Future Generation Computer Systems ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems

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HIGHLIGHTS

- Internet of things (IoT) applied in SCM for building a smart and secure system of SCM.
- An efficient framework which integrates (N-DEMATEL) technique with AHP is proposed.
- The proposed framework help researchers to design secure system of supply chains.
- The proposed framework provide secure environment of SCM processes.

ARTICLE INFO

Article history:
Received 24 February 2018
Received in revised form 12 April 2018
Accepted 17 April 2018
Available online xxxx

Keywords:
Supply chain management (SCM)
Internet of Things (IOT)
Radio frequency identification (RFID)
Multi-criteria decision making (MCDM)
DEMATEL technique
Analytic hierarchy process (AHP)
Neutrosophic set

ABSTRACT

The traditional supply chains faces several challenges such as uncertainty, cost, complexity and vulnerable problems. To overcome these problems the supply chains must be more smarter. For establishing a large-scale of smart infrastructure to merge data, information, products, physical objects and all processes of supply chain, we applies the internet of things (IOT) in supply chain management (SCM) through building a smart and secure system of SCM. We have prepared a website for suppliers and managers. We tracked the flow of products at each stage in supply chain management through the Radio Frequency Identification (RFID) technology. Each product attached with RFID tag and scanned through RFID reader and ESP8266 at each phase of supply chain management. After scanning the tag we stores tag id in the database. All information about products will be entered by suppliers and then uploaded to managers. In our system the supplier and manager gets perfect information of the entire life cycle of goods, and this will achieve transparency of supply chain management. For assessing security criteria of proposed system of supply chain management, we also proposed a framework which integrates neutrosophic Decision Making Trial and Evaluation Laboratory (N-DEMATEL) technique with analytic hierarchy process (AHP). The neutrosophic Decision Making Trial and Evaluation Laboratory (N-DEMATEL) technique is utilized to infer cause and effect interrelationships among criteria of smart supply chain security requirements. Depending on obtained information from (N-DEMATEL) the neutrosophic AHP is utilized to calculate weight of criteria and sub-criteria. Then the integrated framework will help researchers and practitioners to design secure system of supply chains. We presented DEMATEL and AHP in neutrosophic environment to deal effectively with vague, uncertain and incomplete information. So the proposed system of supply chain management will be able to overcome all challenges of traditional SCM and provide secure environment of SCM processes.

1. Introduction

A sharp competition environment was created due to the emergence of global markets. The global and competitive environment droves the flow of business via supply chain (SC) because firms are not individually self-adequate. These chains should coordinate their processes to become more competitive and achieve desired objectives of partners.

Supply chain (SC) is a set of processes and entities (suppliers, customers, factories, distributors and retailers) which are interested to fulfill customer order. The plan, source, make, deliver, return and enable are the main processes of SC according to Supply Chain Operations Reference Model (SCOR) [1].

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https://doi.org/10.1016/j.future.2018.04.051
0167-739X/

Supply chain management (SCM) means having the correct item in the correct volume at the correct time at the correct place for the correct price in the correct condition to the correct customer [2]. In traditional supply chain management systems there exist several problems such as overstocking, delivery delays and stock out. These problems returns to several factors such as complexity and uncertainty which exist usually in real supply chains.

The cheaper, better and faster item is the desirable for SC managers. Also maximizing surplus which is the whole payments from end customers minus all costs which incurred via SC. Traditional supply chains are becoming more costly, complex and vulnerable. To overcome these challenges, the supply chains must be more smarter.

We can define smart supply chain as a modern and interconnected system which expands from separated, regional and single firm applications to wide and systematic implementation of supply chains.

For effective management of supply chain, the information technology (IT) plays a very important role [3]. The IT has ability to integrate different processes, suppliers and customers internally and externally via enhancing communication, collection and transfer of data and information and then improve supply chain performance.

One of the most important development of information technology is the internet of things (IOT). The term IOT has coined by Kevin Ashton in 1999 [4]. We can define it as a set of physical and virtual objects which are connected together via a network for communication and sensing or interaction with internal and external environment.

If we define internet of things relates to supply chain management, we can define it as a set of physical objects which are connected digitally for sensing, monitoring and interaction within a firm and among the firm and its SC cementing agility, visibility, sharing of information and tracking to facilitate plan, control and coordination of processes for supply chains.

Our goal here is to apply IOT in SCM for making connection between supply chain entities and processes, identifying products and goods automatically, tracking flow of products at each stage, providing a complete information during the entire life cycle of products, and achieving transparency of supply chain system to overcome challenges of traditional SC.

In order to achieve our goal we designed a website for suppliers and managers. We tracked the flow of products at each stage in SCM through the RFID technology. Each product attached with RFID tag and scanned through RFID reader and ESP8266 at each phase of supply chain management. After scanning the tag we stores tag id in the database. The ESP8266 is a Wi-Fi chip with depressed cost. All information about products will be entered by suppliers and then uploaded to managers. In our system the supplier and manager gets perfect information of the entire life cycle of products, and this will achieve transparency of supply chain management.

For assessing security criteria of the proposed system of supply chain management, we also proposed a framework which integrates neutrosophic Decision Making Trial and Evaluation Laboratory (N-DEMATEL) technique with analytic hierarchy process (AHP). We present the DEMATEL and AHP in neutrosophic environment because security criteria are always complex, vague and inconsistent in nature.

The generalization of classic set, fuzzy set, and intuitionistic fuzzy set, is the neutrosophic set. Each value in neutrosophic set has three membership degrees for representing reality effectively, which are the truth, indeterminacy and falsity degrees. For more information about neutrosophic sets see [5].

The remainder of this research is structured as follows:

A literature review about internet of things and its applications in SCM presented in Section 2. Section 3 illustrates the basic concepts of SCM and IOT. The proposed framework of smart supply chain management presented in Section 4. The integrated model of neutrosophic DEMATEL and AHP techniques for assessing security criteria for SCM system presented in Section 5. For validating the proposed model we solved a case study in Section 6. The conclusions and the future directions of the research presented in Section 7.

2. Literature review

A survey on various applications of IOT and its applications in SCM processes presented in this section. To gather the most pertinent literature to our research we have searched Google Scholar and we have also searched some publishers websites such as Springer, Elsevier, Emerald, and Taylor & Francis.

The impact of internet of things (IOT) on various processes of supply chain management is not known. Since SCOR model divides the processes of SC into plan, source, make, deliver, return and enable, then we will illustrate the impact of IOT on each process with detail in our literature review.

– **Enable process of supply chain**

The enabling technologies of internet of things usually consists of four major layers which are as follows [6]:

1. Layer for data collection, which use RFID technology and sensors,
2. Layer for transmission process which use stable and mobile networks,
3. Layer for service, and
4. Layer for interface.

The goods are monitored at anytime and anywhere by Yuvaraj and Sangeetha [7] via integrating RFID tags with GPS technology to track product indoor and outdoor. A new concept of cloud of things is developed by Yan et al. [8] for facilitating resource sharing and collaboration between supply chains partners. A framework for collaborative SC presented by Gnimpieba et al. [9] via using various IT enablers with cloud platform. The internet of things technologies regarding to data acquisition in industrial management of asset presented by Kinnunen et al. [10]. The recent trends in smart transportation presented by Singh and Gupta [11]. An IoT architecture was used by Shih and Wang [12] to develop a Time Temperature Indicator (TTI) of SC.

The problems and challenges which relates to IT enablers technologies, researched by several authors. The security and privacy issues presented by Bi et al. [13]. According to several authors, the major enablers of IT are the RFID technologies and sensors. For studying the impact of RFID technology on supply chains, several researches are presented. For papers which published before 2010, you can see [14]. A new technique for RFID optimal deployment in SC network, presented by Chang et al. [15]. Assessing RFID technology as enablers for integrating SC, presented by Wamba [16]. Also for studying the impact of RFID technology on manufacturing and efficiency of SC, Zelbst et al. [17] presented a research. Also, for align RFID with SC strategies, Leung et al. [18] presented a study.

– **Source process of supply chain**

The request for materials and services by companies is the sourcing process. Planning source activities strategically across the SC, is a sign of supply chain success. The virtualization of supply chain enables by using internet of things according to Verdouw et al. [19]. For tracking and tracing goods through their lifecycle in supply chain a virtual control of SC has been presented. A model for integrating collected data from internet of things strategic planning for product assortments, has been presented by Ng et al. [20].

The impact of internet of things on supplier selection studied by Yu et al. [21]. Also several advantages of internet of things regarding to sourcing process have been identified. For analyzing the impact of the cost of sensors and notifications on the purchase cost of unit, Decker et al. [22] developed a simple model of linear cost.

– **Make process of supply chain**

The regions which can be improved by IOT applications and relevant to SC make process involve: factory visibility as in [23], management of innovative production networks as in [24], smart design and production control as in [25], systematic design of the virtual factory as in [26], smart factory in the petrochemical industry [27], opportunities for sustainable manufacturing in industry 4.0 [28]. Other application areas presented in [29–31].

– **Deliver process of supply chain**

One of the most significant tasks of logistics is the delivery function. Logistics includes: plan, storage and control of goods and services flow [32]. In supply chain, the delivery process is concerned with warehouse, inventory and order management, and transportation. The main impact of IOT on SC delivery process includes:

- Warehousing function: the IOT enables time saving of joint ordering via using smart RFID tags [33]. IOT also achieve collaborative warehousing via using smart things and multi-agent systems. It also increase safety and security of supply chain [34].
- In order and inventory management: the IOT enables sharing of information, inventory accuracy [35] via using RFID tags.
- In transportation function: the IOT achieve accurate and timely delivery via using sensors and networks [36]. It also saves scanning and recording times via using smart phones [37].

– **Return process of supply chain**

A closed loop SC model to meet the demand of sales collection center using both new and remanufactured products presented by Paksoy et al. [38]. The e-reverse logistic framework designed by Xing et al. [39]. An integrated three-stage model for optimizing procurement, pricing, product recovery and strategy of return acquisition, proposed by Fang et al. [40].

