rest of the correlation values of the constructs; therefore, discriminant validity is accepted for SCI elements. In addition, collinearity statistics (VIF) values have been checked for each item The accepted VIF value of each item must be lower than 5, and all items meet that criteria.

3.3.3. Reliability and Validity Tests for the Items of SCP

The factor loadings of the indicators of SCP have been observed, and all items show the values higher than 0.70, except OPERF1 item. Therefore, this item has been removed for further analysis, while the rest of the items were retained in the model.

The internal consistency reliability and convergent validity tests were conducted for the elements of SCP: RPERF, OPERF and FPERF. The values of Cronbach's Alfa and Composite Reliability were measured as 0.867 and 0.91 for RPERF, 0.87 and 0.89 for OPERF, and 0.90 and 0.92 for FPERF respectively; thus, these values are accepted for the model (> 0.70). As for convergent validity, The AVE values were calculated as 0.66, 0.61 and 0.70 for RPERF, OPERF and FPERF consecutively. Since the values are higher than 0.50 threshold, convergent validity for the elements of SCP meets the criteria.

The results of the discriminant values of the elements are accepted for the model since all elements square roots of AVE are larger than the correlation values of the other constructs for SCP. Finally, the collinearity statistics (VIF) values were calculated for each item. The findings of the VIF values of each item are lower than 5; thus, the collinearity is not an issue between the items of SCP.

3.4.Structural Model Analysis and Hypotheses Testing

Considering the findings of reliability and validity tests, the structural model has been measured with a total of 15 items for Industry 4.0, including 3 items for S&O, 4 items for E&C and 8 items for T elements. For SCI, none of the items was removed from the structural model so a total of 12 items were evaluated, including 4 items each for SInt, IInt and CInt. For SCP, only OPERF1 item was eliminated from the model; therefore, 5, 6, and 5 items were included in representing RPERF, OPERF and FPERF respectively.

Two sets of techniques, PLS and Bootstrapping, in the PLS-SEM framework was adopted in testing the relationships between the measurement variables.

Table 4 displays the results of the coefficients of determination (R^2) to examine the predictive power of the model, estimated path coefficients and their significance level (p-values) and t-values for the three endogenous variables.

-H1: The effect of Industry 4.0 on SCI: The first hypothesis proposed is that the higher degree of assessment of Industry 4.0 positively affects the degree of SCI. The findings of the structural model show that the assessment of Industry 4.0 has a positive and significant impact on SCI (β=0.63, $p < 0.001$), explaining 39.8% (R^2) of the variance of SCI. "t-value" is also acceptable since it is higher than 2.58 in $p < 0.001$. Therefore, the test results supported the hypothesis H1.

-H2: The effect of SCI on SCP: The second hypothesis is that the higher degree of SCI positively affects the degree of SCP. It has been found that SCI has a positive and significant influence on SCP (β=0.632, $p < 0.001$), where t value is greater than 2.58 in $p < 0.001$. Therefore, the test results supported hypothesis H2.

Table 4. Hypotheses and Main Research Model Results

Relationship	Path coefficents *(β)*	t-values	P values
H1: Industry 4.0 → Integration	0.630	12.135	**
H2: Integration→ Performance	0.635	9.964	**
H3: Industry 4.0 → Performance	0.17	2.670	*
H4: Industry 4.0 → Integration → Performance	0.395	7.838	**
Coefficients of determination (R^2)			
	R^2		**Adjusted** R^2
Integration	0.398		0.395
Performance	0.566		0.56

$p < 0.001$ *$p < 0.05$ (all two-tailed)
Source: Author

-H3: The effect of Industry 4.0 on SCP: The third hypothesis of the research is that the higher degree of assessment of Industry 4.0 positively affects the degree of SCP. The results of the structural model indicate that Industry 4.0 has a positive and statistically influence on SCP; however, the relationship between these two has been observed as very weak (β=0.17, $p < 0.05$), where t value is accepted (higher than 1.96 in $p < 0.05$). Industry 4.0 and SCI have an influence on SCP, explaining 56.6% (R^2) of the variance of SCP. Therefore, H3 is also supported statistically.

-H4: Mediating Effect of SCI Between Industry 4.0 and SCP: The indirect effect of SCI was observed between Industry 4.0 and SCP. The results show that SCI is partially mediating the relationship between Industry 4.0 and SCP (β=0.398, $p < 0.001$ and t value= 7.838) since it is statistically positive and significant. The magnitude of the effect observed higher than the direct relationship between Industry 4.0 and SCP. Therefore, the test results partially supported the hypothesis H4.

Table 5 indicates the findings of the hypotheses put forth in this study.

