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Abstract:	

The role of Industry 4.0 Technologies on Performance Measurement Systems of Supply chains during Global Pandemics: An Interval-Valued-Intuitionistic-Hesitant-Fuzzy Approach

Abstract

Purpose. This paper investigates Supply Chain (SC) Performance Measurement Systems (PMSs) (SCPMSs) that are suitable and applicable to evaluate SC performance during unexpected events such as global pandemics. Furthermore, the contribution of Industry 4.0 Disruptive Technologies (IDTs) to implement SCPMSs during such Black Swan events is investigated in this study.

Method. The research methodology is based upon a novel qualitative and quantitative mixed-method. A Systematic Literature Review (SLR) was initially employed to identify two complete lists of SCPMSs and IDTs. Then, a novel Interval-Valued-Intuitionistic-Hesitant-Fuzzy (IVIHF)-Delphi method was firstly developed in this paper to screen the extracted SCPMSs. Afterward, the PEARL indicator of the Hanlon method was innovatively applied to prioritise the identified IDTs for each finalised SCPMS.

Findings. Two high-score SCPMSs including the *SC operations reference model (SCOR)* and *sustainable SCPMS were* recommended to improve measuring the performance of the pharmaceutical SC of emerging economies such as Iran; in which the societal, biological, and economic issues were undeniable, particularly during unexpected events. Employing nine IDTs such as *Simulation*, *Big Data Analytics*, *Cloud Technologies*, etc., would facilitate implementing *sustainable SCPMS* from distinct perspectives.

Originality. This is one of the first papers to provide in-depth insights into determining the priority of contribution of IDTs in applying different SCPMSs during global pandemics. Proposing a novel multi-layer mixed-methodology involving SLR, IVIHF-Delphi, and the PEARL indicator of the Hanlon method is another originality offered by this paper.

Keywords. Global pandemics, PMSs, SCPMSs, IDTs, IVIHF-Delphi, PEARL indicator.

1. Introduction

The global epidemics not only intensely impact human health, but also cripple the economic facet encompassing different SC networks. E.g., the Covid-19 outbreak, a global epidemic that emerged in December 2019 in Wuhan, China (Huang et al., 2020), has greatly hit the worldwide SC networks. SC network is defined as a set of firms participating in the process of distribution of materials, goods/services, financial, resources, and informational flows between primary and end consumers (Masteika and Čepinskis, 2015). As such, SC Management (SCM) is the centralised decision-making point of the flows of materials, financial/non-financial resources, information, and goods/services to prepare final products with value-added for customers and competitive advantages in the marketplace (Power, 2005). The disruption propagation that occurred throughout SCs owing to the Covid-19 widespread reflected the supply chains inability to cope with such unexpected events. Nonetheless, both scholars and practitioners have contributed to discussions to exchange knowledge and discover strategies to increase the robustness and resilience of SCs to diminish disruptions while facing such intensive crises. For instance, Love et al. (2021) provided the solutions to improve SC resilience with aid of assessing the impacts of Covid-19 particularly on SC. Cai and Luo (2020) reviewed the impacts of the Covid-19 on SC (e.g., turnover, wastage, Labour livelihoods and well-being, technological advancements, communication-related issues, etc.) and also explored the countermeasures to reach SC resiliency during such an unexpected incident.

On the other hand, the outbreak of Covid-19 has undoubtedly been a pure chance to learn from its side effects which supports the business owners to improve their future decision-making in such disruption situations. As a lesson learned from the current global crisis, the disruption propagation throughout the SC impacts both the financial and operational performances of SCs (Macdonald and Corsi, 2013). This issue sheds light on the SC Performance Measurement (PM) challenge coupled with the requirement of choosing the well-suited SCPMSs. This point provides warnings regarding the risk of disruptions for acquiring better SC performance with the effective use of resources and capabilities, as well as powerful internal and external communications; hence, triggering a seamlessly coordinated SC. To highlight the necessity of managing the whole SC performance instead of the singular organisations, Maestrini et al. (2017) argued that the organisational performance increasingly leans on external SC partners. To achieve SC objectives, individual firms must keep their SC performance under control and extend the view of PM management across the SC. In turn, SCM is defined as the "systematic, strategic coordination of the traditional business functions and the tactics across these business functions within an SC, to improve the long-term performance of the individual firms and the entire SC" (Maestrini et al. 2017). Hereupon, the importance of SC PM management has been recently emphasised, particularly during the global epidemics. For instance, Grida et al. (2020) evaluated the impacts of the Covid-19 prevention policies on SC performance using multi-layer decision-making approaches including the best-worst method (BWM) and technique for order preferences by similarity to ideal solution (TOPSIS). Furthermore, Goel et al. (2021) assessed the impact of the Covid-19 disruptions on SC performance and consequently economic growth by employing available data and estimation techniques. To the best knowledge of the authors, it is required to investigate suitable SCPMSs that are applicable to evaluate the SC performance during unexpected events. Furthermore, the IDTs (e.g., Big Data Analytics, Cloud Technologies, etc.) have been attracting high focus from researchers and practitioners in the SCM area, particularly in the Covid-19 outbreak era (Frederico et al., 2020). E.g., Xu et al. (2020) discussed the role of new disruptive technologies in improving the resilience of SC in the outbreak of Covid-19. In recent literature, IDTs have the critical potential for value creation and transformation of the traditional SCs schemes (Frederico et al., 2020). However, Büyüközkan and Göçer (2018) highlighted the embryonic research background on Industry 4.0 focused on SCs. Moreover, the research studying IDTs from the context of the SCPMSs is undeniably demanding innovative efforts from the academic community. This issue is more essential in case a global epidemic occurs in an emerging economy like Iran. To the best knowledge of the authors, the contribution of IDTs to the PM of pharmaceutical SCs of Iran's emerging economy during the Black Swan events has not yet been studied. Indeed, the challenge of SCPMS focused on IDTs is worth studying in the pharmaceutical sector during global pandemics. Since the pharmaceutical industry plays a critical role in the provision of quality healthcare services; the medicines SC can be overwhelmed or shut down for several reasons e.g., lockdowns, closed borders, restricted local/international communications, etc. (Tirivangani et al., 2021).

Furthermore, recently scholars have employed only qualitative methodologies to study SCPMSs and reveal future research directions. For instance, Maestrini et al. (2017) assessed the maturity of the SCPMSs discipline and set the future research directions using the SLR approach. Hald and Mouritsen (2018) employed SLR and a multi-case study to analyse how forces located outside focal firm boundaries influence the evolution of PMSs in SCs. Frederico et al. (2020) used SLR to combine the literature on PM and the dimensions of SC in the context of industry 4.0. However, the advantages of applying qualitative and quantitative mixed methods have been emphasised by recent scholars to attain more reliable results (Jafari-Sadeghi et al., 2021). The integration of the SLR and fuzzy-Delphi method is such a well-known mixed-method for extracting and screening the research items (Hajiagha et al., 2021). To the best knowledge of the authors, the integration of the Interval-Valued-Intuitionistic-Hesitant-Fuzzy (IVIHF)-Delphi has not been yet developed and has been introduced in this article. On the other hand, since priority setting is a prominent component of strategic planning, several methods, in turn, are available for priority setting. the Priority Rating Models (PRMs), e.g., the Hanlon method is such an appropriate quantitative method used to prioritise health problems (Choi et al., 2019). The Hanlon method could innovatively be employed here to score the IDTs for each SCPMSs. In brief, the research objectives of this paper include (i) investigating Supply Chain (SC) Performance Measurement Systems (PMSs) (SCPMSs) that are suitable and applicable to evaluate SC performance during unexpected events such as global pandemics; (ii) studying the contribution of IDTs to implement SCPMSs during such Black Swan events; and (iii) developing a novel uncertain Delphi approach called IVIHF-Delphi to include the hesitation effect of decision-makers. To this end, this paper attempts to initially extract the whole list of SCPMSs and IDTs through an SLR approach in two distinct streams. Afterwards, the SCPMSs list is screened via a novel development of IVIHF-Delphi with evidence of the pharmaceutical industry of the emerging economy of Iran during the outbreak of the Covid-19. The priority of IDTs for each selected SCPMSs is subsequently measured through the PEARL (P: propriety, E: economics, A: acceptability, and R: resources) indicator of the Hanlon method. The implications would provide business owners and policymakers with an appropriate practical and managerial strategy to improve the SCs financial and operational performances during such unexpected events.