– **Other applications**

The internet of things (IOT) also applied in various research areas such as pharmaceutical supply chain [41], construction industry [42], petrochemical industry [43], retail industry and food supply chains [44].

3. Internet of things (IOT) and supply chain management

We presents in this section the basic definitions of internet of things (IOT) and supply chain management. The characteristics of smart supply chain also illustrated here, and the impact of IOT on supply chain management also presented. The meaning of "supply chain" is the alignment of companies which fetch products or services to market. The traditional supply chain is a grid of raw materials, information, services and processes which characterize supply, transformation and demand as presented by Chen and Paulraj [45]. The supply chain can be internal within the enterprise or external which express enterprise boundaries as presented in Fig. 1.

Supply chain management (SCM) is the management process of supply chain activities for maximizing customer satisfaction and realizing a sustainable competitive benefit. A simple diagram of supply chain management presented in Fig. 2.

In traditional supply chain management systems there exist several problems such as overstocking, delivery delays and stock out. These problems returns to several factors such as complexity and uncertainty which exist in real supply chains.

In order to overcome these drawbacks of supply chain management systems, we need to make it more smarter. So we applied IOT in SCM systems in this research.

There exist several definitions of IOT, some researchers defined it as a grid of software, hardware, databases, virtual and physical objects, and sensors connecting and working together for serving humanity [47].

The internet of things [IOT] enables anytime, anywhere, anything and any media communications. The IOT can be applied in any aspect of our lives as in Fig. 3. The smart devices of IOT enables supply chain companies to reduce cost which results from acquisition process of knowledge.

Applying IOT in supply chain management will make it more smarter and have the following characteristics: (1) Instrumented: information in supply chain being machine generated. (2) Interconnected via using smart objects and IT systems. (3) Intelligent: optimize performance via making a large-scale of optimal decisions. (4) Automated: all processes must be automated to substitute low efficiency resources. (5) Integrated: collaboration between supply chain stages. (6) Innovative: the evolution of new values via solutions for meeting new requirements.

The impacts of IOT on SC:

1. Enhance management of inventory: the real time visibility of the inventory has been created through using internet of things (IOT). The management process of inventory will rely on guessing without having a real time visibility. Also manual collection of data cause inventory disorder problem. Adding sensors leads to 100% accuracy rate of inventory.
2. Real time supply chain management: in traditional supply chain management information on demand passes only to one partner instead of sharing it. But the new technologies of RFID tags enables recording process of all types of information such as production and expire date, warrant period and this will achieve effective management of supply chain.
3. Maximize transparency of logistics: all transport information (transport condition, destination, etc.) will be available to the entire supply chain through using smart objects. This will increase the chance of monitoring and saving goods. It also minimize cost of return and has a great impact on customer satisfaction.

4. The proposed framework of smart supply chain management

In this section we have constructed a system for supplier and manager. For tracking products at each stage of supply chain management, we used RFID technology. Each product attached with RFID tag and the RFID reader and Esp8266 are used for scanning the products at each stage of SCM. After scanning products, the tag ID uploads to database. The product information will be filled by supplier through the manager. The general framework of supply chain management presented in Fig. 4.

In Fig. 4, each supplier will login system and insert all information which relates to product or service and these information saves in system. Manager by logging in system can obtain all required information about supplier and his/her product. He/she will send the product status and final decision to system. Each product attached with Tag ID, the RFID reader scans the product and send Tag ID to database. Through using RFID technology all information about products will be available such as production, expire date, and warranty period. These information can be shared

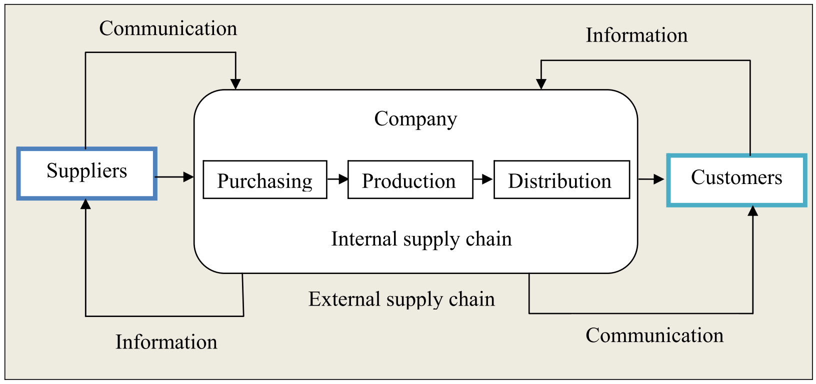

Fig. 1. Internal and external supply chain model [46].

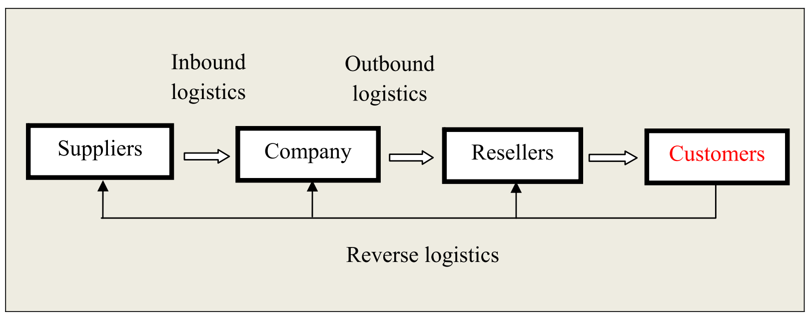

Fig. 2. Supply chain management.

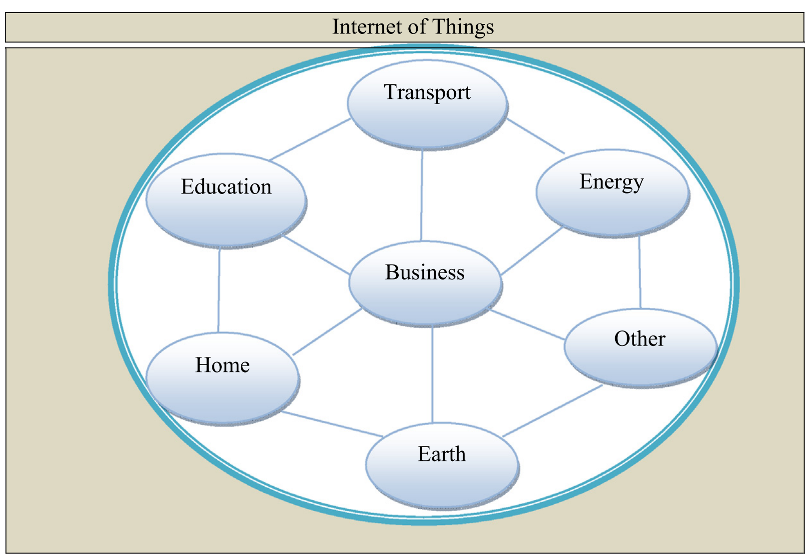

Fig. 3. Internet of things applications fields.

across supply chain stages through using Esp8266 which is a low cost Wi-Fi module. The detailed diagram of the proposed framework of smart SCM presented in Fig. 5.

The previous framework of smart supply chain management as appears in Fig. 5, consist of three stages:

In the first stage, we have designed a website for supplier and manager in order to facilitate communication process. We used several technologies related to IOT such as RFID tag for tracking products at each stage and scanning them via RFID reader and store all information about products in a database. This will enhance data collection process. These information shares between suppliers and managers easily via using Esp8266 which is a low cost Wi-Fi module. This will achieve system transparency. Both manager and supplier can obtain product information from system database.

In the second stage, according to obtained information from database the manager will evaluate supplier's product and select only the high quality products. The selected products, purchases from supplier and then store in the warehouses. The supplier in this phase can access to system via entering username, password and track product status (accept, reject).

In the final stage, after evaluating suppliers products and selecting the best, then a purchase process should be executed. After purchasing and processing products, a smart transportation system should be available for distribution process. We used GPS

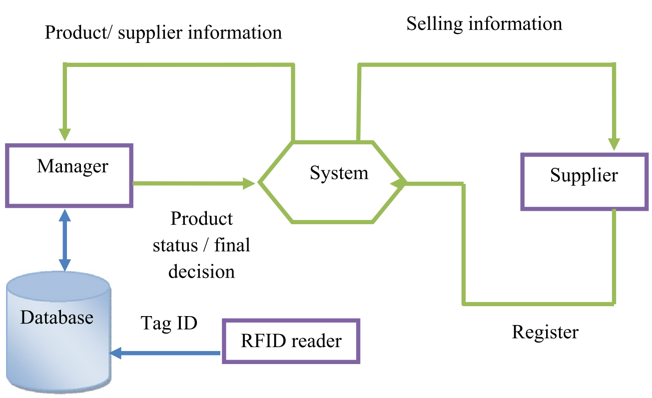

Fig. 4. The general form of supply chain management system.

(Global Positioning System), GIS (Geographic Information System), and sensors technology to track vehicle location and ensure safety of on board products. According to order information, the products will deliver to customers. The obtained information from customer order established via smart phones technology.

For implementing proposed framework we needs the following:

1. Software implementation: the HTML, CSS, JavaScript and PHP languages.
2. Hardware implementation: the RFID tags, RFID readers, GIS, GPS, and Esp8266 technologies. The scanning of products tags via using FRID reader presented in Fig. 6.
   The smart transportation system for distributing products and goods to customer depends on GPS, GIS, and sensors. The vehicle sensors includes: humidity and temperature sensor, and sensor of tire pressure. The previous technologies enables location tracking and monitoring of vehicle system.