Table 5. Summary of The Hypotheses

Hypotheses	
H1: Industry 4.0 affects Supply Chain Integration positively.	Supported
H2: Supply Chain Integration positively affects Supply Chain Performance.	Supported
H3: Industry 4.0 positively affects Supply Chain Performance.	Supported
H4: Supply Chain Integration has a mediating role between Industry 4.0 and Supply Chain Performance.	Partially Supported

Source: Author's own analysis

-Control Variables: Control variables were also considered in the research; three variables, firm size - number of employees, annual revenue - and sector of the companies were added into the structural model to check their impacts on the endogenous variables. Regarding the results, Industry 4.0 is affected by the number of employees ($p<0.05$) and annual revenue ($p<0.001$); SCI by only annual revenue ($p<0.05$) and SCP by the only number of employees ($p<0.05$). The impact of the sector is not accounted for as significant in any of the variables. The findings show that firm size appears to be the most significant control variable in all of the variables; however, as checked the impacts of the endogenous variables with each other, the final results observed are still the same except for the direct relationship between Industry 4.0 and SCP. Therefore, when control variables are added into the structural model, the results are still supported for the direct effects of Industry 4.0 on SCI (β=0.659, p < 0.001), SCI on SCP (β=0.631, p < 0.001); however, the results for the direct effect of Industry 4.0 on SCP show an insignificant impact (p > 0.05), while mediating the role of SCI is still significant (p< 0.001) between Industry 4.0 and SCP.

3.5. The Importance-Performance Matrix Analysis (IPMA)

Based on the framework of the IPMA, first, the importance and performance scores of Industry 4.0 and SCI were measured for a target construct, SCP. Compared with Industry 4.0, SCI achieved both higher importance score (0.519) and a higher performance score (66.068) for SCP. The scores of Industry 4.0 show 0.389 and 57.439 for importance and performance for SCP respectively. Therefore, organisations first should prioritise SCI for achieving higher SCP since this construct has a more important score than Industry 4.0. However, to deepen the understandings of the level of importance and performance analysis, IPMA has been conducted at the indicator level analysis with each construct’s items.

Furthermore, it is important to investigate which items of Industry 4.0 should be prioritised for SCP; therefore, the IPMA matrix at the item level was measured. As indicated in the matrix, the items of S&O1, S&02, E&C1 and T14 represent the “availability of roadmap”, “investing Industry 4.0 infrastructure”, “employee familiarity” and “embrace to digitalisation” consecutively, having low performance, but high importance for SCP. For this reason, organisations firstly concentrate on these indicators, which could offer more potential for improvement of SCP. Immediate investments to these indicators could increase the performance in supply chains. The items of T1, T2, T4 and E&C4 represent the “advanced connectivity of technology”, “level of supplier technology”, “analysing data for decision making” and “continuous culture of organisation” respectively, showing high performance and importance. Therefore, organisations should keep up their current performance on these indicators since they have high importance scores. The items of E&C3, T3, T5 and T7 refer to “openness to innovation”, “data access for operations”, “usage of sensor technology” and “trace to manufacturing systems” consecutively, displaying high performance; however, low importance.

Another step was to examine which items of SCI should be prioritised for SCP; thus, the IPMA matrix was evaluated for each item of SCI. The items of II1, II2, II3, II4 and CI4 represent “information sharing with the purchasing department”, “decision -making with the purchasing department”, “information sharing with the sales department”, “decision -making with the sales department” and “decision making” with main customers respectively, showing high performance and importance. For this reason, organisations should continue their performance on these indicators because they could lead to the development of SCP. The items of CI1 and CI2 correspond to “information sharing” and “collaboration” with main customers consecutively, having high performance, but low importance. Therefore, companies could reduce their resources on these indicators. Finally, the items of SI1, SI2, SI3, SI4 and CI3 present “information sharing”, “collaboration”, “decision making”, “system development” with main suppliers and system development with main customers respectively, displaying low performance and low importance. These indicators could have a low priority by organisations.