The remainder of this paper is organised as follows. To identify the SCPMSs and IDTs, two streams of the literature review are presented in section 2. Section 3 is assigned to the research methodology to illustrate the IVIHF-Delphi and PEARL indicator of the Hanlon method. The results and findings are then reported in section 4 according to the experts opinions from the pharmaceutical sector. The implications are discussed in section 5. The conclusion and future research agendas are provided in section 6.

2. Literature review

PM has received a great deal of attention since the 1990s when Eccles (1991) highlighted the need for comprehensive frameworks for PMSs. As a balanced and dynamic system, the PMSs support the decision-making process through gathering, elaborating, and analysing information. A PMS is a “set of metrics applied in quantifying the efficiency and effectiveness of actions” (Neely, 1999) to support the strategy implementation at different levels. A matrix is defined as a piece of information with three distinct characteristics (Maestrini et al., 2017) (i) it is a verifiable performance measure to evaluate what is occurring in both qualitative and quantitative terms, (ii) it is evaluated via a reference or target value, (iii) it is relevant to the consequences of being equal in target or lower/higher than it. The extent relevant literature particularly assumes the PMS as a system approved within a single firm’s boundaries (Neely, 1999). It covers various organisational units, processes, and functions, to fulfill the objectives of monitoring and reporting activities of the firm’s management interest (Maestrini et al., 2017). Generally, the traditional PMSs typically target processes and data related to the individual firms. Nevertheless, it does not consider the processes and relationships between multiple SC actors which fall outside the sphere of influence of a single firm. Following the criticism of traditional PMSs, which focused on only the performance of the individual firms, SCPMSs were employed to measure the effectiveness and efficiency of the entire SC (Maestrini et al., 2017). SCPMSs are defined as “a set of metrics used to quantify the efficiency and effectiveness of SC processes and relationships, spanning multiple organisational functions and multiple firms and enabling SC orchestration” (Maestrini et al., 2017).

Since the organisational performance undoubtedly counts on external SC partners, SCPMSs deserve specific attention (Maestrini et al., 2017). PM has been more challenging when it should serve the distinct aims of different SC levels, i.e. the suppliers, manufacturers, retailers, consumers, and SC overall as well. Accordingly, different SCPMSs, e.g., SC balanced scorecard (Kaplan and Norton, 1992), SC operations reference model, etc., have recently been proposed in the literature to evaluate the SC performance. To extract the whole list of the extant SCPMSs, an SLR has been performed in this manuscript. In doing so, a keywords-based search of the Google Scholar and ISI Web of Knowledge databases was initially performed by applying keywords e.g., “different type of SCPMSs”, “PMSs related to SCs”, “revolution of the PMS”, and “evolution of the PMS in SC”. Consequently, nine relevant papers were reviewed from 2001 to 2020. The main contribution, type of SCPMS extraction approach, employed methodology, data type, as well as case study/industry of the abovementioned papers are concisely provided in Table 1.

Insert Table 1

As stated, studying SCPMSs from various perspectives has recently received much scholarly interest. For instance, Hald and Mouritsen (2018) argued how forces located outside focal firm boundaries impact the evolution of PMSs in SC. Ka et al. (2019) reviewed the dearth of research into PMSs in the context of the SC to evoke the potential avenues for future research. Frederico et al. (2020) synthesised the literature on PMS and dimensions of SC in the context of Industry 4.0. Excluding (De Toni and Tonchia, 2001) who employed statistical analysis with the crisp data type, other scholars have mainly employed the popular qualitative approaches (i.e., SLR, case-study, etc.) to identify and investigate different SCPMSs to set the future research directions. They additionally took the Electro-Mechanical industry and Automotive SC into consideration (see Table 1). Most importantly, the empirical support of the existing literature on the SCPMSs provides a complete list of 25 SCPMSs together with their description as demonstrated in Table 2.

Insert Table 2

Industry 4.0 has dramatically received a great deal of attention from academicians and researchers (Bai et al., 2020; Frederico et al., 2020). It is known as a new paradigm of smart and autonomous manufacturing; which profoundly integrates manufacturing operations systems with communication, information, and intelligence technologies (Bai et al., 2020). Industry 4.0 could alter the way how firms compete with each other and how the value-added is created for their customers (Frederico et al., 2020). The main focus of Industry 4.0 is on disruptive technologies which would profoundly impact SCs. Generally, these technologies can radically change the SC operations and consequently performance; which would result in efficiency, integration, transparency, and agility over the SC process and the improvement of customer satisfaction and financial issues. The profitable business models, higher efficiency, performance, and quality, as well as improved workplace conditions reveal such prominent benefits of employing IDT. However, critical challenges (e.g., lack of knowledge, costs, legacy system alteration, etc.) still hinder using IDT (Bai et al., 2020). Recent scholars have frequently discussed the role of IDT in SCM improvement. For instance, Wamba et al. (2020) analyse IDT adoption and SC performance and they revealed that SC performance is dramatically influenced by blockchain transparency. Dolgui and Ivanov (2020) explored the structural dynamics of SC influenced by new positive disruptive technologies and its negative disruptive risks. Nevertheless, yet research on promises and impacts of Industry 4.0 on SC PM is still scarce (Frederico et al., 2020).

Bai et al. (2020) divided IDT into *physical* and *digital* technologies where *physical* IDT mainly refers to manufacturing technologies such as drones, additive manufacturing, etc. *Digital* IDT mainly refers to modern information and communication technologies like Big Data Analytics, Cloud Technology, Simulation, etc. To establish a list of various IDT, a keywords-based search of the Google Scholar and ISI Web of Knowledge databases was initially performed employing keywords e.g., “IDT used in SC PM”, “IDT related to SCM”, “IDT”. Consequently, 14 IDTs associated with SCM have been extracted from six relevant papers that occurred in 2019 and 2020. To this end, Table 3 demonstrates the list of 14 extracted IDTs along with their definition/example, as well as relevancy to SC PM.

Insert Table 3

As stated, the previous researchers have only applied qualitative approaches to extract the SCPMSs and provide future research directions (see Table 1). However, the advantages of qualitative and quantitative mixed methods have recently been highlighted to gain more reliable and precise results (Jafari-Sadeghi et al., 2021). Besides, the importance of considering the uncertainty of the environment as well as the hesitation and intuition of experts have been highlighted by recent scholars to gain such valid and reliable results (Hajiagha et al., 2021). In this domain, the combination of the fuzzy-Delphi technique and new uncertainty approaches e.g., hesitant fuzzy and intuitionistic fuzzy are recommended by recent scholars to screen and finalise research items (Hajiagha et al., 2021). On the other hand, the interaction between SCPMSs and IDT has not been yet researched to adopt a well-suited technology for each SCPMS to improve SC performance. To this end, the PRMs, e.g., the PEARL indicator of the Hanlon method, could be innovatively used here to prioritise the selected IDTs for each SCPMSs (Choi et al., 2019; Neiger et al., 2011). Furthermore, no research has considered the impacts of global epidemics like Covid-19 on the performance evaluation of SCM in different sections such as the pharmaceutical industry associated with human health. While the ripple effect of such unexpected events has greatly hit the SCPMSs (Macdonald and Corsi, 2013). To bridge the aforementioned research gaps, this paper attempts to extract and screen SCPMSs related to the pharmaceutical industry of emerging economies like Iran through a mixed method of SLR and IVIHF-Delphi. In turn, this is the first paper that integrates interval-valued, hesitant, and intuitionistic fuzzy-Delphi approaches to finalise relevant SCPMSs. Moreover, a complete list of IDTs relevant to SC PM are additionally extracted via SLR. Afterwards, the PEARL indicator of Hanlon method, as a PRM, is innovatively employed to prioritise the most influential IDT for each finalised Pharmacutical SCPMS in an era of the global epidemics alike Covid-19. The results and findings would provide authors with an appropriate strategies to promote pharmaceutical SC operational and financial performance during such as intense propagation disruption.