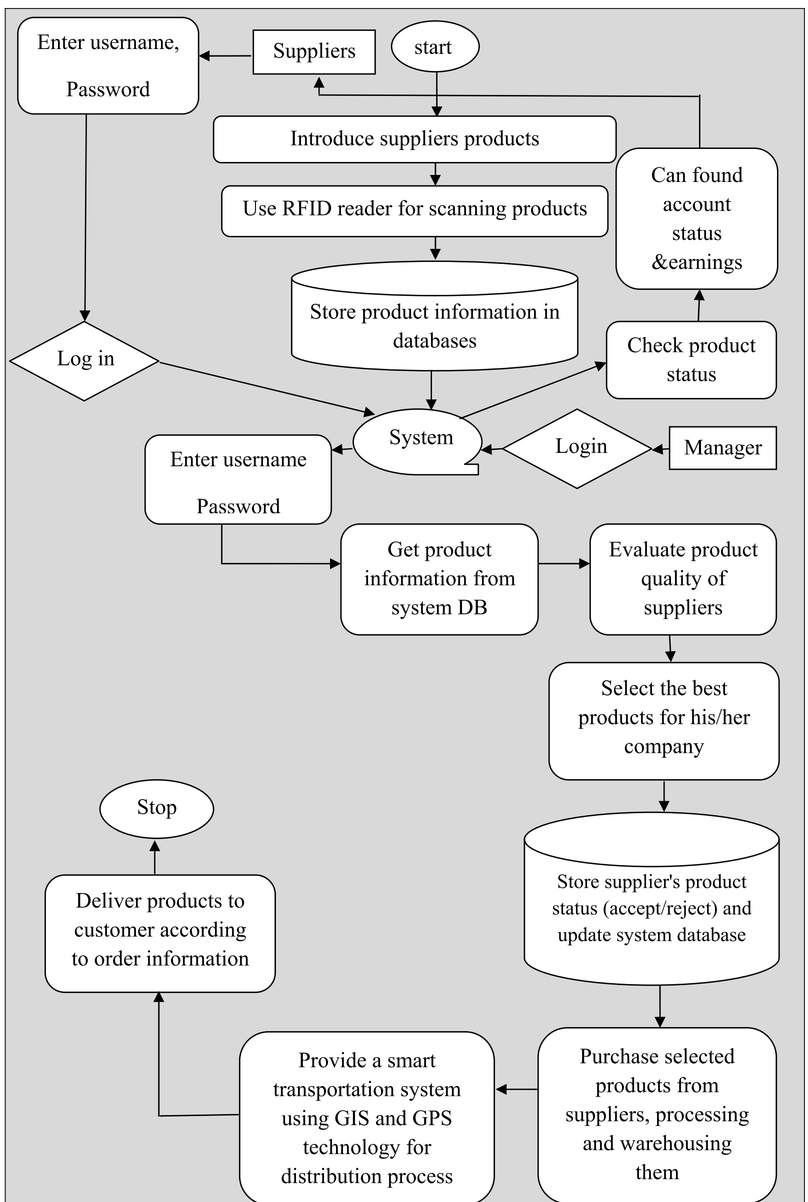

Fig. 5. The detailed diagram of the proposed framework for smart SCM.

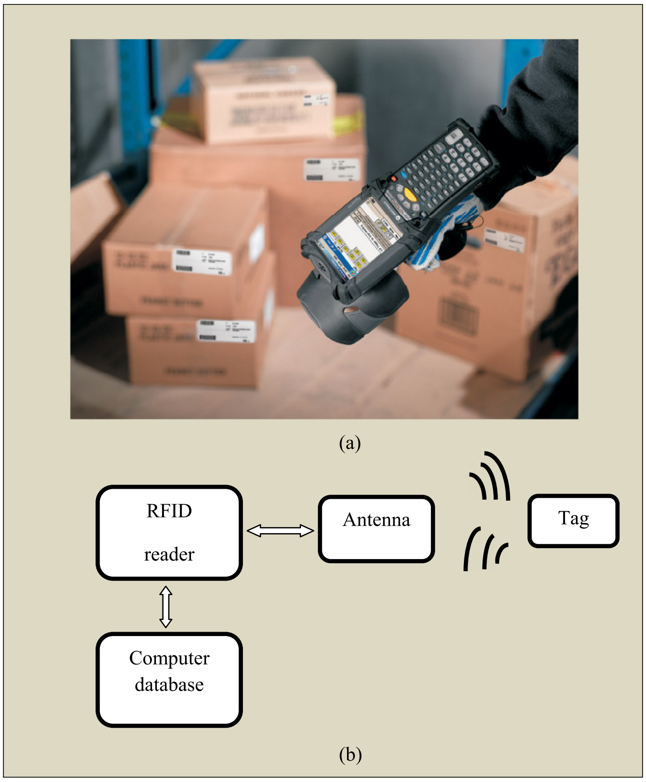

Fig. 6. The RFID reader via scanning products and store tag ID in computer database.

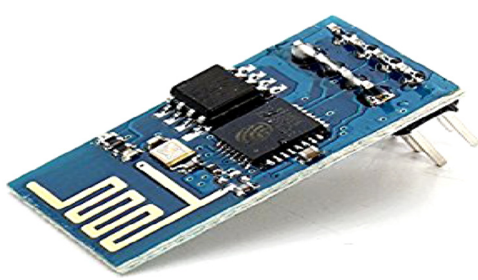

Fig. 7. The Esp8266 Wi-Fi module.

All gathered data and information in the entire supply chain management system shares through using Esp8266 technology. The Esp8266 is a Wi-Fi chip with a low cost. The Esp8266 Wi-Fi module presented in Fig. 7.

In order to determine security requirements of the proposed system for supply chain management, we present a framework for assessing security criteria of system in the next section.

5. The integrated model of neutrosophic DEMATEL and AHP techniques for assessing security criteria for SCM system

There is a significant necessity to understand how to realize security in supply chain management systems. So the main objective of this section is to explore the major security requirement for smart SCM systems. The security requirement criteria are always multi-dimensional, complex, vague and inconsistent in nature. So we integrated DEMATEL and AHP in neutrosophic environment to deal effectively with all types of uncertainty. The neutrosophic DEMATEL is utilized to infer cause and effect interrelationships among criteria. The neutrosophic AHP is applied to calculate weight of security requirements.

5.1. The related work of DEMATEL and AHP techniques

The decision making trial and evaluation laboratory technique has been implemented in different situations such as :(1) manufacturing planning and control [48] as management control systems, (2) marketing strategy and enhance customer performance [49], (3) measurement of security and safety factors [50], (4) expert systems and fuzzy methods [51], (5) determining success factors for achieving quality of hospital service [52], (6) selecting suitable material for industry.

DEMATEL technique also applied to evaluate and select green supplier [53]. It also utilized to evaluate sustainable supplier, prioritize distribution centers for supply chain [54].

DEMATEL technique also integrated with several multi-criteria decision making (MCDM) techniques. The DEMATEL technique combined analytic network process (ANP) for making a novel cluster weighted method [55]. It integrated with ANP and VIKOR for evaluating brand marketing through creating brand value depend on a MCDM model [56].

It also presented in fuzzy environment with other MCDM techniques such as ANP and TOPSIS for evaluating green suppliers [57]. Also a fuzzy MCDM model for selecting suppliers presented in [58] via combining DEMATEL with TOPSIS technique. It also integrated with ANP in fuzzy environment to provide framework for assessing security criteria [59]. It also integrated with analytic hierarchy process (AHP) to evaluate criteria of auto spare parts industry [60], and to evaluate intertwined effects in e-learning programs [61].

DEMATEL technique also presented in neutrosophic environment to develop supplier selection criteria [62]. We are the first to integrate neutrosophic DEMATEL with AHP for assessing security criteria of supply chain management systems.

5.2. The proposed framework for assessing security criteria of supply chain systems

The security criteria are always complex, vague, uncertain and inconsistent in nature. Also, understanding the method to assess security criteria is a very significant process. So, in this part we integrated neutrosophic DEMATEL with neutrosophic AHP to handle these issues.

We applied DEMATEL technique to find cause and effect among criteria. Then we applied AHP to calculate weights of criteria for presenting the final framework of security. The reason for introducing DEMATEL and AHP in neutrosophic environment is to handle vague, uncertain and inconsistent information which exist usually in reality.

5.2.1. Neutrosophic set theory and neutrosophic numbers

Neutrosophic set theory, introduced by Smarandache [63], to overcome drawbacks of classical, fuzzy and intuitionistic fuzzy sets. It is a mathematical approach used to demonstrate uncertainty in systems or events since inexactitude in decision making process arises uncertainty. Unquantifiable or not measurable information, incomplete or inaccessible data or part-time ignorance are the major causes of uncertainty.

The neutrosophic set theory has proved to be very important for modeling all types of uncertainty in different research domains [5]. Since decision makers judgments returns to decision makers opinions, then neutrosophic concept is very suitable in these problems.

Among neutrosophic numbers, triangular neutrosophic numbers (TNN) have been specified as beneficial in quantifying the uncertainty. Triangular neutrosophic numbers is denoted by $\tilde{a} =$

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$\langle (l, m, u); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$, where l, m, u denotes smallest, median and largest possible value which depict fuzzy event. The $\alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}$ denotes the maximum degree of truth membership, minimum degree of indeterminacy and falsity memberships respectively.