3.6. New Scientific Results

The unprecedented improvement of digital technologies will lead to significant changes in supply chains; however, there are ongoing discussions regarding how these changes will affect supply chains. As a reflection of these discussions, more empirical contributions are necessary for the linkages between Industry 4.0 and supply chains. The main contribution of this thesis is to fill the research gap in this field by giving empirical evidence. In this context, the author underlines the novel results of this thesis as follows below:

1) The dissertation offers a novelty of the proposed model: The complex and structured model was created to analyse the effect of Industry 4.0 practices on supply chains. Prior to devising the conceptual model, the literature was systematically reviewed and the findings of the literature were synthesised for three constructs: Industry 4.0, SCI and SCP. Furthermore, the semi-structured interviews were conducted to examine the current level of Industry 4.0 on supply chain operations. This helps the author create a consistent model of under-investigated research. The final proposed model consists of 24 items for Industry 4.0, 12 items for SCI and 17 items for SCP. These items were also tested in reliability and validity for each construct. Thus, the complex relationships were observed between three constructs; this also gives more precise findings on three constructs. Notably, the model of Industry 4.0 was mainly measured by technological items by the scholars; however, in this dissertation, the items of Industry 4.0 was perceived in both managerial and technological point of view. Finally, the analyses confirmed that Industry 4.0 has an important role in enhancing integration and performance in supply chains, whilst, the integration in supply chains increases SCP. Also, integration in supply chains partially mediates the linkage between Industry 4.0 and performance in supply chains.

2) The dissertation contributes to up-to-date analysis on SCI and SCP literature: Although the relationship between integration and performance in supply chains has been researched in many prior studies, this dissertation provides the novelty towards up-to-date analysis in relevance to this relationship. Since the scholars had conflicting arguments related to the influence of SCI on SCP, this research has empirically proved the importance of SCI on performance. Moreover, with the help of in-depth review analysis, these two concepts were conceptualised attentively.

3) The dissertation provides the analysis of an emerging country context: Prior studies generally concentrate on the role of Industry 4.0 in the developed economies; however, it is not widely known that how the technologies of Industry 4.0 are utilised by the emerging economies. This dissertation offers a model in an emerging country context, Turkey; it is among the first studies that identify an empirical relationship between Industry 4.0 and the performance in supply chains in an emerging context. Thus, the proposed model could be used for further academic investigations. Furthermore, it helps organisations understand the impacts of Industry 4.0 on their supply chains and provide better insights on their digital transformations.

4) The effects of company size and sector have been shown on Industry 4.0, SCI and SCP: This dissertation also displays that Industry 4.0, SCI and SCP are affected by company size; however, the sectors of organisations do not have any effects on these three constructs. Therefore, these findings raise further investigations in academic research. The adoption level of large companies could be different from small and medium-sized companies; for this reason, the different assessment models could be suggested considering the company size.

5) The dissertation contributes to prioritisation of the items for SCP: It is also significant to guide organisations about which items of Industry 4.0 and SCI should be used to have higher performance in supply chains because the allocation of the resources could be considered as strategic decision-making for companies. Thus, this dissertation provides the importance and performance regarding the indicators of Industry 4.0 and SCI, and which of them should be prioritised by organisations. After the data analysis, the findings indicated that how strategy, organisational culture, employee familiarity and embrace of digitalisation are important for organisations while they perform at a low level to implement these items to have a higher SCP. Also, the internal integration items are viewed as more important than customer and supplier integration; thus, organisations should allocate their resources more into the indicators of internal integration to accomplish SCP.

6) The dissertation used the two well-known theories for the relationships between Industry 4.0, SCI and SCP: This dissertation also contributes to Industry 4.0, SCI and SCP literature theoretically; additionally, these relationships are grounded the two well-known theories in the strategic management, the Resource-Based View (RBV) and Relational View (RV). This is particularly imperative because the theories explain the application of the study to the practice and give clear insights into the field. The role of Industry 4.0 was identified as a resource and SCI as a capability that both increase the dyadic relationships between partners in order to capture an increase in SCP.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The overarching aim of this dissertation is to fill the gap in the assessment of Industry 4.0 within the supply chain. For this reason, the research which has presented the mindset of the respondents engaged in manufacturing industries in Turkey is in the context of the effects of Industry 4.0 on SCM practices particularly SCI and SCP. Four research questions have been formulated to shed light on the relationship between these concepts.

RQ.1. How does Industry 4.0 affect SCI?

RQ.2. How does SCI affect SCP?

RQ.3. How does Industry 4.0 affect SCP?

RQ4. How should organisations prioritise the indicators of Industry 4.0 and SCI strategically to achieve higher performance in the context of the supply chain?

Response to Research Question 1: The relationship between Industry 4.0 and SCI

Through empirical analysis in PLS-SEM, the practices of Industry 4.0 are strongly related to the degree of SCI; and the relationship is taken as positive between these concepts. Therefore, H1 is supported in this study, which is that 'the higher degree of assessment of Industry 4.0 positively affects the degree of SCI'.

Response to Research Question 2: The relationship between SCI and SCP

Based on the results of structural model analysis, SCI has a positive and significant effect on SCP; hence, a higher degree of SCI activities means a higher degree of SCP, and H2 is supported.

