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# Roles of Innovation Leadership on Using Big Data Analytics to Establish Resilient Healthcare Supply Chains to Combat the COVID-19 Pandemic: A Multimethodological Study

Surajit Bag, Shivam Gupta, Tsan-Ming Choi, and Ajay Kumar

***Abstract*—This article empirically examines the effect of big data analytics (BDA) on healthcare supply chain (HSC) innovation, supply chain responsiveness, and supply chain resilience under the moderating effect of innovation leadership in the context of the COVID-19 pandemic. The scanning interpretation–action–performance model and organization information processing theory are used to explain BDA, HSC innovation, responsiveness, and resilience relationships. First, the hypotheses were tested using data collected from 190 experienced respondents working in the healthcare industry. Our structural equation modeling analysis using the partial least squares (PLS) method revealed that BDA capabilities play a pivotal role in building a responsive HSC and improving innovation, which has contributed to resilience during the current pandemic situation. High innovation leadership strengthens the effect of BDA capabilities on HSC innovation. High innovation leadership also increases the effect of BDA capabilities on responsiveness. Second, we validated and supplemented the empirical research findings using inputs collected in 30 semistructured qualitative questionnaires. Our article makes a unique contribution from the perspective of innovation leaderships. In particular, we argue that the role of innovative leadership in the COVID-19 pandemic situation is critical as it indirectly affects HSC resilience when BDA is in place.**

***Index Terms*—Big data analytics (BDA), COVID-19, healthcare supply chain, multi-methods research, responsive supply chain, supply chain innovation, supply chain resilience.**

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## I. Introduction

GLOBAL spending on healthcare is expected to dramatically increase in the near future. This partially relates to changing consumer requirements [1] as well as the higher expectation on timely response to disasters [2]–[4]. Most recently, the COVID-19 pandemic has made it clear that healthcare supply chains (HSCs) are far from perfect. Not much improvements were made from the experiences acquired during various prior epidemics such as middle east respiratory syndrome (MERS) and severe acute respiratory syndrome (SARS) [5], [6]. Massive disruptions in HSCs have reached the level of a global crisis. The availability of personal protective equipment (PPE), medical equipment, and lifesaving drugs has been severely limited [7]–[9]. Under COVID-19, high demands have challenged the HSC, highlighting the need to manage supply chains differently in crisis situations [9], [10]. Undoubtedly, supply chain responsiveness and innovation are essential to build a resilient HSC to combat the COVID-19 pandemic when the demand uncertainties are extremely high [11], [12].

In the literature, Peeri *et al.* [6] pointed out the need to focus on using digital technologies to monitor pandemic situations. In particular, big data analytics (BDA) is a powerful tool to help [13]. For example, BDA supported inventory management of medical supplies during emergency responses is critical to ensure the distribution of appropriate supplies [14]. Medical devices with high volumes of data can apply BDA to understand trends and future requirements of PPE. This enhances the management and planning of activities in HSCs [1]. Digital technologies can remove barriers in pharmaceutical supply chains and improve flexibility and innovation related to drug supplies, thereby enhancing coordination, information sharing, and minimizing wastes [2], [15].

In healthcare, BDA is valuable for environmental-scanning (forecasting and observation) purposes [10]. It helps predict the results of drug administration, and analyze patient categorization and emergency response [16], all of which are of paramount significance during a pandemic like COVID-19 [13]. BDA not only can sense information, it can also enhance interpretation to support key business decision making [17], [18] in a timely manner [110]. Prior studies have shown that innovative supply chains have the ability to manage risks, determine an organization's competitive position [11], and enhance the interpretation of key information as well as strategy development [19]. Note that innovation leaderships (IL) can improve supply chain innovation and, hence, improve efficiency [20].

Supply chain responsiveness aims to reduce manufacturing throughput and transportation/distribution lead times [21]. BDA capabilities can assist in building a responsive supply chain that positions resources and key players (suppliers, transporters, distributors) at the right places to gain a competitive advantage [22]. BDA improves productivity in the supply chain process by offering an added level of flexibility [23]. Moreover, following the arguments in [24], BDA can positively affect supply chain transparency. Note that a few studies have examined the role of BDA in the HSC during pandemics (e.g., [25]–[29]). However, no prior research has comprehensively examined the links between BDA and supply chain responsiveness and innovation together. This article aims to fill this gap in the context of COVID-19.