The truth, indeterminacy and falsity membership functions of triangular neutrosophic number are as follows:

$$T_{\tilde{a}}(x) = \begin{cases} \alpha_{\tilde{a}}\left(\frac{x-l}{m-l}\right) & (l \le x \le m) \\ \alpha_{\tilde{a}} & (x = m) \\ \alpha_{\tilde{a}}\left(\frac{u-x}{u-m}\right) & (m < x \le u) \\ 0 & \text{otherwise}, \end{cases} \tag{1}$$

$$I_{\tilde{a}}(x) = \begin{cases} \frac{(m-x+\theta_{\tilde{a}}(x-l))}{(m-l)} & (l \le x \le m) \\ \theta_{\tilde{a}} & (x = m) \\ \frac{(x-m+\theta_{\tilde{a}}(u-x))}{(u-m)} & (m < x \le u) \\ 1 & \text{otherwise}, \end{cases} \tag{2}$$

$$F_{\tilde{a}}(x) = \begin{cases} \frac{(m-x+\beta_{\tilde{a}}(x-l))}{(m-l)} & (l \le x \le m) \\ \beta_{\tilde{a}} & (x = m) \\ \frac{(x-m+\beta_{\tilde{a}}(u-x))}{(u-m)} & (m < x \le u) \\ 1 & \text{otherwise}. \end{cases} \tag{3}$$

5.2.2. Neutrosophic DEMATEL and AHP techniques: Proposed framework

In this part we presents the proposed framework for assessing security criteria of supply chain management systems. We integrates DEMATEL and AHP through using neutrosophic set theory and triangular neutrosophic numbers for handling vague, uncertain, inconsistent and incomplete information effectively.

Geneva research center of the Battelle Memorial Institute, originated the DEMATEL technique to build and analyze a structural model involve cause and effect interrelationships among complex criteria [64].

Saaty proposed the analytic hierarchy process (AHP) for solving complex problems [65]. AHP compose complex problems to subproblems for solving them easier. The first level of hierarchy is goal which wanted to be achieved. Followed it by criteria and sub-criteria. Finally, all available alternatives should be presented for ranking them and selecting the best one. The AHP construct comparison matrices for comparing criteria together with respect to goal, and comparison matrices for comparing alternatives with respect to criteria. Saaty proposed the 9 point scale for comparing alternatives and criteria.

The calculations and steps of proposed framework (neutrosophic DEMATEL–AHP technique) are as follows:

Step 1: Construct committee of experts who had experience in security domain for evaluating security criteria.

Step 2: Determine problem's goal and relevant criteria. All criteria (factors) in DEMATEL technique are cause and effect.

Step 3: Use the DEMATEL scale (four point scale) for determining the values of relationships among various criteria regarding to expert's opinions. The scale are as follows: "No influence", "Low influence", "High influence", and "very high influence". Represent each scale value using triangular neutrosophic number as in Table 1.

Table 1
Linguistic terms and scale of neutrosophic DEMATEL.

DEMATEL scale	Meaning	Triangular neutrosophic value
0	No influence	$\tilde{0} = \langle (0, 0, 0) \rangle$
1	Low influence	$\tilde{1} = \langle (0, 1, 2) \rangle$
2	High influence	$\tilde{2} = \langle (1, 2, 3) \rangle$
3	very high influence	$\tilde{3} = \langle (2, 3, 4) \rangle$

In the previous table each triangular number as we illustrated should has degree of truth, indeterminacy and falsity, and in our research we lets experts to inset them according to their opinions via making their judgments.

Step 4: Calculate direct relation (average) matrix: each expert in decision making process will compare criteria with respect to goal, and sub-criteria with respect to each criterion by using the presented scale in Table 1. According to number of experts, the direct relation matrix obtains by taking average of all experts' matrices. In order to take average of experts' matrices we need to transform neutrosophic matrix to crisp matrix via using a score function:

Let $\tilde{a} = \langle (l, m, u); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$ is a triangular neutrosophic number then to obtain its crisp value a, we apply this score function equation [5]:

$$S(\tilde{a}) = \left| \frac{(l+m+u)}{3} + (\alpha_{\tilde{a}} - \theta_{\tilde{a}} - \beta_{\tilde{a}}) \right| \tag{4}$$

After obtaining crisp values, then taking average of all experts matrices is now become simple. Then the direct relation (average) matrix $A = \left[a_{ij}\right]_{n \times n}$, where a_{ij} represents the degree to which criterion i effect criterion j.

Step 5 : Obtain normalized direct relation matrix (n) using the following equation:

$$N = k \times A \tag{5}$$

where A is the direct relation matrix and $k = \frac{1}{max_{1 \le i \le n}} \sum_{j=1}^{n} a_{ij}$

Step 6 : Calculate total relation matrix T using the following equation:

$$T = N \times (I - N)^{-1} \tag{6}$$

Step 7 : Calculate r which is the sum of rows of the total relation matrix, and calculate c which is the sum of columns of the total relation matrix as in Eqs. (4) and (5) respectively:

$$[r_i]_{n \times 1} = (\sum_{j=1}^{n} t_{ij})_{n \times 1} \tag{7}$$

$$\left[c_j\right]_{1 \times n} = (\sum_{i=1}^{n} t_{ij})_{1 \times n} \tag{8}$$

Step 8: Draw the cause and effect diagram or network relation map (NRM). The horizontal axis is represented by $(r+c)$, the vertical axis $(r-c)$. The greater value of $(r+c)$ represents the high effect and it represent the degree of significance (effect) which the criterion plays in the entire system. The $(r-c)$ represents the casual relation among criteria, the greater value means that the criterion is the cause of other criteria.

Step 9: Let us begin to calculate weight of criteria via using neutrosophic AHP: in order to calculate weight we should first construct the comparison matrices of criteria with respect to goal and sub-criteria with respect to criteria by using triangular neutrosophic scale of neutrosophic AHP as in Table 2. Note that, we construct comparison matrices only for the most important elements which have determined from using neutrosophic DEMATEL technique, and this will save time.

Also the truth, indeterminacy and falsity degrees of each triangular number will determine through the calculations by experts and according to their opinions.

Then, the neutrosophic pair-wise comparison matrix of criteria, sub-criteria are as follows:

$$\tilde{A} = \begin{bmatrix} \tilde{1} & \tilde{a}_{12} \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} \cdots & \tilde{1} \end{bmatrix} \tag{9}$$

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Table 2
Linguistic terms and neutrosophic scale of AHP.

Saaty scale	Explanation	Triangular neutrosophic scale
1	Equally significant	$\tilde{1} = \langle(1, 1, 1)\rangle$
3	Slightly significant	$\tilde{3} = \langle(2, 3, 4)\rangle$
5	Strongly significant	$\tilde{5} = \langle(4, 5, 6)\rangle$
7	Very strongly significant	$\tilde{7} = \langle(6, 7, 8)\rangle$
9	Absolutely significant	$\tilde{9} = \langle(8, 9, 10)\rangle$
2		$\tilde{2} = \langle(1, 2, 3)\rangle$
4	Sporadic values between two close scales	$\tilde{4} = \langle(3, 4, 5)\rangle$
6		$\tilde{6} = \langle(5, 6, 7)\rangle$
8		$\tilde{8} = \langle(7, 8, 9)\rangle$

where $\tilde{a}_{ji} = \tilde{a}_{ij}{}^{-1}$, and it is the triangular neutrosophic number that measures the vagueness of decision makers.

Step 10: Transform neutrosophic matrices to crisp by using score function as in Eq. (4).

Step 11: Check consistency of pairwise comparison matrices which generated in the previous step by experts. We utilized super decisions software for calculating consistency ratio (CR). The consistency ratio (CR) should be less than 0.1.

Step 12: Calculate weights of criteria for prioritizing them.

The whole steps of proposed approach presented in Fig. 8.

6. The empirical analysis

For deriving a security estimation framework of smart supply chain management (SSCM), we combined neutrosophic DEMATEL and neutrosophic AHP for investigating internal relations between different security criteria and calculate overall weight and priorities of these criteria.

For determining and evaluating security criteria of proposed SCM system, we selected 8 experts. Each expert had over 5 years of experience in various fields of security. The experts have great capability to estimate the security framework and then make decisions.

There exist two methods for making estimation process by experts:

1. Most estimation values gathered by face-to-face meeting,
2. The little part gathered by e-mail.

The security criteria to be considered in smart supply chain management systems according to experts opinions are as in Fig. 9.

The evaluation process of security framework depends on two phases:

1. The first phase is for investigating the interrelations of security criteria. The experts uses the scale of neutrosophic DEMATEL as presented in Table 1. The data from this phase analyze by neutrosophic DEMATEL method.
2. The second phase is for calculating weights of sub-criteria. The 9 point neutrosophic scale which presented in Table 2 is utilized in this phase.

For applying first phase of evaluation: let experts use the DEMATEL scale (four point scale) for determining the values of relationships among various criteria regarding to expert's opinions. The scale are as follows: "No influence", "Low influence", "High influence", and "very high influence". Represent each scale value using triangular neutrosophic number as in Table 1.

For each triangular neutrosophic value in Table 1, let experts insert the degree of truth, indeterminacy and falsity according to their opinions through making their judgments.

After making comparison matrices of all criteria and sub-criteria according to the 8 experts in system, then calculate the direct relation (average) matrix. Since each expert in decision making

Table 3
Direct relation matrix between criteria.

Goal	C_1	C_2	C_3	C_4
C_1	0	7.7	5.7	5.6
C_2	1.7	0	7.7	4.8
C_3	3.3	6.3	0	6
C_4	5.9	4.9	6.3	0

Table 4
Direct relation matrix between sub-criteria according to (dependability).

C_1	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
C_{11}	0	2.8	2.9	0.9	2	7
C_{12}	5	0	4.6	1	2.3	1.7
C_{13}	0.8	2.8	0	0.5	4.5	0.82
C_{14}	1.8	2.4	6	0	4.7	0.46
C_{15}	4.2	3.5	7	1	0	2.9
C_{16}	7	0.5	6	0.7	3.3	0

Table 5
Direct relation matrix between sub-criteria according to (service).

C_2	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
C_{21}	0	3	2	8	8	7
C_{22}	4	0	24	5	2	2
C_{23}	5	8	0	3	8	2
C_{24}	7	2	3	0	7	8
C_{25}	3	5	2	2	0	5
C_{26}	7	2	6	8	8	0

Table 6
Direct relation matrix between sub-criteria according to (network).