3. Methodology

To deal with uncertainty, Zadeh introduced Fuzzy Sets (Zadeh, 1996), which consider a membership for each element of a set. Since then, various developments of fuzzy sets have been proposed to improve the initial its idea. Each of these approaches studies uncertainty from a different standpoint. These developments include Type-2 fuzzy sets (Castillo and Melin 2012), intuitionistic fuzzy sets (Atanassov, 1999), interval-valued fuzzy sets (Lee et al., 2001), hesitant fuzzy sets (Torra, 2010), Z-numbers (Zadeh, 2011), neutrosophic sets (Peng et al., 2014), Pythagorean sets (Peng and Selvachandran, 2019), among others. By combining each of these approaches, uncertainty conditions can be modeled with more complexity and accuracy. Therefore, interval-valued intuitionistic hesitant fuzzy sets (IVIHF) have been proposed (Joshi and Kumar, 2016). Hesitation, uncertainty, and intuition of experts are considered simultaneously in this approach; hence, this article has employed it for the decision-making procedure and Delphi approach. The following are some important definitions related to this approach.

Definition 1. Assuming that U is a reference set. An IVIHF $\tilde{H} = \{(\vartheta, h_{\tilde{H}}(\vartheta)) | \vartheta \in U\}$ can be represented where $h_{\tilde{H}}(\vartheta)$ is an interval-valued intuitionistic hesitant fuzzy number (IVIHFN) defining the possible interval-valued intuitionistic fuzzy values of an element $\vartheta \in U$ (Narayanamoorthy et al., 2019). As it is clear, in defining the IVIHF set, the two approaches of hesitation through hesitant fuzzy (HF) sets and intuition via interval-valued intuitionistic fuzzy (IVIF) sets are aggregated with each other to describe the uncertainty more perfectly. In the following the HF, IVIF, and IVIHF scores are introduced.

Definition 2. Assume $h = \{h^{(1)}, h^{(2)}, ..., h^{(n)}\}$ as an HF set. The arithmetic mean score function of $(\underline{h})$ is measured by Eq. (1) (Farhadinia, 2014).

$$S(h) = \frac{\sum_{i=1}^{n} h^{(i)}}{n} \tag{1}$$

Definition 3. Assume $\tilde{\alpha} = ([\mu^-, \mu^+], [\nu^-, \nu^+])$ as an IVIF value where $[\mu^-, \mu^+]$ is the interval of membership, $[\nu^-, \nu^+]$ is the interval of non-membership, $0 \le \mu^- \le \mu^+ \le 1,\ 0 \le \nu^- \le \nu^+ \le 1$ and $\mu^+ + \nu^+ \le 1$. The IVIF score is then measured via Eq. (2) (Wang and Chen, 2017).

$$S(\tilde{\alpha}) = \frac{\mu^+ - \nu^+ + \mu^- - \nu^-}{2} \tag{2}$$

Definition 4. Assume $\tilde{h}$ as a set of IVIFNs, then an IVIHF score is attained by Eq. (3).

$$S(\tilde{h}) = \frac{S(\tilde{\alpha})}{\#\tilde{h}} \tag{3}$$

It is notable that in Eq. (3), $\#\tilde{h}$ is the number of IVIFNs. Although the score function of IVIHF is the result of combining the score functions of HF and IVIF, it does not seem to take into account the hesitation sufficiently. Therefore, to the best knowledge of the authors, for the first time, a two-step method for computing the IVIHF score is introduced in this article. In the following, the basics of the Delphi and Hanlon methods are briefly explained.

Delphi. The Delphi method is a structured method for combining and aggregating the opinions of experts (Goodman, 1987). In this method, the experts' opinions are approached step by step to reach their final consensus. Accordingly, the opinion of experts is asked and their consensus is calculated by various methods. In cases where consensus is reached, Delphi is stopped; otherwise, the next round is performed by informing the mean and standard deviation of the opinions, and the experts are asked to adjust their opinion accordingly if possible. After collecting opinions again, the achievement of consensus is analysed. The Delphi method rounds are repeated long enough to ensure consensus is achieved (Belton et al., 2019). Numerous extensions of Delphi have been introduced to consider uncertain situations e.g. fuzzy Delphi and hesitant fuzzy Delphi (Mahdiraji et al., 2021). In this paper, an IVIHF- Delphi method is introduced using a modified approach to analyse the consensus.

Basic Priority Model (BPR) of Hanlon. Priority setting has always been one of the most highlighted concerns of any organisation. For this reason, numerous models have been presented. Hanlon first developed the priority rating process to rank the health problems in developing countries (Hanlon, 1954). Next, Hanlon revised his model in 1984 in collaboration with Pickett (Pickett and Hanlon, 1990). BPR 2.0 included four elements (i) size of the problem (A: 0-10 points), (ii) the seriousness of the problem (B: 0-20 Points), (iii) effectiveness of intervention (C: 0-10 Points), and PEARL indicators (D: 0 or 1). The final score was measured by Eq. (4) (Neiger et al., 2011).

$$BPR = \frac{(A + B) \times C}{3} \times D \tag{4}$$

In Eq. (4), D is the PEARL indicator including propriety, economic advantage, acceptability, resource availability, and legality. In this research, PEARL indicators are modified and applied to the research context. This research is a mixed-method of qualitative and quantitative approaches. At first, a systematic review of the literature was applied in two thematic sections (i) previous research in the field of SCPMSs and (ii) a list of IDTs. These two outputs together were considered in the quantitative part of the research. The research framework employed in this article is illustrated in Figure 1.

<u>Insert Figure 1</u>

After the SLR, three panels of experts were invited to share their experience and opinions in this research regarding the SCPMs and IDTs from the pharmaceutical sector of the emerging economy of Iran. The profile of the experts is elaborated in Table 4.

<u>Insert Table 4</u>

As demonstrated in Table 4, experts were gathered from both industry and academia with experience and qualifications that included (i) at least 8 years of experience in academia or industry; (ii) minimum education of bachelor; (iii) education in the areas of decision-making, supply chain, logistics, international business, and management science; (iv) at least 30 years old; and (v) eager to participate and be accessible. Furthermore, for the academic participants, two additional criteria were considered including (i) at least a senior lecturer or assistant professor position; and (ii) published at least five international articles in the area of supply chain management and logistics performance measurement in the last three years. A hybrid judgemental-snowball sampling approach was employed to identify the 15 experts introduced in Table 4. In the first step, to complete the IVIHF-Delphi questionnaire, a separate session was held for each panel for 2 hours to explain the problem in detail to the experts and to introduce the IVIHF approach along with the structure of the questionnaire. At the end of the first session, a questionnaire was delivered to the panels to express their views on each of the SCPMSs using several IVIFNs. After collecting the completed questionnaires, they were analysed as follows.

IVIHF-Delphi. As previously explained, experts were free to select several IVIFNs to present their views. These intervals were elected from the linguistic terms presented in Table 5. For instance, a panel expresses its opinion for an SCPMS by the term "*maybe <u>at most nearly available but more than very unavailable</u> or maybe <u>absolutely unavailable</u>*". Hence, the panel has used two IVIFNs that are underlined. The terms are first structured as linguistic interval-valued intuitionistic fuzzy values as {([Not available, Nearly Available], [Very Unavailable, Absolutely Unavilable]), ([Not Available, Not Available], [Absolutely Unavialbale, Absolutely Unavailable])}. Then, these linguistics are translated into their IVIFNs as {([0, 1], [3, 4]), ([0, 0], [4, 4])}.

Insert Table 5

After, the score of each comment was calculated using a two-step approach as follows.

Step 1. Four sets of elements for lower membership limits (μ_i^-), upper membership limits (μ_i^+), lower non-membership limits (ν_i^-) and upper non-membership limits (ν_i^+) were extracted from the experts' opinions. For each of these sets, the hesitant fuzzy score was obtained via Eq. (1) and the scored IVIF values are constructed as ([S(μ_i^-), S(μ_i^+)], [S(ν_i^-), S(ν_i^+)]). For instance, to obtain the hesitation score of the previous example, four sets were constructed including $\mu_i^- = \{0\}$, $\mu_i^+ = \{0, 1\}$, $\nu_i^- = \{3, 4\}$ and $\nu_i^+ = \{4, 4\}$. Then, the score of each hesitant fuzzy set was computed via Eq (1) and scored IVIF value results as ([0, 0.5], [3,5, 4]).

Step 2. Now, the score of IVIF values is computed by Eq. (2). For the considered example, the final score is $\frac{0 - 3.5 + 0.5 - 4}{2} = -3.5$.