A recent insightful study by Dubey *et al.* [94] used the organization information processing theory (OIPT) to explain the relationships between blockchain technology and operational supply chain transparency. Dubey *et al*. [94] further argued that blockchain technology and operational supply chain transparency can further enhance collaboration among actors engaged in disaster relief operations and this finally leads to improved supply chain resilience. This study supplements [94] and others in the related domain, and contributes to the supply chain resilience literature. It is noteworthy to mention one more important recent study on supply chain resilience by Dubey *et al.* [95] who highlighted the importance of BDA in enhancing information processing capacity and supply chain resilience for faster recovery after any disruptions. However, IL (which is related to supply chain resilience) for HSC innovation (SCI) is still an underexplored area. Carmeli *et al.* [64] pointed out that IL increases strategic fit (internal/external) and further improves firm performance. Hence, the role of leaders (irrespective of whether they are political leaders of the country or leaders of companies) is crucial in this pandemic time. To be specific, IL includes the proper way to encourage individuals to take various initiatives, develop a transparent performance measurement system, and build an environment in which quality relationships would be treasured. Having good IL will lead to increased creativities in the organization [64]. Innovation is related to "out-of-the-box" thinking and introducing something new such as new ideas, methods, or devices. Innovations in the sphere of healthcare products and services are keys to combat the COVID-19 pandemic and yield quick recovery from the current state. Thus, innovative leadership is critical for establishing a resilient healthcare system.

Motivated by the importance of BDA in HSCs and the critical role of IL, we study the moderating effect of IL on the contribution of BDA to SCI and responsiveness during COVID-19 pandemic. This article is unique from a few perspectives:

1) we examine the effect of BDA on HSC responsiveness (RSC) and innovation;
2) we investigate the effects of RSC and innovation on supply chain resilience.
3) We adopt the multimethodological approach in deriving more scientifically sound results.

The main research questions that the study sought to answer are as follows.

*RQ1:* What are the effects of BDA on (i) supply chain responsiveness and (ii) supply chain innovation under the moderating effect of IL during the COVID-19 pandemic?

*RQ2: What are the effects of (i) responsive supply chain and (ii) supply chain innovation on HSC resilience (*SCR*) during COVID-19 pandemic?*

The theoretical model is built through the lenses of OIPT and scanning interpretation–action–performance (SIAP) modeling. We argue that BDA is useful for environmental scanning and information processing to drive SCI (interpretation of key information), which helps establish the responsive supply chain (actions). Finally, SCI and responsiveness are essential to build SCR (performance). During part 1 of the study, data were collected in South Africa using a structured questionnaire and hypotheses were tested using structural equation modeling (SEM) applying the partial least squares technique (PLS-SEM). In the second part, a thematic analysis was performed using the data obtained from 30 semistructured qualitative questionnaires. The themes that emerged from this second-phase highlight major dimensions associated with BDA in the HSC.

The rest of this article is organized as follows. Section II presents the theoretical background and hypotheses, Section III provides the methods used for conducting the analysis. Section IV presents the data analysis. Finally, Section V and Section VI concludes this article.

## II. Theoretical Background and Hypotheses Development

### A. Organization Information Processing Theory

OIPT theory proposes that organizations must enhance their information processing capacity to survive in an increasingly uncertain business environment [30], [31]. The COVID-19 pandemic has brought tremendous uncertainties to the lives of both humans and businesses [32]. Uncertainty is driving the need for building information processing capability [33], and companies involved in HSC need to leverage disruptive Industry 4.0 technologies such as BDA to scan and process information and make strategic decisions. OIPT explains how firms can develop the information processing capability during the COVID-19 pandemic to assess external information such as supply crises, market demands, sales and competitors' distribution activities, rate of infection spreading, number of infected cases, number of recoveries, number of deaths, and clinical trials monitoring and outcomes. Past studies have used OIPT to explain disruptions in supply chains [34]. We argue that BDA enhances firms' information processing capability during these uncertain pandemic times. Furthermore, supply chain innovation and responsiveness reduce uncertainty by fostering resilience. However, OIPT cannot single-handedly explain the entire mechanism (BDA–innovation–responsiveness–resilience). Therefore, we supplement it with the SIAP model to better explain these relationships.