C_3	C_{31}	C_{32}	C_{33}	C_{34}
C_{31}	0	2.4	5.6	5.3
C_{32}	1.5	0	7.6	5
C_{33}	3.3	6	0	6
C_{34}	6	4.6	5	0

Table 7
Direct relation matrix between sub-criteria according to (privacy).

C_4	C_{41}	C_{42}	C_{43}
C_{41}	0	4	6
C_{42}	3	0	6
C_{43}	5	7	0

process compared criteria with respect goal, and sub-criteria with respect to each criterion by using the presented scale in Table 1. According to number of experts, the direct relation matrix obtains by taking average of all experts' matrices. In order to take average of experts' matrices we need to transform neutrosophic matrix to crisp matrix via using a score function as in Eq. (4). Then the final form of direct relation matrices are presented in Tables 3–7.

After then, calculate the normalized direct relation matrix (N) using Eq. (5).

Calculate the total relation matrix T using Eq. (6). The total relation matrix are presented in Tables 8–12 and for each total

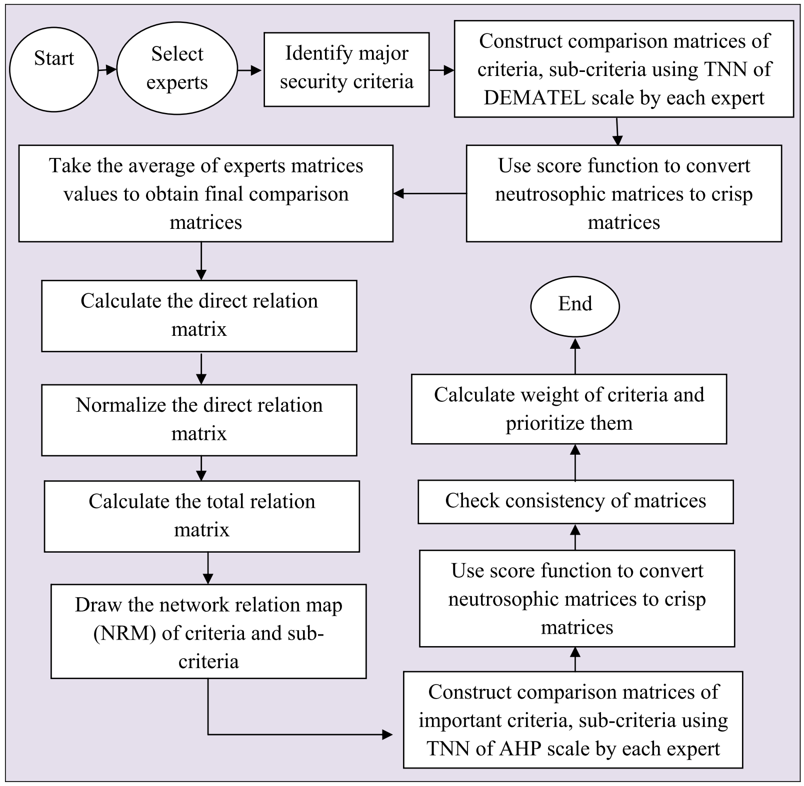

Fig. 8. The proposed framework.

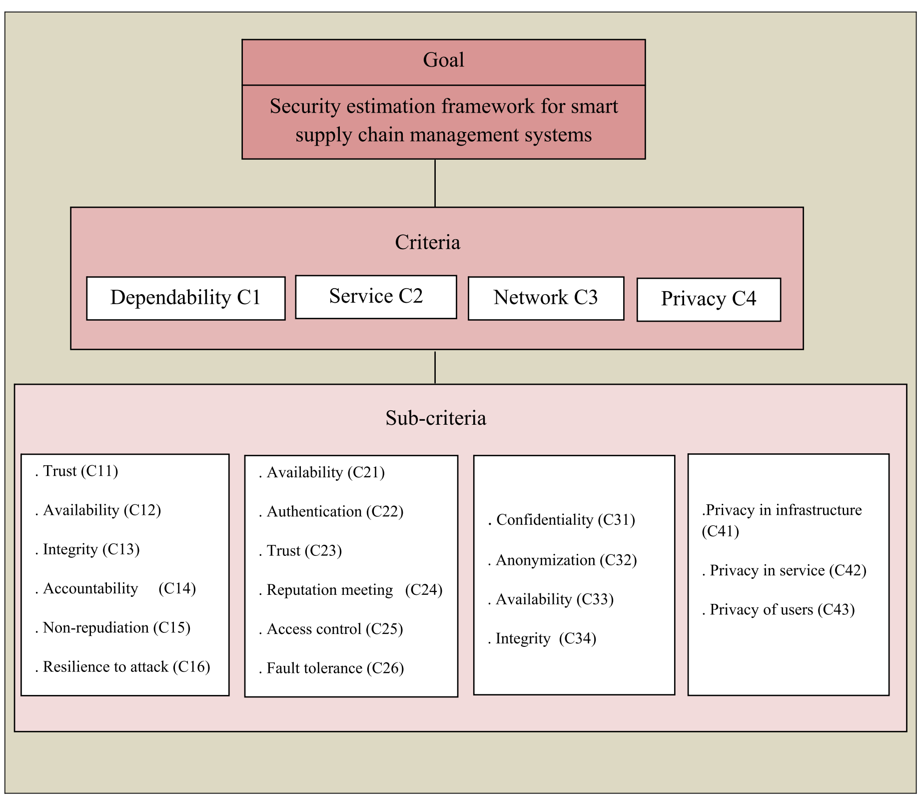

Fig. 9. The SSCM system's security criteria.

relation matrix, calculate r which is the sum of rows of the total relation matrix, and calculate c which is the sum of columns of the total relation matrix using Eqs. (7) and (8).

Let us now draw the cause and effect diagram or network relation map (NRM). The horizontal axis is represented by $(r + c)$, the vertical axis $(r - c)$. The greater value of $(r + c)$ represents the

Table 8
Total relation matrix between criteria.

Goal	C_1	C_2	C_3	C_4	r	$r+c$	$r-c$
C_1	0.94	1.72	1.70	1.44	5.8	9.6	2
C_2	0.80	1.05	1.38	1.07	4.3	10.1	−1.5
C_3	0.96	1.43	1.23	1.24	4.9	10.8	−1
C_4	1.11	1.56	1.59	1.12	5.4	10.3	0.5
C	3.8	5.8	5.9	4.9			

high effect and it represent the degree of significance (effect) which the criterion plays in the entire system. The $(r-c)$ represents the casual relation among criteria, the positive value means that the criterion is the cause of other criteria and negative value means that the criterion is affected by other criteria. The cause and effect diagram or network relation map (NRM) of criteria and sub-criteria presented in Figs. 10–14.

As shown in Fig. 10, the dependability (C1) and privacy (C4) criteria have positive $(r-c)$values, and thus they are the essence criteria of security which affect other security criteria. Also the criteria which are affected by other dimensions are service (C2), and network (C3). The criteria with the highest value of $(r+c)$ are the network criterion (C3), and followed by privacy (C4) criterion. These criteria are the major criteria for security components. The threshold value eliminates some of the minor effects of elements and can be determined by taking the average of elements in total relation matrix.

The cause and effect diagram of sub-criteria regarding to dependability shows that the integrity (C13) criterion has the height $(+c)$ value and it is the highest effect between elements.

Also in cause and effect diagram of sub-criteria regarding to service shows that the trust (C23) criterion has the height $(+c)$ value and it is the highest effect between elements.

According to network, the availability (C33) is the higher value of $(r+c)$ and then it is the most important sub-criteria.

Also, in the cause and effect diagram of sub-criteria regarding to privacy shows that the privacy in infrastructure (C41) criterion has the height $(r+c)$ value and it is the highest effect between elements, and privacy in service (C42) is affected by other security elements.

The previous steps represented by neutrosophic DEMATEL for finding cause and effect relationships of criteria and sub-criteria. In order to calculate weight of each criteria and sub-criteria we focus only on the major important sub-criteria.

In the next phase the experts construct comparison matrices of criteria and sub-criteria via using triangular neutrosophic scale of AHP as illustrated in Table 2.

Table 11
Total relation matrix between sub-criteria according to (network).

C_3	C_{31}	C_{32}	C_{33}	C_{34}	r	$r+c$	$r-c$
C_{31}	2.53	3.12	3.99	3.72	13.4	24.7	2.1
C_{32}	2.76	3.18	4.29	3.90	14.1	27.5	0.7
C_{33}	2.97	3.59	4.14	4.11	14.8	31.6	−2
C_{34}	3.09	3.55	4.40	3.86	14.9	30.5	−0.7
C	11.3	13.4	16.8	15.6			

Table 12
Total relation matrix between sub-criteria according to (privacy).

C_4	C_{41}	C_{42}	C_{43}	r	$r+c$	$r-c$
C_{41}	1.57	2.23	2.41	6.2	11.5	0.9
C_{42}	1.67	1.86	2.26	5.8	12.5	−0.9
C_{43}	2.05	2.60	2.32	7	14	0
c	5.3	6.7	7			

Table 13
The crisp comparison matrix between criteria.

	C_1	C_2	C_3	C_4	Weights
C_1	1	2	1/3	1/4	0.14
C_2	0.5	1	1/4	1/2	0.11
C_3	3	4	1	2	0.45
C_4	4	2	1/2	1	0.30

Because we have 8 experts in our case study then we let each expert to use the predetermined scale in Table 2 to construct comparison matrices, and then utilize the score function as in Eq. (4) to transform neutrosophic matrices to crisp matrices. Then we integrate matrices of 8 experts by taking average of experts matrices.

The final form of comparison matrix for criteria with respect to goal represented in Table 13.

For checking consistency of previous matrix we utilized the super decisions software. The consistency ratio (CR) =0.08 <0.1, then its acceptable ratio.

We ask experts to focus only on the important sub-criteria which have determined by making analysis of data by using neutrosophic DEMATEL technique.