Using a two-step IVIHF scoring approach, the opinion of each panel was reached and the average of the panels' opinions was calculated. Next, the consensus of the experts was investigated. In this regard, the standard deviation of the panel's opinions for each SCPMS was computed. If the average of the standard deviations was less than 1, a consensus was reached and the Delphi stopped. Otherwise, another round of Delphi was performed. After consensus, the SCPMSs with higher scores were selected. Subsequently, the PEARL indicators of the Hanlon method were applied to analyse the effect of each IDT on selected SCPMSs during global pandemics and the compatibility of implementing each SCPMS with IDTs. In this regard, three online sessions (two hours on average for each session) were held (via MS-TEAMS) for panels so that each panel, following its expertise, reviewed some of the PEARL indicators and presented their opinions. As described before, PEARL indicators were applied to check the feasibility of using IDTs during pandemics for measuring the performance of SCs in the pharmaceutical sector. To align PEARL with the context of this research, a more accurate definition for each indicator was considered as provided in Table 6. Each of the indicators received values of 0 or 1.

Insert Table 6

4. Results and findings

By reviewing the literature systematically, the initial list of SCPMSs and IDTs has been provided and presented in Tables 2 and 3. As a result, 25 SCPMs have been extracted as illustrated in Table 2 and 14 IDTs have been presented in Table 3. To screen the main SCPMSs suitable during global pandemics, experts were asked to evaluate the degree of availability and unavailability of implementing each SCPM in the pharmaceutical SC of the emerging economy of Iran by linguistics terms according to Table 5. Hence, the score of each assessment was calculated by the two-step score measurement approach proposed in Section 3 employing Eqs 1 to 3. In the first step, the hesitation was considered to obtain the scored IVIF values, and following, in the second step the final score for each panel was measured. Consequently, the SCPMs were weighted and screened by the average score of the three panels of experts. The results are elaborated in Table 7.

Insert Table 7

As illustrated in Table 5, the standard deviation amongst the three panels for each SCPM was measured. The average standard deviation was 0.94 which indicates that the consensus was obtained and the Delphi was stopped in the first round. Therefore, six SCPMSs were selected (as highlighted in grey) including BSC, BSCSM, SCOR, SUS, SUP, and MT. To analyse the relevancy of IDTs with the selected SCPMs, the PEARL indicator of the Hanlon approach was employed as described in Section 3. In this stage, experts were asked to determine the PEARL five sub-criterias (i.e. proper to use (P), economically beneficial (E), applicable in pharmaceutical SCs (A), resources and infrastructures available in pharmaceutical SCs (R), legally possible to implement (L)) relationship with the selected SCPMs by a binary value of 0 or 1 (i.e. the value of 1 for possible and 0 for impossible). Finally, the PEARL indicator (D) was calculated via the multiplication of each sub-criteria ($D = P \times E \times A \times R \times L$). The results of this stage are illustrated in Table 8.

Insert Table 8

Found in the results of Table 6, when D is equal to zero in row i and column j, the SCPM(i) is not aligned to IDT(j). Thus, there are no benefits or advantages for the pharmaceutical SC to invest in that technology to improve their performance measurement system. On the other hand, when the value of D is equal to 1 (highlighted in grey), the story is entirely opposite and it is recommended for pharmaceutical SCs to invest in that technology for more efficient SCPM systems. To evaluate the priority of IDTs, the sum of the row and sums of the columns of the PEARL indicator for each SCPM/ IDT were measured as illustrated in Table 9.

Insert Table 9

As demonstrated in Table 9, simulation, artificial intelligence, big data analytics, automatic identification and data collection are the technologies that are more relevant and applicable for SCPMs in pharmaceutical SCs. These technologies are more aligned to improve the efficiency and effectiveness of the PMSs. In Figure 2 the evaluation of SCPMs and IDTs is illustrated. Accordingly, in the first figure, the adaptability of each selected SCPM with the IDTs is presented and after, the applicability of implementing each IDT in SCPMs is revealed.

Insert Figure 2

As demonstrated in Figure 2_a, SUS, SUP, and MT, respectively, were the most adaptable SCPMSs with IDTs. However, BSC, BSCSM, and SCOR were similarly the less adoptable. On the other hand, according to Figure 2_b, T_2, T_4, T_5, and T_{10} with the value of 6 formed the most applicable IDTs for SCPMSs. Besides, T_6, T_{13}, and T_{14} with the value of 3 were the later applicable technologies. Moreover, T_7 and T_8 were the less applicable technologies with a value of 1.

5. Discussion and Implications

Organisations with a high-performance SC generally disclose superior business performance approaches (Chand et al., 2020). The importance of SC PM has been acknowledged by recent researchers to achieve greater customer experience and retention, increased cost-competitiveness, gain market share with faster product innovation, etc. (Maestrini et al., 2018). Hence, the individual firms have attempted to keep their SC performance under control and extend the view of PM management across the SC (Maestrini et al., 2017). Parallelly, the academic community has endeavored to enrich the existing body of literature associated with SCPMSs (Frederico et al., 2020). To the best knowledge of the authors, a qualitative and quantitative mixed-method, i.e. the combination of the SLR and IVIHF-Delphi method, has not been yet employed to identify and screen pharmaceutical SCPMSs. This novel mixed-method has enriched this paper including both intuition and hesitant of experts integrated with contemporary literature. Furthermore, this study has attempted to compensate for the dearth of research into IDTs in the context of the SCPMSs (Frederico et al., 2020). In turn, this is one of the first papers to provide in-depth insights into determining the priority of contribution of the IDTs in applying different SCPMSs. Innovatively employing the PEARL indicator of the Hanlon method to prioritise IDTs for each finalised SCPMSs, is another theoretical novelty of this paper. To the best of our knowledge, this research has endeavored to enrich the extant literature associated with SCPM in an era of global pandemics with a novel theoretical contribution. The pharmaceutical SC is a backbone of healthcare systems tackling the global health threat (Tirivangani et al., 2021). According to either intuition or hesitation of both industry and academic experts, six SCPMSs were deemed useful for the pharmaceutical industry of emerging economies, like Iran during the global pandemics.

According to the results of IVIHF-Delphi, six finalised SCPMSs would be divided into four levels. With the same highest score (2.75), the *SC operations reference model (SCOR)* and *sustainable SCPMS* have been extracted as the best pharmaceutical SCPMSs to tackle SCPM challenges during unexpected events (Maestrini et al., 2017). Since, the SCOR model encircles performance attributes and metrics according to five distinct management processes (i.e. plan, source, make, deliver, and return) (Ka et al., 2019). Indeed, SCOR couples the internal SC (make) with the external upstream (source), downstream (deliver) and returns (reverse) SC. Moreover, SCOR includes 13 metrics that fall into five categories; (i) SC reliability metrics, (ii) flexibility metrics, (iii) responsiveness metrics, (iv) cost metrics, and (v) assets metrics. The first three categories are customer-facing, directly coupled with customers. The rest of the metrics, namely internal facing, consider the measurements within the internal operation of the SC (Ka et al., 2019). On the other hand, *sustainable SCPMS* considers social responsibility and sustainability in measuring the SC performance (Beske-Janssen et al., 2015), as the need of acquiring a pharmaceutical sustainable SC has critically been emphasised throughout the world (Tat and Heydari, 2021). Particularly, the social facet has been more remarkable when the pharmaceutical industry deals with the health and lives of humans (Tirivangani et al., 2021).