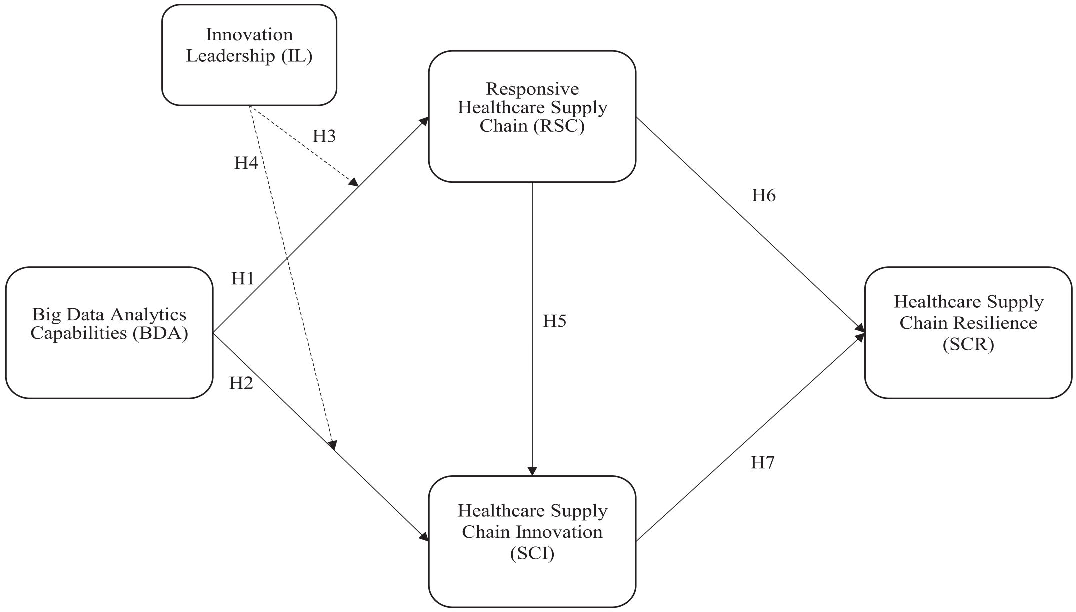


Fig. 1. Theoretical model.

### B. *SIAP Model*

For the relationships among BDA, SCI, RSC, and SCR, we can refer to Yu *et al*. [35], and the adopted SIAP model [36] and OIPT [37]. Whether operating at a local or international level, every business is influenced by external factors. Situations change rapidly due to variations in political, environmental, or technological scenarios. Running a business is, therefore, an uneasy task, especially during turbulent times such as the COVID-19 pandemic. The SIAP model argues that firms adjust in the business environment by following three basic steps, namely "scanning, interpreting, and responding" [38]. First, organizations scan information that can influence performance [36]. Accuracy is key to any effective environmental scanning [39], and BDA can be used to scan important data to generate useful information from various internal and external sources to gain rich business insights and develop competitive edges [40], [41]. BDA fundamentally works by scanning information in the changing business environment [42], [43]. Common sources of big data include social media, websites, shop floor machines, meters, and sensors.

There is enormous potential for BDA applications in the HSC [16]. BDA has been demonstrated to be a useful scanning tool that can equip organizations with the ability to scan risks and reconfigure resources and competencies [44], [45]. The potential of artificial intelligence (AI) and BDA in fighting COVID-19 has been confirmed in the literature (see, e.g., [46]). BDA can be used to model the spread of infection during a pandemic, monitor clinical trials, and outcomes, which can be useful for framing policy and controlling infection [16]. Big data generated from social media, smart phones, and other digital equipment can be immensely helpful in controlling the spread of COVID-19 [13]. The second step in SIAP is "interpretation," whereby management uses diverse models as information processing methods to understand and label information [36]. Managers can make use of information to identify opportunities and threats. We argue that firms should resort to supply chain innovation involving all stakeholders to pursue creative methods and services. The third step is "action," i.e., the strategic initiatives that the firm undertakes to adapt in the changing business environment, which can range from slight shifts in procedures of the business processes to major alterations in product, sales, and distribution strategies. We argue that RSC is a strategic initiative to respond facing the COVID-19 pandemic. The final step of the SIAP model is "performance" [36]. We argue that SCR is the final outcome that every healthcare organization intends to achieve during pandemic situation.