For dependability criteria the most important sub-criteria are trust (C11), integrity (C13), non-repudiation (C15). So we ask experts to make comparison matrix of only these three sub-criteria using neutrosophic AHP scale. After transforming neutrosophic matrices to crisp matrices and taking average of experts matrices, then the final form of comparing C11, C13 and C15 regarding to dependability as in Table 14.

Table 9
Total relation matrix between sub-criteria according to (dependability).

C_1	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	r	$r+c$	$r-c$
C_{11}	0.63	0.55	0.93	0.19	0.63	0.78	3.7	7.8	−0.4
C_{12}	0.74	0.39	0.88	0.18	0.58	0.52	3.3	6.3	0.3
C_{13}	0.43	0.42	0.52	0.13	0.54	0.34	2.4	7.9	−3.1
C_{14}	0.60	0.53	0.99	0.14	0.72	0.44	3.4	4.4	2.4
C_{15}	0.82	0.63	1.14	0.21	0.59	0.65	4	7.8	0.2
C_{16}	0.92	0.50	1.09	0.20	0.72	0.54	3.9	7.2	−0.6
C	4.1	3	5.5	1	3.8	3.3			

Table 10
Total relation matrix between sub-criteria according to (service).

C_2	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	r	$r+c$	$r-c$
C_{21}	0.35	0.33	0.42	0.50	0.60	0.47	2.7	5.2	0.2
C_{22}	0.51	0.39	1.05	0.49	0.59	0.40	3.4	5.5	1.3
C_{23}	0.41	0.45	0.42	0.36	0.56	0.32	2.5	5.7	−0.7
C_{24}	0.48	0.29	0.42	0.31	0.57	0.48	2.5	4.9	0.1
C_{25}	0.28	0.28	0.33	0.25	0.26	0.30	1.7	4.9	−1.5
C_{26}	0.51	0.33	0.53	0.52	0.63	0.33	2.8	5.1	0.5
C	2.5	2.1	3.2	2.4	3.2	2.3			

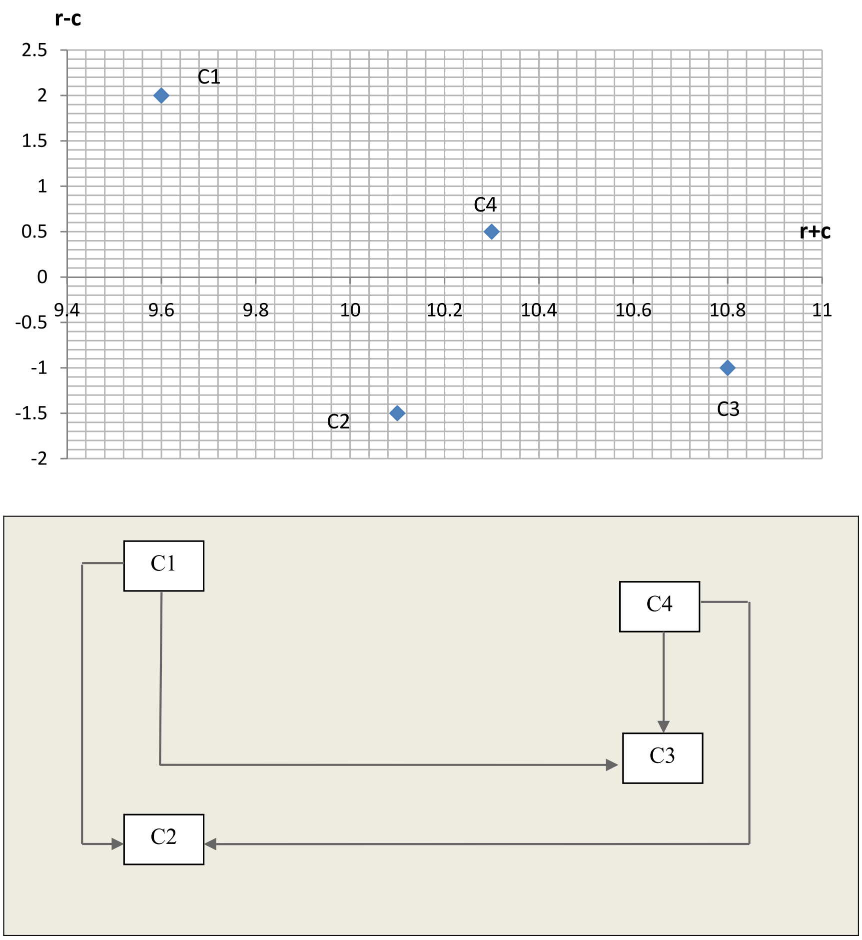

Fig. 10. The cause and effect of criteria.

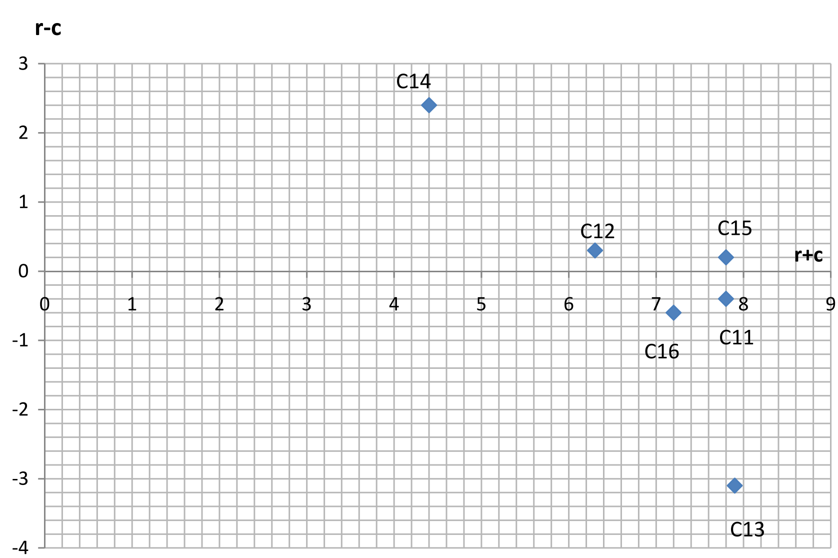

Fig. 11. The cause and effect for sub-criteria of dependability.

For checking consistency of previous matrix we utilized the super decisions software. The consistency ratio (CR) = 0.019 <0.1, then its acceptable ratio.

For service criteria the most important sub-criteria are availability (C21), authentication (C22), trust (C23). So we ask experts to make comparison matrix of only these three sub-criteria using neutrosophic AHP scale. The final form of comparing sub-criteria regarding to service as in Table 15.

For checking consistency of previous matrix we utilized the super decisions software. The consistency ratio (CR) = 0.02 <0.1, then its acceptable ratio.

For network criteria the most important sub-criteria are Anonymization (C32), availability (C33), integrity (C34), so we ask

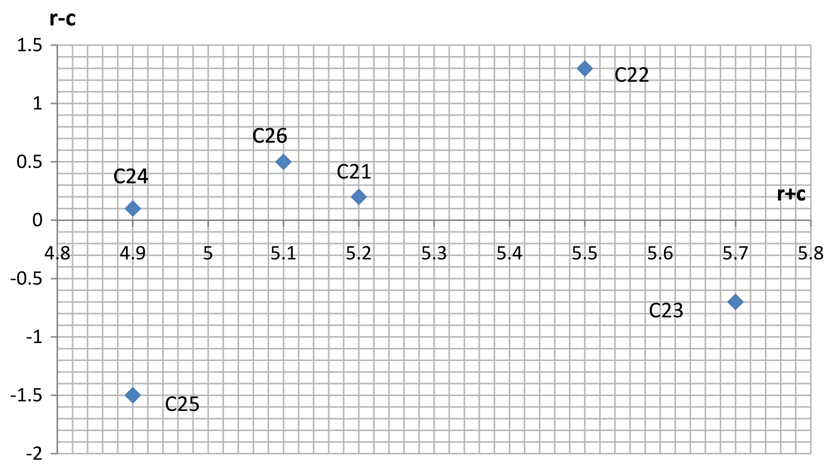

Fig. 12. The cause and effect for sub-criteria of service.

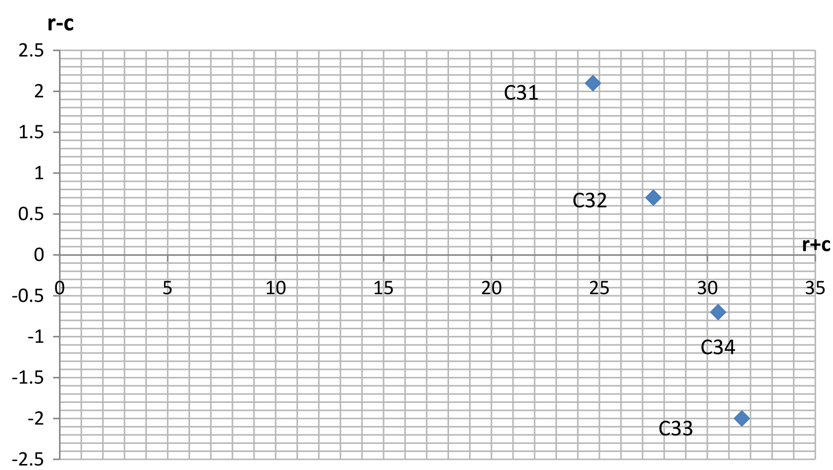

Fig. 13. The cause and effect for sub-criteria of network.