SC balanced scorecard (SCBS) was ranked second to apply in the pharmaceutical SC during the global pandemics. This system works beyond the financial purpose and takes the social aspect (i.e. customer and stakeholders satisfaction) into consideration. Generally, the mechanism of *SCBS* is based upon four dimensions; (i) finance, (ii) customer, (iii) internal business process, and (iv) learning and growth (Kaplan and Norton, 1992). Notably, each dimension includes some critical success factors aligned with either SCM scope or goals. This mechanism leads to an SC strategy compatible with the business strategy. Moreover, *SCBS* is aimed at end-customer satisfaction and financial benefits, and SCM improvement as well (Frederico et al., 2020). The *balanced scorecard and strategy map-based quantitative framework* (*BSSMQ*) could be the third suitable selection to measure the pharmaceutical SC performance in emerging economies like Iran, particularly in an era of global pandemics. In addition to the abovementioned charactristics of *SCBS*, this system is able to assess the lean and green performance of pharmaceutical SC (Thanki and Thakkar, 2018). A profound analysis of causal network relationships among performance measures results in this complement aim (Thanki and Thakkar, 2018). Without such appropriate SCPMS, achieving a lean and green pharmaceutical SC is hardly feasible, particularly in emerging economies; in which the technological infrastructure is not sufficiently accessable. However, improving the environmental and economic aspects of this industry is critical looking to the global health concerns; when the activity of the pharmaceutical SC being increased as a consequence of growing demand. Per a similar score with *BSSMQ*, the *Multi-tier PMS* is also the third priority to consider. As an advantage of this system, evolution of first-tier supplier and customer PMSs can be studied (Maestrini et al., 2017). Generally, this SCPMS can expand the measurement process to additional downstream or upstream SC actors. Nonetheless, the *supplier PMS* that focuses on the immediate supplier PM gained the last priority to employ. It contains a set of matrices used to quantify the efficiency and effectiveness of suppliers' actions (Maestrini et al., 2018). The *supplier PMS* is a well-suited system to facilitate the performance communication between buyer and supplier companies; in which the buyer company feedback on supplier performance could be condensed and formalised (Maestrini et al., 2018). This issue is more critical in a pharmaceutical SC involving tires of the first and second supplier.

Bearing the results of the PEARL indicator of the Hanlon method in mind, four new disruptive technologies, namely *simulation*, *artificial intelligence (AI)*, *big data analytics (BDA)*, *automatic identification and data collection (AIDC)*, would be appropriate for applying all four levels of SCPMSs. Indeed, employing *Simulation* technology provides pharmaceutical SC practitioners with computer modeling to imitate a real-world process/system (Bai et al., 2020). The results of simulating a real problem support them to improve the financial and operational performance of pharmaceutical SC. Besides, using *AI* provides pharmaceutical SC members with intelligent machines working and reacting like humans. These can improve the financial and operational performance of pharmaceutical SC by reducing cost, delay time, lead time, toxic waste of chemical materials, etc (Bai et al., 2020). Moreover, by analysing large volumes of data, *BDA* leads to the high transparency of pharmaceutical SC performance; which is necessary especially for traceability requirements, e.g., traceability of materials through the waste stream (Garay-Rondero et al., 2020). Furthermore, *AIDC,* as a family of technologies would be useful to identify, verify, record, communicate and store information on discrete, packaged, or containerised items. These can improve the pharmaceutical SC performance through receiving and putting away, inventory picking, order fulfillment, determination of weight and volume, as well as tracking and tracing throughout the SC (Garay-Rondero et al., 2020).

As stated, the characteristics of these four disruptive technologies are compatible with the requirements of applying the abovementioned four-level SCPMSs. However, other three disruptive technologies, that is a *cloud technology (CT)*, *cyber-physical systems (CPSs)*, and *cybersecurity,* have been acknowledged as proper tools for establishing three of SCPMSs, i.e., *sustainable SCPMSs*, *multi-tier PMS*, and *supplier PMS*. Cloud computing centers can store and compute a huge amount of data; hence, promoting production and distribution processes, and further bringing higher performance and lower cost. Moreover, resource pooling and sharing, dynamic allocation, flexible extension, etc., are some outcomes of *CT* consistent with the requirements of the three abovementioned SCPMSs (Koh et al., 2019). Resulting of *Cybersecurity*, the prevention methods would be useful to protect information from being stolen, compromised, or attacked (Bai et al., 2020). Moreover, *CPSs* contain interacting special-purpose embedded systems and software to physical (societal, biological, economic) components, engineered to charge non-functional requirements like trust, security, safety, etc (Garay-Rondero et al., 2020). These are essential complementary characteristics to have an effective *sustainable SCPMS*, *multi-tier PMS*, and *supplier PMS.* Regarding superior compatibility of *sustainable SCPMSs* with IDTs, two rest of disruptive technologies, namely *the internet of things (IoT),* and *radio frequency identification (RFI),* have additionally been recognised as useful tools to fulfill the objectives of *sustainable SCPMSs*. Indeed, *IoT* aims at promoting productivity, efficiency, and reliability of SC by combining intelligent machines, advanced predictive analytics and machine-human collaboration. The remote operation of SC members and collaboration among stakeholders resulting from virtual networks hence leads to coordination of product and information flow, decentralised decision-making process, etc. (Koh et al., 2019). Further, *RFI* works as a wireless communication system. It is such a useful tool for inventory control, traceability of materials, products, personnel tracking, etc. Since waste management would prevent environmental, economical and societal problems. These items are critically highlighted in improving the performance of pharmaceutical sustainable SC (Frederico et al., 2020). Nonetheless, five IDTs, namely *virtual reality*, *additive manufacturing or 3D-printing*, *machine-to-machine communication*, *robotics*, and *delivery drone,* would not have much effect on applying any SCPMS based on the experts' view.

Accordingly, three levels of managers (senior, middle, and operational) should take the financial/operational performance of the pharmaceutical SC into consideration during the global pandemics. Senior managers who seek to improve or sustain the performance of the pharmaceutical SC in a high position, need a guideline to adopt an appropriate SCPMS along with the most compatible IDTs. The necessity of this issue is more considerable in case a global health threat occurs in emerging economies. As a managerial implication, the first level of SCPMS including *SCOR* and *sustainable SCPMS,* are recommended to the pharmaceutical industries of emerging economies same as Iran, which almost faces a huge amount of chemical toxic waste, low level of social responsibility, high total costs, long lead times, quality, safety and security problems, etc. Employing nine IDTs (*simulation, AI, BDA, AIDC, CT, CPSs, cybersecurity, IoT, RFI*) would facilitate implementing *sustainable SCPMS* from distinct perspectives. For countries in which customer satisfaction and economic facet are more remarkable than environmental problems, the second level of SCPMS involving *SCBS* is recommended. It is compatible with four essential IDTs, which are *simulation*, *AI*, *BDA*, and *AIDC.* The third level including *BSSMQ* and

Multi-tier PMS is recommended to other countries where in addition to the previous sustainability dimensions (societal and economic), the biological dimension is also considerable in measuring SC performance. Obviously, in addition to the four abovementioned IDTs, *CT*, *CPSs*, and *cybersecurity* are useful tools for implementing the third level. Eventually, the last level covering *supplier PMS* would be useful for developed countries; in which measuring the performance of suppliers requires modern infrastructures. However, the consistent IDTs of this level is the same as the previous one.

6. Conclusion and future recommendation

This research advances the study of PMSs with a contribution of IDTs that could be employed to evaluate the pharmaceutical SC performance during global pandemics. The study has been enriched by involving intuition and hesitation of the industry and academic experts integrating with contemporary literature. To this end, a complete list of 25 SCPMSs was initially extracted through an SLR. This list has been screened via a novel version of IVIHF-Delphi which was firstly developed in this research. Evidence of the pharmaceutical industry of Iran's emerging economy has been applied in this stage. Furthermore, the most relevant IDTs to SCPM were additionally identified through an SLR. The priority of the selected IDTs for each finalised SCPMSs has innovatively been measured by the PEARL indicator of the Hanlon method. Thus, this paper provided a comprehensive strategy guide for pharmaceutical SC practitioners of emerging economies like Iran, in performance management compatible with organisation goals.

The research framework of this study could be extended to other industrial sectors with similar sensitivity to global pandemics, such as healthcare, food industry, etc. Furthermore, the case study of this research was based on the emerging economy of Iran; nonetheless, the pharmaceutical industry of a developed country could be considered in the future and then the results could be benchmarked and contrasted with those obtained from the present study. Accordingly, the results could be employed in emerging economies to improve the performance of pharmaceutical SCs. On the other hand, as in this research, the initial list of SCPMs and IDTs was extracted from a SLR. In the future, scholars can focus on applying other explained research frameworks with additional qualitative approaches (e.g., multi-case study, action research, etc.). Although the authors have developed the IVIHF-Delphi and used it for the first time in this article, other novel versions of uncertainty that include subjective judgments, hesitation and intuition could be developed and applied, for instance, the Pythagorean fuzzy-Delphi, Farmetean fuzzy-Delphi, etc. methods. The results of this research are based on the experts opinion of the emerging economy of Iran. Thus, changing the number of experts, their area of expertise, the SC or industry sector, the country, etc. may impact the results and findings derived from this study. As a result, it is recommended to investigate the role of IDTs in facilitating the SCPM in different areas, sectors and regions during global pandemics to provide a source of comparison and benchmarking for the future and to illustrate an integrated framework. As the IDTs implementation in SCs is relatively new, experts opinions were employed in this research and the results are reliable on their eligibility. However, in the future, and by making these technologies popular and applicable for logistic and SC enterprises, real and numerical data could be used instead of experts subjective judgments.