Response to Research Question 3: The relationship between Industry 4.0 and SCP

The results reveal that Industry 4.0 is positively related to SCP; which means a higher degree of the practices of Industry 4.0 increases the degree of SCP. Therefore, H3 is supported. However, a weak relationship has been observed between these two in terms of the results.

The indirect effect of SCI was also observed between Industry 4.0 and SCP; which means SCI might play a mediating role in the positive relationship between Industry 4.0 and SCP. Based on the results of the analysis of this thesis, SCI is partially mediating the link between Industry 4.0 and SCP. Therefore, H4 is partially supported.

Response to Research Question 4: prioritisation of the indicators of Industry 4.0 and SCI for higher performance in supply chains

The findings which correspond to the relationships between three constructs were also extended by the IPMA matrix. This analysis also showed which items of Industry 4.0 and SCI should be prioritised to achieve higher SCP. Based on the results, strategy items such as roadmap and investments to Industry 4.0 infrastructure as well as employee familiarity were viewed as important items, but organisations perform at a low level on these items. Thus, companies should focus on these indicators first, by reducing their investments from less important items. As for the items of SCI, all internal integration items and decision making with main customers showed high importance to increase SCP. The rest of the items of customer and supplier integration showed low importance. Therefore, organisations first accomplish internal integration items and allocate their investments to this area to succeed in their SCP.

From an academic point of view, this research comprehensively explains the concepts of Industry 4.0, SCI and SCP. The elements were determined for each concept to measure their conceptual frameworks; and further, these frameworks were validated through large scale questionnaire and empirically tested. By discussing the current literature, this dissertation offers an analysis of Industry 4.0 practices on the SCM concept, which will be practical for operations management and supply chain researchers who are likely to develop further research on that field.

The research firstly seeks the relevant framework related to Industry 4.0; otherwise, it may be hard to explore the issues in a developing country since they are considered as a low level of implementation on advanced technologies. Secondly, the research also extended the current literature on SCI and SCP by employing their definitions and key elements, which might be relevant for different SCs. Thirdly, the proposed model that examines the relationship between Industry 4.0, SCI and SCP, covers the research gap in Industry 4.0 activities on the SCM context. Finally, the current research applied in two strategic management theories, the Resource-Based View and Relational View, to present the role of Industry 4.0 for SCP, thereby, extending the insights of this study through theoretical support.

From a managerial point of view, the findings of this dissertation can be practical for operations, production and supply chain managers and practitioners. For an operational perspective, the results indicate that the implementations of Industry 4.0 enhance not only the activities of SC integration but also overall performance across SC in an emerging country context, according to the perceptions of the manufacturing industry. The enterprises which are willing to start to assess their production and operational activities toward the Industry 4.0 path should also consider their strategic objectives, employee factor, technology-driven culture and requirements of implementing a particular technology for their organisations. For this reason, the findings of this research provide a guideline about what items need to be followed and prioritised by managers and practitioners regarding improvements of Industry 4.0 practices.

4.2. Future Research Directions and Recommendations

Despite some arguments of this research regarding the implementation of Industry 4.0 in SC practices; due to the theoretical nature of the field, there are still several open questions to be responded to, which delimitate the generalisability of the findings of this study. Thus, the current study recommends that future studies also consider implementation and standardised facets of these technologies as well as creating a digital environment in workplaces where employees, network partners or machines can integrate with each other. However, it is not enough to only focus on the technological side of Industry 4.0, but also the impacts must be evaluated at a management level. There are many concerns that Industry 4.0 outweighs the related costs, specifically, investing heavily in new technologies, qualified manpower costs or technical expenditures such as data security, integrity might be taken as outlays for organisations. For this reason, scholars must be encouraged to put forth more research on performance assessments including both short and long-term strategies of organisations when they utilise these technologies. In reality, it is not always enough to provide a comprehensive assessment model for enterprises, transformation toward Industry 4.0 may also begin with particular areas such as procurement, ordering or inventory activities. In this sense, future studies should concentrate on case studies, pilot projects or interviews to identify the particular needs of organisations at a company level basis.

The resistance of employees against these technologies should not be underestimated since they are an important factor in enterprises. The new methods of training and adaptation of employees must be examined in more detailed forms. The improvement of specific job profiles and individual qualification layouts should be exploited as a part of increasing the operational performance of organisations. Therefore, the current study also calls for further empirical studies which may be done on the competencies of organisations.

Finally, this research explained the organisational and human aspects as well as the technological point of view of the assessment of Industry 4.0. Future studies might extend this work by adding more aspects such as government role, leadership, agile architecture and several competencies of organisations by examining their benefits and challenges in the SCM concept.

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