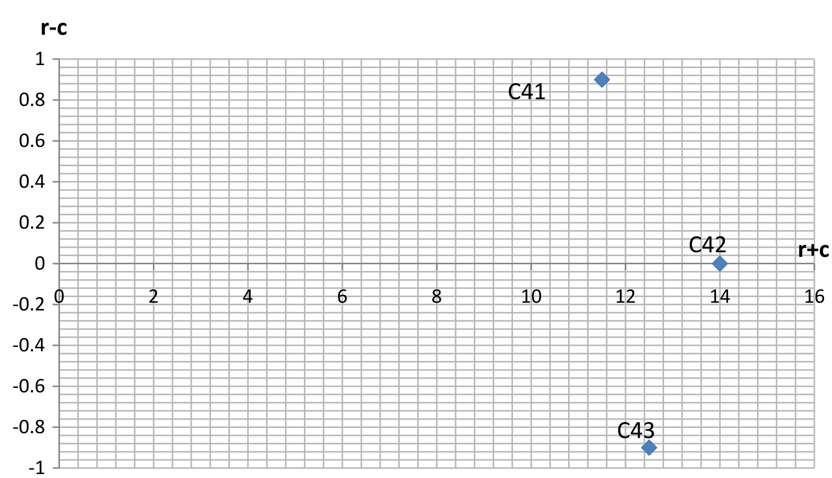

Fig. 14. The cause and effect for sub-criteria of privacy.

experts to make comparison matrix of only these three sub-criteria using neutrosophic AHP scale. The final form of comparing sub-criteria regarding to network as in Table 16.

For checking consistency of previous matrix we utilized the super decisions software. The consistency ratio (CR) = 0.0 <0.1, then its acceptable ratio.

The crisp comparison matrix between sub-criteria regarding to privacy as in Table 17.

For checking consistency of previous matrix we utilized the super decisions software. The consistency ratio (CR) = 0.0 <0.019 then its acceptable ratio.

By calculating the overall priorities we presented them in Fig. 15.

Please cite this article in press as: M. Abdel-Basset, et al., Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems, Future Generation Computer Systems (2018), https://doi.org/10.1016/j.future.2018.04.051.

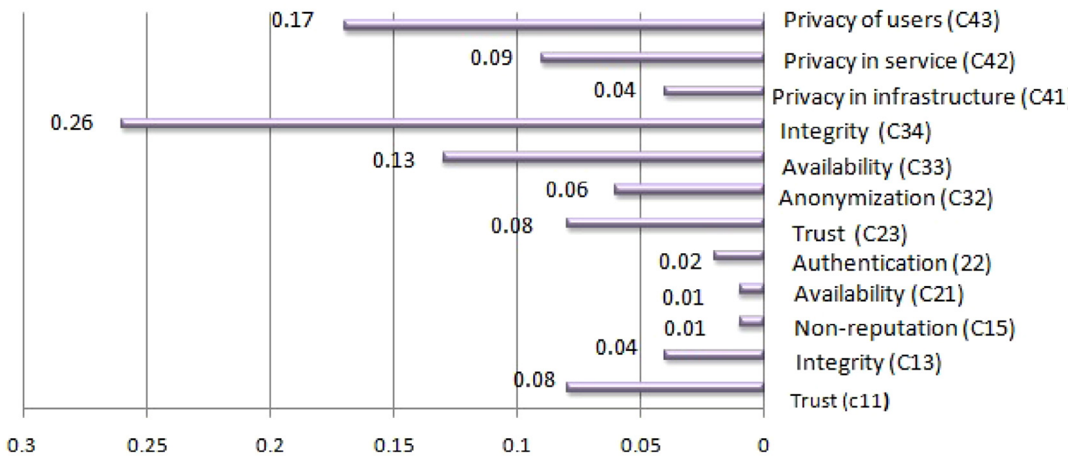

Fig. 15. The major priorities required for smart supply chain management systems.

Table 14
The crisp comparison matrix between sub-criteria according to (dependability).

	C_{11}	C_{13}	C_{15}	Weight
C_{11}	1	2	8	0.6
C_{13}	0.5	1	6	0.3
C_{15}	0.12	0.17	1	0.1

Table 15
The crisp comparison matrix between sub-criteria according to (service).

	C_{21}	C_{22}	C_{23}	Weight
C_{21}	1	0.5	0.11	0.08
C_{22}	0.20	1	0.25	0.18
C_{23}	9	4	1	0.74

Table 16
The crisp comparison matrix between sub-criteria according to (network).

	C_{32}	C_{33}	C_{34}	Weight
C_{32}	1	0.25	0.5	0.14
C_{33}	4	1	0.25	0.29
C_{34}	2	4	1	0.57

Table 17
The crisp comparison matrix between sub-criteria according to (privacy).

	C_{41}	C_{42}	C_{43}	Weight
C_{41}	1	0.33	0.25	0.12
C_{42}	3	1	0.5	0.32
C_{43}	4	2	1	0.58

The main security requirements of smart supply chain management systems appeared in Fig. 15. Since experts defined four major criteria for assessing security framework of SSCM systems which are Dependability (C1), Service (C2), Network (C3), and Privacy (C4). Then, we used neutrosophic DEMATEL technique to find cause and effect of criteria and determine the major sub-criteria which simplify calculations and save time. According to results of neutrosophic DEMATEL technique we utilized neutrosophic AHP to determine weights and priorities of important elements of security framework. As we notes in Fig. 15, the most important element according to Dependability (C1) is Trust (C11), the most important element according to Service (C2) is Trust (C23), the most important element according to Network (C3) is Integrity (C34), the most important element according to Privacy (C4) is Privacy of users (C43). So, we should focus on these elements for building a secure system of smart supply chain.

7. Conclusions and future directions

In this research we presented a framework for supply chain management which based on IOT technologies. The proposed system automates identification process of products, trace and track products globally, achieves transparency, reduce time and cost, and then will achieve customer satisfaction. The designed website between company managers also enhances coordination process, makes suppliers able to find selling information of their products easily through entering system with their username and password. Our website remove middlemen via direct communication between suppliers and managers via system, and then it increase profit for both manager and supplier.

In order to assess security framework for our proposed framework of smart supply chain, we integrated neutrosophic DEMATEL with neutrosophic AHP. The reason for integrating two techniques by using neutrosophic theory returns to the advantages of neutrosophic theory in handling vague, uncertain, inconsistent and incomplete information which exist in real life judgments. So neutrosophic set theory here is better than crisp set theory and fuzzy set theory. Since it considers truth degree, indeterminacy degree and falsity degree for each judgment, but crisp and fuzzy set theories does not.

The neutrosophic DEMATEL helped us to determine cause and effect of criteria and sub-criteria. For calculating weights of criteria, sub-criteria we used neutrosophic AHP.

When we combined neutrosophic DEMATEL with neutrosophic AHP, we noted that the hybrid method saves time and present precise result and this will appears in large problems with large criteria and alternatives. For example if we compare some alternatives with respect to 20 criteria, this will be hard process in calculation and take much time. But if we used neutrosophic DEMATEL method we can determine the cause and effect of criteria and focus only on the most important criteria of system. This will make us focus only on say 10 criteria and this help in generating precise results. After then the neutrosophic AHP method used in deriving weights and criteria for its capabilities to handle both qualitative and quantitative problems.

By using neutrosophic DEMATEL–AHP technique we determined the major elements for assessing and structuring the security framework of smart supply chain management systems.

The hybrid technique will help also in making a strategic planning process for assessing and constructing various important systems.

In the future we will use various IOT technologies and sensors for SCM, and apply it in various organizations. Also, we will apply neutrosophic DEMATEL–AHP technique in several areas such as project management and scheduling.

Limitation of Proposed Research: More involvements from more companies will make our research better.

Competing Interests

The authors announce that there is no discrepancy of interests concerning the publication of this research.