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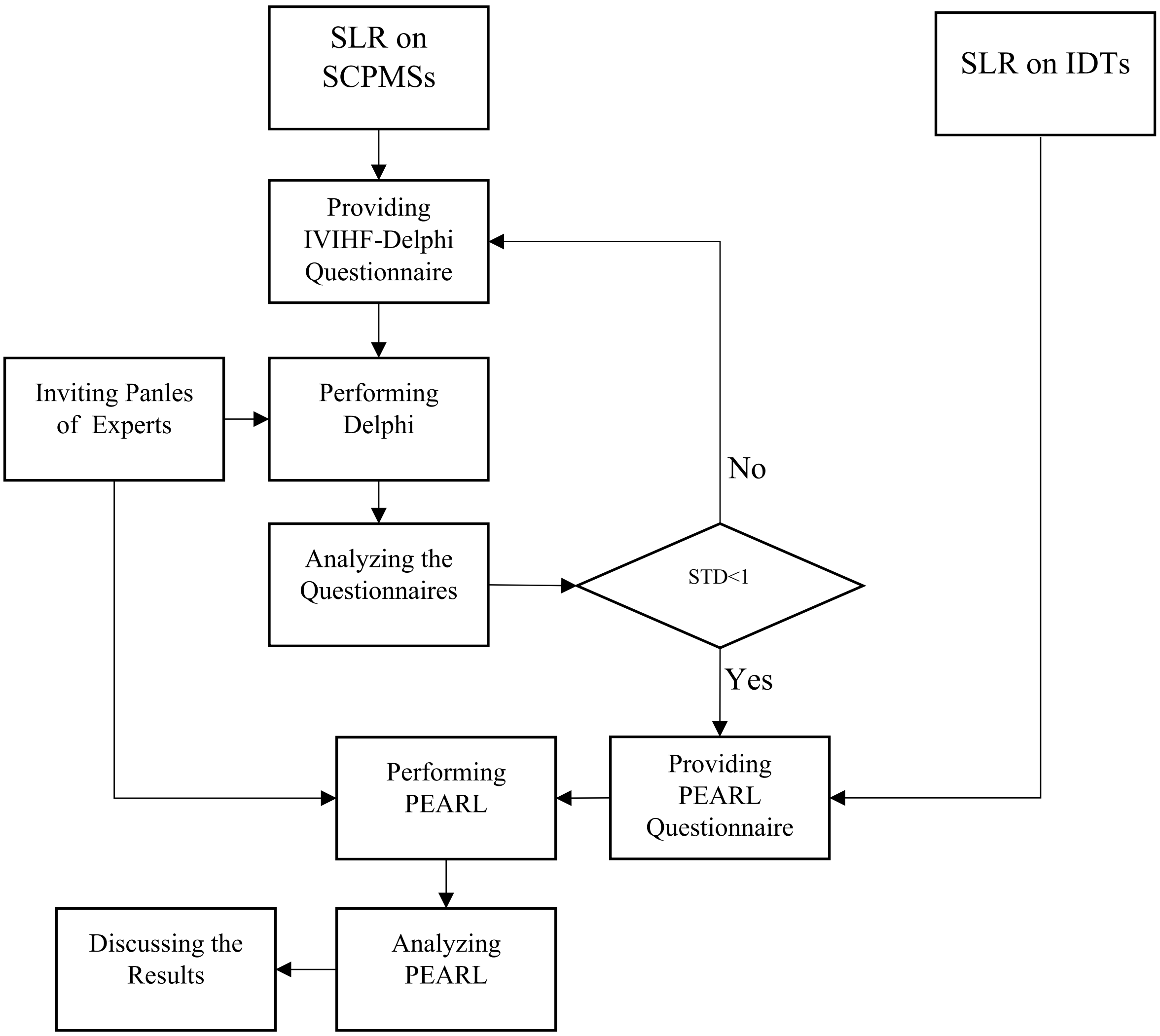

Figure 1. Research Framework

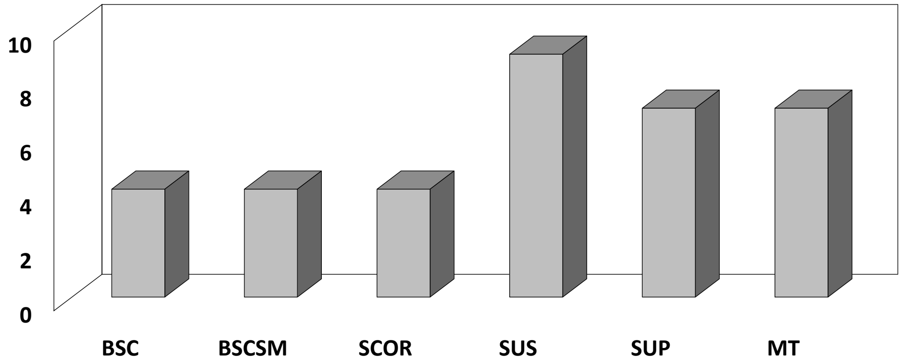

Figure 2_a. The evaluation of SCPMSs adaptability with IDTs

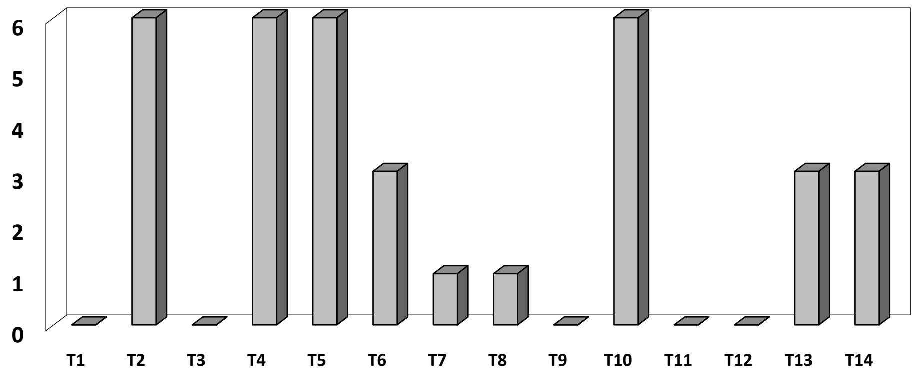

Figure 2_b. The evaluation of IDTs applicability for SCPMs

Figure 2. The evaluation of each SCPMS/IDT's adaptability and applicability

Table 1. SCPMSs: Relevant researches overview

Scholar (s)	Year	Contribution	Type of SCPMS Extraction Approach	Type of Methodology		Data Type	Case Study/ Application
				Qualitative	Quantitative		
De Toni and Tonchia	2001	Identify the conceptual dimensions and constructive variables of the modern PMSs	SLR	Questionnaires	Statistics analysis	Crisp	mechanical industry, electro-mechanical, electronic industries
Garengo et al.	2005	Analyse the diffusion, characteristics, and determinants of PM in SMEs	SLR	SLR		-	Manufacturing SMEs
Franco-Santos et al.	2012	Review the literature on the consequences of contemporary PMSs and the theories that explain these consequences	SLR	SLR		-	-
Balfaqih et al.	2016	Review the literature in the field of SC PM	SLR	SLR		-	-
Maestrini et al.	2017	Assess the maturity of the SCPMSs discipline and set the future research directions	SLR	SLR		-	-
Maestrini et al.	2018	Analyse the dynamics resulting from the use of a supplier PMS between the buyer and the supplier company	SLR	Signaling Theory		-	Automotive SC
Hald and Mouritsen	2018	Analyse how forces located outside focal firm boundaries influence the evolution of PMSs in SCs	SLR	Multiple case study longitudinal case study approach		-	AudioCom ShipCorp TeleTech MicroCorp
Ka et al.	2019	Review the dearth of research into PMSs in the context of the SC	SLR	SLR		-	-
Frederico et al.	2020	Combine the literature on PM and the dimensions of SC in the context of industry 4.0.	SLR	SLR		-	-
Current paper	2022		SLR, IVIHF-Delphi		Hanlon method	IVIHF	Pharmaceutical industry

Table 2. List of SCPMSs

SCPMS	Code	Description	Literature support
SC balanced scorecard (or tableaux de bord)	SCBS	It measures operational performance via the well-known four dimensions (i.e., finance, customer, internal business process, learning, and growth) proposed by Kaplan and Norton (1992). It aims at designing an SC strategy coherent with the business strategy, including critical success factors within the four abovementioned dimensions; which are shaped according to the SCM scope with consideration of SCM goals, end-customer and financial benefits, and SCM improvement.	(Maestrini et al., 2017)
Sustainability-balanced scorecard	SBSC	It was initially identified by Figge et al. (2002) to compensate for the deficiencies of the traditional BSC via the incorporation of environmental, social, and sustainability structures; which were ignored in BSC. It is known as an essential management strategy or tool to increase the consciousness of corporate responsibility.	(Lu et al., 2018)
balanced scorecard and strategy map-based quantitative framework	BSSMQ	It was formed by Thanki & Thakkar (2018) by integrating BSC with a strategy map; which can provide a profound analysis of causal network relationships among performance measures. It additionally allows showing the road map for lean and green SC performance improvement.	(Thanki & Thakkar, 2018)
SC operations reference model	SCOR	It was developed by the Supply Chain Council in 1996 to provide a balanced set of performance measures: four metrics of cycle time, cost, service quality, and asset. These metrics are then categorized based on the five management processes: plan, source, make, deliver, and return. This SCPMS links the internal SC (make) with the external upstream (source), downstream (deliver), and returns (reverse) SC.	(Hald & Mouritsen, 2018)
Resource output flexibility	ROF	It is based upon the seminal work of Beamon (1999). It takes three performance areas (i.e., resources (various dimensions of cost), output (various dimensions of customer service), and flexibility (it measures the ability to respond to environmental changes)) into consideration. It keeps a mainly internal perspective.	(Hald & Mouritsen, 2018)
Process-based	PB	It takes the SC process (i.e., demand management, order fulfillment, manufacturing flow management, procurement, etc.) into consideration with aid of qualitative and quantitative performance measures.	(Hald & Mouritsen, 2018)
Hierarchical-based PMS (or strictly hierarchical/ vertical PMSs)	HB	It is useful to measure the performance of SC at different hierarchical levels. These SCPMS are characterized by cost and non-cost performances on different levels of aggregation until they finally become economic-financial. The first HB model was that of Gold (1955), which connects productivity and ROI.	(Ka et al., 2019)
Frustum PMSs	FRM	However, it leads to a synthesis of low-level measures into more aggregated indicators without the scope of translating non-cost performance into a financial one. In this model, the economic-financial measures are kept separate from the aggregate ones of customer satisfaction.	(De Toni & Tonchia, 2001)
PMSs that distinguish between internal/ external performances	IE	these PMSs distinguish between internal and external performances. The latter are the only ones directly comprehended by the customers.	(De Toni & Tonchia, 2001)
PMSs based on value chain	BVC	These models are related to the value chain. Concerning the preceding ones, additionally, consider the internal relationship of customer/ supplier.	(De Toni & Tonchia, 2001)
Performance Prism	PP	This is a three-dimensional model for measuring the whole organization's performance. Each aspect of the prism is relevant to a specific area of analysis: stakeholder satisfaction, strategies, processes, capabilities, and stakeholder contribution.	(Neely et al., 2001)

SCPMS	Code	Description	Literature support
Performance measurement matrix	PMM	It was firstly introduced by Keegan et al. (1989) to help a firm define its strategic objectives and translate them into performance measures using a hierarchical and integrated approach. With aid of a two-by-two matrix, it combines cost and non-cost perspectives with external and internal ones. Simplicity and flexibility are two features of this model.	(Garengo et al., 2005)
Performance pyramid system	PPS	It was initially defined by Lynch & Cross (1991) as a pyramid four-level model. It also shows the connections between corporate strategy, strategic business units, and operations. It measures stakeholder satisfaction and operational activity.	(Garengo et al., 2005)
PMS for service industries (results and determinants framework)	RD	According to Fitzgerald et al. (1991), this model particularly focuses on the relationship between six dimensions divided into results (competitiveness, financial performance) and determinants of these results (quality of service, flexibility, resource utilization, and innovation). This framework introduces a close link between PMS, strategy, and competitiveness.	(Garengo et al., 2005)
Integrated PMS	IPMS	Bititci et al. (1997) defined this model as the information system which enables the performance management process to function effectively and efficiently.	(Garengo et al., 2005)
Organizational performance measurement	OPM	This model was proposed by Chennell et al. (2000), particularly for small and medium-sized enterprises (SMEs), and is based upon three principles: Alignment, process thinking, and practicability. Both zones of management and open systems theory form two key management constructs of this model.	(Garengo et al., 2005)
Integrated performance measurement for small firms	IPMSF	Laitinen (1996) proposed this model as a hybrid accounting system connecting the traditional view and the activity-based costing together in a causal chain. It is based on two external and five internal dimensions.	(Garengo et al., 2005)
Sustainable SCPMSs	SUS	This model was proposed by Beske-Janssen et al. (2015) to consider social responsibility and sustainability management.	(Maestrini et al., 2017)
Downstream focused PMS	DSM	It focuses on the delivery performance associated with customers and cost in distribution processes in outbound logistics.	(Hald & Mouritsen, 2018)
Upstream focused PMS	USM	It represents delivery performance from strategic suppliers in inbound logistics.	(Hald & Mouritsen, 2018)
Supplier PMS	SUP	It includes a set of metrics measuring the efficiency and effectiveness of suppliers' actions and the goodness of the relationship with them.	(Maestrini et al., 2017)
Customer PMS	CUS	It includes a set of metrics measuring the efficiency and effectiveness of customers' actions and the goodness of the relationship with them.	(Maestrini et al., 2017; Maestrini et al., 2018)
First-tier PMS	FT	It includes a set of metrics measuring the efficiency and effectiveness of immediate supplier or customer action.	(Maestrini et al., 2017)
Multi-tier PMS	MT	It demonstrates an evolution of first-tier supplier and customer PMSs, expanding the measurement process to additional downstream or upstream actors.	(Maestrini et al., 2017)
Many-to-many SCPMS	MTM	It includes a set of metrics used to quantify both the efficiency and the effectiveness of inter-firm processes shared by multiple buyers and multiple suppliers.	(Maestrini et al., 2017)

Table 3. List of Industry 4.0 Technologies

IDTs	Definition/Example	Reference
Virtual Reality (T_1)	It is typically known as a computer simulation that employs 3D graphics and devices to provide an interactive experience.	(Frederico et al., 2020)
Simulation (T_2)	It refers to technologies applying computer modeling to imitate a real-world process/system.	(Bai et al., 2020; Garay-Rondero et al., 2020)
Additive manufacturing or 3D-printing (T_3)	It is a manufacturing technology that initiates three-dimensional (3D) solid objects by applying a set of additive or layered development frameworks.	(Bai et al., 2020)
Artificial intelligence (T_4)	It is a field of computer science that highlights the invention of intelligent machines working and reacting like humans.	(Bai et al., 2020)
Big Data Analytics (T_5)	It reflects the strategy of analyzing large volumes of data that are employed when traditional data mining and handling techniques cannot discover the insights and meaning of the underlying data.	(Garay-Rondero et al., 2020; Koh et al., 2019)
Cloud Technologies (T_6)	Cloud computing is a computing technology. It can store and compute a huge amount of data which leads to higher performance and lower cost.	(Bai et al., 2020; Garay-Rondero et al., 2020; Koh et al., 2019)
Internet of Things (IoT) (T_7)	It is an emerging industrial ecosystem including a distinct set of hardware pieces that work together via IoT connectivity to boost manufacturing and industrial processes.	(Frederico et al., 2020; Koh et al., 2019)
Radio Frequency Identification (T_8)	It is a wireless system including two components: tags and readers. The reader is a device that has one or more antennas that emit radio waves and receive signals back. Tags employ radio waves to communicate their identity and other information to nearby readers.	(Frederico et al., 2020)
Machine to Machine Communication (T_9)	It refers to direct communication between devices using any communication channel such as wired or wireless.	(Frederico et al., 2020)
Automatic Identification and Data Collection (T_{10})	It refers to a family of technologies that identify, verify, record, communicate and store information on discrete, packaged, or containerized items. The usual applications include receiving and putaway, inventory picking, order fulfillment, determination of weight and volume, as well as tracking and tracing throughout the supply chain.	(Garay-Rondero et al., 2020)
Robotics (T_{11})	It is an interdisciplinary branch of computer science and engineering. Its goal is to design machines that can assist humans.	(Frederico et al., 2020)
Delivery drone (T_{12})	It is an unmanned aerial vehicle (UAV) employed in transporting packages, medical supplies, food, etc.	(Bai et al., 2020; Garay-Rondero et al., 2020)
Cyber-Physical Systems (T_{13})	It refers to an intelligent or a computer system in which a mechanism is controlled or monitored by computer-based algorithms. Smart grid, autonomous automobile systems, medical monitoring, industrial control systems, robotics systems, and automatic pilot avionics are examples of this technology.	(Frederico et al., 2020; Garay-Rondero et al., 2020)
Cybersecurity (T_{14})	It refers to the activities to protect critical systems and sensitive information from digital attacks. It is able to combat threats against networked systems and applications.	(Bai et al., 2020; Garay-Rondero et al., 2020)