References

[1] S.C. Council, Supply chain operations reference model: Revision 11.0, Chicago, IL, 2012.
[2] L. Wu, X. Yue, A. Jin, D.C. Yen, Smart supply chain management: A review and implications for future research, Int. J. Logist. Manage. 27 (2016) 395–417.
[3] D.F. Ross, Introduction to e-Supply Chain Management: Engaging Technology to Build Market-Winning Business Partnerships, CRC Press, 2016.
[4] S. Greengard, The Internet of Things, MIT Press, 2015.
[5] M. Abdel-Basset, M. Mohamed, V. Chang, NMCDA: A framework for evaluating cloud computing services, Future Gener. Comput. Syst. (2018).
[6] E. Borgia, The internet of things vision: Key features, applications and open issues, Comput. Commun. 54 (2014) 1–31.
[7] S. Yuvaraj, M. Sangeetha, Smart supply chain management using internet of things (IoT) and low power wireless communication systems, in: Wireless Communications, Signal Processing and Networking, WiSPNET, International Conference on, 2016, pp. 555-558.
[8] J. Yan, S. Xin, Q. Liu, W. Xu, L. Yang, L. Fan, et al., Intelligent supply chain integration and management based on cloud of things, Int. J. Distrib. Sens. Netw. 10 (2014) 624839.
[9] Z.D.R. Gnimpieba, A. Nait-Sidi-Moh, D. Durand, J. Fortin, Using Internet of Things technologies for a collaborative supply chain: Application to tracking of pallets and containers, Procedia Comput. Sci. 56 (2015) 550–557.
[10] S.-K. Kinnunen, S. Marttonen-Arola, A. Ylä-Kujala, T. Kärri, T. Ahonen, P. Valkokari, et al., Decision making situations define data requirements in fleet asset management, in: Proceedings of the 10th World Congress on Engineering Asset Management, WCEAM 2015, 2016, pp. 357–364.
[11] B. Singh, A. Gupta, Recent trends in intelligent transportation systems: A review, J. Transp. Lit. 9 (2015) 30–34.
[12] C.-W. Shih, C.-H. Wang, Integrating wireless sensor networks with statistical quality control to develop a cold chain system in food industries, Comput. Stand. Interfaces 45 (2016) 62–78.
[13] Z. Bi, L. Da Xu, C. Wang, Internet of things for enterprise systems of modern manufacturing, IEEE Trans. Indust. Inform. 10 (2014) 1537–1546.
[14] Q. Zhu, J. Sarkis, Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises, J. Oper. Manage. 22 (2004) 265–289.
[15] S. Chang, D. Klabjan, T. Vossen, Optimal radio frequency identification deployment in a supply chain network, Int. J. Prod. Econ. 125 (2010) 71–83.
[16] S. Fosso Wamba, Achieving supply chain integration using RFID technology: The case of emerging intelligent B-to-B e-commerce processes in a living laboratory, Bus. Process Manage. J. 18 (2012) 58–81.
[17] P.J. Zelbst, K.W. Green, V.E. Sower, P.M. Reyes, Impact of RFID on manufacturing effectiveness and efficiency, Int. J. Oper. Prod. Manage. 32 (2012) 329–350.
[18] J. Leung, W. Cheung, S.-C. Chu, Aligning RFID applications with supply chain strategies, Inform. Manage. 51 (2014) 260–269.
[19] C. Verdouw, A. Beulens, J. Van Der Vorst, Virtualisation of floricultural supply chains: A review from an Internet of Things perspective, Comput. Electron. Agricult. 99 (2013) 160–175.
[20] I.C. Ng, S.Y. Wakenshaw, The Internet-of-Things: Review and research directions, Int. J. Res. Market. 34 (2017) 3–21.
[21] Y. Jie, N. Subramanian, K. Ning, D. Edwards, Product delivery service provider selection and customer satisfaction in the era of internet of things: A Chinese e-retailers' perspective, Int. J. Prod. Econ. 159 (2015) 104–116.
[22] C. Decker, M. Berchtold, L.W.F. Chaves, M. Beigl, D. Roehr, T. Riedel, et al., Cost-benefit model for smart items in the supply chain, in: The Internet of Things, Springer (ed.), 2008, pp. 155–172.
[23] T. Wang, Y. Zhang, D. Zang, Real-time visibility and traceability framework for discrete manufacturing shopfloor, in: Proceedings of the 22nd International Conference on Industrial Engineering and Engineering Management 2015, 2016, pp. 763–772.
[24] I. Veza, M. Mladineo, N. Gjeldum, Managing innovative production network of smart factories, IFAC-PapersOnLine 48 (2015) 555–560.
[25] P. Zawadzki, K. Zywicki, Smart product design and production control for effective mass customization in the industry 4.0 concept, Manage. Prod. Eng. Rev. 7 (2016) 105–112.
[26] S. Choi, B.H. Kim, S. Do Noh, A diagnosis and evaluation method for strategic planning and systematic design of a virtual factory in smart manufacturing systems, Int. J. Precis. Eng. Manuf. 16 (2015) 1107–1115.
[27] D. Li, Perspective for smart factory in petrochemical industry, Comput. Chem. Eng. 91 (2016) 136–148.
[28] T. Stock, G. Seliger, Opportunities of sustainable manufacturing in industry 4.0, Procedia Cirp 40 (2016) 536–541.
[29] L.D. Xu, Information architecture for supply chain quality management, Int. J. Prod. Res. 49 (2011) 183–198.
[30] H.-C. Yang, H. Tieng, F.-T. Cheng, Total precision inspection of machine tools with virtual metrology, J. Chinese Inst. Eng. 39 (2016) 221–235.
[31] S. Weyer, M. Schmitt, M. Ohmer, D. Gorecky, Towards industry 4.0-standardization as the crucial challenge for highly modular multi-vendor production systems, IFAC-PapersOnLine 48 (2015) 579–584.
[32] R.H. Ballou, Business Logistics/supply Chain Management, 5/E (With Cd), Pearson Education India, 2007.
[33] R. Angeles, RFID technologies: Supply-chain applications and implementation issues, Inform. Syst. Manage. 22 (2005) 51–65.
[34] M. Liukkonen, T.-N. Tsai, Toward decentralized intelligence in manufacturing: Recent trends in automatic identification of things, Int. J. Adv. Manuf. Technol. 87 (2016) 2509–2531.
[35] P. Bowman, J. Ng, M. Harrison, T.S. Lopez, A. Illic, Sensor based condition monitoring, Building Radio frequency IDentification for the Global Environment (Bridge) Euro RFID project, 2009.
[36] J. Fang, T. Qu, Z. Li, G. Xu, G.Q. Huang, Agent-based gateway operating system for RFID-enabled ubiquitous manufacturing enterprise, Robot. Comput.-Integr. Manuf. 29 (2013) 222–231.
[37] B. Li, C. Yang, S. Huang, Study on supply chain disruption management under service level dependent demand, J. Netw. 9 (2014) 1432–1439.
[38] T. Paksoy, İ. Karaoğlan, H. Gökçen, P.M. Pardalos, B. Torğul, An experimental research on closed loop supply chain management with internet of things, J. Econom. Bibliograph. 3 (2016) 1–20.
[39] B. Xing, W.-J. Gao, K. Battle, F.V. Nelwamondo, T. Marwala, e-RL: the Internet of things supported reverse logistics for remanufacture-to-order, 2011.
[40] C. Fang, X. Liu, P.M. Pardalos, J. Pei, Optimization for a three-stage production system in the Internet of Things: Procurement, production and product recovery, and acquisition, Int. J. Adv. Manuf. Technol. 83 (2016) 689–710.
[41] B. Yan, G. Huang, Supply chain information transmission based on RFID and internet of things, in Computing, in: Communication, Control, and Management, 2009. CCCM 2009. ISECS International Colloquium on, 2009, pp. 166–169.
[42] T.-H. Shin, S. Chin, S.-W. Yoon, S.-W. Kwon, A service-oriented integrated information framework for RFID/WSN-based intelligent construction supply chain management, Autom. Constr. 20 (2011) 706–715.
[43] D. Li, Perspective for smart factory in petrochemical industry, Comput. Chem. Eng. 91 (2016) 136–148.
[44] C.N. Verdouw, J. Wolfert, A. Beulens, A. Rialland, Virtualization of food supply chains with the internet of things, J. Food Eng. 176 (2016) 128–136.
[45] I.J. Chen, A. Paulraj, Towards a theory of supply chain management: the constructs and measurements, J. Oper. Manage. 22 (2004) 119–150.
[46] H.T. Quang, P. Sampaio, M.S. Carvalho, A.C. Fernandes, D.T. Binh An, E. Vilhenac, An extensive structural model of supply chain quality management and firm performance, Int. J. Qual. Reliab. Manage. 33 (2016) 444–464.
[47] C. Mims, Here's the one thing someone needs to invent before the internet of things can take off, ed: Quartz, 2013.
[48] S. Hori, Y. Shimizu, Designing methods of human interface for supervisory control systems, Control Eng. Pract. 7 (1999) 1413–1419.
[49] C. Chiou, C.-W. Hsu, H. Chen, Using DEMATEL to explore a casual and effect model of sustainable supplier selection, in: Business Innovation and Technology Management, APBITM, 2011 IEEE International Summer Conference of Asia Pacific, 2011, pp. 240–244.
[50] J.J. Liou, G.-H. Tzeng, H.-C. Chang, Airline safety measurement using a hybrid model, J. Air Transp. Manage. 13 (2007) 243–249.
[51] W.-W. Wu, Y.-T. Lee, Developing global managers' competencies using the fuzzy DEMATEL method, Expert systems with applications, 32 (2007) pp. 499–507.
[52] J.-I. Shieh, H.-H. Wu, K.-K. Huang, A DEMATEL method in identifying key success factors of hospital service quality, Knowl.-Based Syst. 23 (2010) 277–282.
[53] R.-J. Lin, Using fuzzy DEMATEL to evaluate the green supply chain management practices, J. Cleaner Prod. 40 (2013) 32–39.
[54] M. Amiri, J. Sadaghiyani, N. Payani, M. Shafieezadeh, Developing a DEMATEL method to prioritize distribution centers in supply chain, Manage. Sci. Lett. 1 (2011) 279–288.
[55] J.L. Yang, G.-H. Tzeng, An integrated MCDM technique combined with DEMATEL for a novel cluster-weighted with ANP method, Expert Syst. Appl. 38 (2011) 1417–1424.
[56] Y.-L. Wang, G.-H. Tzeng, Brand marketing for creating brand value based on a MCDM model combining DEMATEL with ANP and VIKOR methods, Expert Syst. Appl. 39 (2012) 5600–5615.
[57] G. Büyüközkan, G. Çifçi, A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers, Expert Syst. Appl. 39 (2012) 3000–3011.

[58] D. Dalalah, M. Hayajneh, F. Batieha, A fuzzy multi-criteria decision making model for supplier selection, Expert Syst. Appl. 38 (2011) 8384–8391.
[59] K.C. Park, D.-H. Shin, Security assessment framework for IoT service, Telecommun. Syst. 64 (2017) 193–209.
[60] H.-H. Wu, Y.-N. Tsai, An integrated approach of AHP and DEMATEL methods in evaluating the criteria of auto spare parts industry, Int. J. Syst. Sci. 43 (2012) 2114–2124.
[61] G.-H. Tzeng, C.-H. Chiang, C.-W. Li, Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL, Expert Syst. Appl. 32 (2007) 1028–1044.
[62] M. Abdel-Basset, G. Manogaran, A. Gamal, F. Smarandache, A hybrid approach of neutrosophic sets and DEMATEL method for developing supplier selection criteria, Des. Autom. Embedded Syst. (2018) 1–22.
[63] F. Smarandache, Neutrosophic set-a generalization of the intuitionistic fuzzy set, Int. J. Pure Appl. Math. 24 (2005) 287.
[64] E. Fontela, A. Gabus, The DEMATEL observer, ed: Dematel, 1976.
[65] S. Tung, S. Tang, A comparison of the Saaty's AHP and modified AHP for right and left eigenvector inconsistency, Eur. J. Oper.

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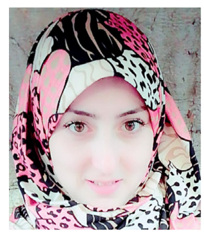

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Please cite this article in press as: M. Abdel-Basset, et al., Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems, Future Generation Computer Systems (2018), https://doi.org/10.1016/j.future.2018.04.051.