Table 4. Experts Profile

Expert Code	Panel	Gender	Age	Type (I Industry; A Academia)	Role	Experience
E01		M	40s	I	Logistic Manager	10
E02		M	50s	A	Professor	20
E03	A	M	40s	I	Operations Manager	10
E04		F	40s	I	Warehouse Manager	10
E05		M	50s	I	Transportation Analyst	24
E06		F	40s	A	Associate Professor	15
E07		F	30s	I	Supply Chain Manager	10
E08	B	M	50s	A	Assistant Professor	20
E09		M	50s	I	Operations Manager	25
E10		M	40s	I	Logistic Manager	12
E11		F	30s	I	Transportation Analyst	8
E12		M	30s	I	Supply Chain Manager	10
E13	C	M	40s	I	Operations Manager	15
E14		M	40s	I	Logistic Manager	12
E15		M	40s	A	Assistant Professor	12

Table 5. Linguistic Terms (adopted from Zhang et al., 2021)

Membership		**Non-membership**	
Term	**Value**	**Term**	**Value**
Not Available	0	Not Unavailable	0
Nearly Available	1	Nearly Unavailable	1
Pretty Available	2	Pretty Unavailable	2
Very Available	3	Very Unavailable	3
Absolutely Available	4	Absolutely Unavailable	4

Table 6. Modified PEARL Indicators for IDTs in SCPMs

Indicator	Definition
P	Proper to use-Facilitates performance measurement in SCs
E	Economically beneficial for Supply chains to use
A	Adaptable-Applicable in supply chains
R	Resources available to implement in SCs
L	Legally possible with no restricting regulations to implement

Table 7. The results of IVIHF- Delphi for selecting the SCPMs

SCPMs	Panel 1					Panel 2					Panel 3					Aggregation	
	ALLS	AULS	ULLS	UULS	Score	ALLS	AULS	ULLS	UULS	Score	ALLS	AULS	ULLS	UULS	Score	Avg.	S.D.
BSC	3	4	0	0	3.5	2	3	0.5	1	1.75	2.5	3	0.5	0.5	2.25	**2.50**	0.74
SBSC	2	3	1	1	1.5	1.5	2	1.5	1.5	0.25	2.5	2.5	0.5	0.5	2	1.25	0.74
BSCSM	3	4	0	1	3	1.5	2.5	1	1	1	3	3	0	1	2.5	**2.17**	0.85
SCOR	3	4	0	1	3	2	3	0	1	2	3	3.5	0	0	3.25	**2.75**	0.54
ROF	2	2	1	2	0.5	2	3	0	1	2	1	1.5	2	2	-0.75	0.58	1.12
PB	3	3	1	1	2	2	4	0	0	3	2	2	2	2	0	1.67	1.25
HB	1	2	2	2	-0.5	0	0	2	4	-3	1	1	3	3	-2	-1.83	1.03
FRM	2	2	2	2	0	1	2	1	2	0	1	1	3	3	-2	-0.67	0.94
IE	1	1	2	3	-1.5	2	2	1.5	2	0.25	1	1	2	2.5	-1.25	-0.83	0.77
BVC	1	2	2	2	-0.5	0.5	1	2	3	-1.75	2	2.5	1	1	1.25	-0.33	1.23
PP	1	1	2	3	-1.5	1	2	1.5	2	-0.25	1	1.5	2	2	-0.75	-0.83	0.51
PMM	1	1	2	3	-1.5	2	3	0	1	2	0.5	1	3	3	-2.25	-0.58	1.85
PPS	2	2	2	2	0	1	2	2	2	-0.5	1	1.5	2	2	-0.75	-0.42	0.31
RD	2	3	1	1	1.5	1	2.5	0.5	1	1	2	3	0	0	2.5	1.67	0.62
IPMS	3	3	0	1	2.5	1	1	2	2.5	-1.25	1	1	2	2.5	-1.25	0.00	1.77
OPM	0	1	2	3	-2	2	2	0	1.5	1.25	2	2	1.5	1.5	0.5	-0.08	1.39
IPMSF	0	1	2	3	-2	0	0	3	3	-3	0	0.5	3	3	-2.75	-2.58	0.42
SUS	3	4	0	0	3.5	2	3	0	1	2	3	3	0	0.5	2.75	**2.75**	0.61
DSM	1	1	2	3	-1.5	2	3	0	0.5	2.25	2	2.5	0	0.5	2	0.92	1.71
USM	2	3	1	1	1.5	1	2	1	2	0	2	2	0	0.5	1.75	1.08	0.77
SUP	2	3	0	1	2	3	3	0	0	3	2	2.5	1	1	1.25	**2.08**	0.72
CUS	2	3	1	1	1.5	2	3	0	0	2.5	2	3	0.5	1	1.75	1.92	0.42
FT	3	3	0	1	2.5	2	3.5	0	0	2.75	2	2	2	2	0	1.75	1.24
MT	2	3	0	0	2.5	2	3	0	1	2	2	2.5	0	0.5	2	**2.17**	0.24
MTM	3	4	0	0	3.5	1	2	2	2	-0.5	3	3	0	0.5	2.75	1.92	1.74

Table 8. Hanlon-based Analysis of IDTs role on selected SCPMs

SCPM	T1						T2						T3						T4						T5						T6						T7					
	P	E	A	R	L	D	P	E	A	R	L	D	P	E	A	R	L	D	P	E	A	R	L	D	P	E	A	R	L	D	P	E	A	R	L	D	P	E	A	R	L	D
1	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	1	0	0	1	0	1	0	1	1	1	0
2	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	1	0	0	1	0	1	0	1	1	1	0
3	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	1	0	0	1	0	1	0	1	1	1	0
4	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	1	1	1	1	**1**
5	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	0	1	1	1	0
6	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	1	1	1	1	**1**	1	0	1	1	1	0

SCPM	T8						T9						T10						T11						T12						T13						T14					
1	1	0	1	0	1	0	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	1	0	1	0	1	1	1	0
2	1	0	1	0	1	0	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	1	0	1	0	1	1	1	0
3	1	0	1	0	1	0	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	1	0	1	0	1	1	1	0
4	1	1	1	1	1	**1**	0	0	0	1	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**
5	1	0	1	0	1	0	0	0	0	0	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**
6	1	0	1	1	1	0	0	0	0	1	1	0	1	1	1	1	1	**1**	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	1	1	**1**	1	1	1	1	1	**1**

BSC=P_1; BSCSM=P_2; SCOR=P_3; SUS=P_4; SUP=P_5; MT=P_6

Table 9. The Final Score for the relationship between SCPMs and IDTs

SCPMs/IDTs	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	Sum
BSC	0	1	0	1	1	0	0	0	0	1	0	0	0	0	4
BSCSM	0	1	0	1	1	0	0	0	0	1	0	0	0	0	4
SCOR	0	1	0	1	1	0	0	0	0	1	0	0	0	0	4
SUS	0	1	0	1	1	1	1	1	0	1	0	0	1	1	9
SUP	0	1	0	1	1	1	0	0	0	1	0	0	1	1	7
MT	0	1	0	1	1	1	0	0	0	1	0	0	1	1	7
Sum	0	6	0	6	6	3	1	1	0	6	0	0	3	3	