### C. *Theoretical Model and Research Hypotheses*

The theoretical model built based on the abovementioned discussion is presented in Fig. 1. Although big data drives supply chain innovation, studies on BDA methods that can help organizations to enhance innovation are limited [47]. In addition, research initiatives on leveraging BDA to unlock values require further investigation [48]. Previous studies have shown how BDA can positively influence supply chain sustainability [40], [48]. We argue that BDA has a positive association with RSC and innovation, whereby innovation has the ability to develop highly responsive supply chains, and innovation and responsiveness lead to supply chain resilience. In this article, we also introduce "IL" as a moderating variable to examine its effect on the relationships between "BDA and health care supply chain responsiveness" and "BDA and SCI."

*1) BDA and Supply Chain Responsiveness and Innovation:* Nowadays, the numbers of actors and products in modern supply chains are much higher than before. Organizations generally prefer big data solutions to curb problems in the supply chain network [49]. BDA involves collecting, managing, and processing a high volume of data generated from various sources. These data can be both structured and unstructured in form, and BDA can be used to analyze them and unlock their value [50]. Under COVID-19, the pandemics create a disaster situation and disrupt supply chains because the local and international borders remain closed to prevent the spread of infection. In this type of situation, rapid action is required to make radical changes in the supply chain that are only possible using BDA information processing capabilities for scanning environmental information [51].

In an HSC, big data is generated from internal enterprise resource planning (ERP systems) and external sources (social media, mobile devices, data portals, and data market platforms). The non structured query language (NoSQL) graph databases are useful for optimizing and configuring supply chains. The Apache Hadoop platform is immensely helpful for managing high volumes of data, and MapReduce helps perform the analytics part to extract information [52]. During pandemic times, batch analysis is untenable to manage when a vast amount of data are generated in the HSC. However, the Lambda architecture can analyze real-time data flows by supporting data stream analytics. Every minute, the data of infected patients, status of infection spread, current drugs, and other medical device requirements at different locations can be gathered using an advanced ICT platform. Further data streams can be analyzed using complex event processing programs. AutoID digital technologies can be useful for tracking purposes as well [49], [53]. BDA can extract information that can be useful for making decisions related to HSC configurations [54]. However, it is important that data scientists and data analysts would closely monitor and control the quality of data to prevent inaccurate information generation [55]. Therefore, we establish the following hypothesis.

*Hypothesis H1: BDA capabilities have a positive relationship with RSC.*

BDA can also offer new opportunities for supply chain innovation [56]. New vaccines and drugs are required to combat pandemic situations [57]. Moreover, the shortage of equipment such as PPE for front-line doctors and healthcare workers can be resolved by securing specialized PPE and making alternative PPE products using 3-D printing and advanced manufacturing. In addition, digital contact tracing apps can play an important role by tracking disease spread [58].

Innovation can involve the development of new products with unique features, alternative manufacturing methods, eco-friendly raw materials for manufacturing, new approaches to transportation and distribution, and the development of new processes that can yield huge benefits for society at large as well as firms [59]. Big data generation capabilities, data integration and management capabilities, advanced analytics, and data visualization capabilities can be immensely useful for supply chain innovation [49], [59]. Therefore, we have the following hypothesis.

*Hypothesis H2: BDA capabilities have a positive relationship with SCI.*

*2) Moderating Effects of IL:* In this article, we have used OIPT to explain the role of BDA in information processing for reducing uncertainties. However, in the literature, Haußmann *et al.* [32, p. 81] highlighted certain shortcomings of the original OIPT theory, which includes the point that interpersonal characteristics and information restrictions are not taken into account. Interpersonal characteristics here include leadership, teamwork, etc. To overcome the limitations of the original theory, we made reference to Hambrick and Mason [96] in which the authors conceptualized the "upper echelons" perspective and argued that firm performance is shaped by managerial background characteristics. "Upper echelons" based leadership theory can put some light on the observable managerial characteristics that the leader can bring to an administrative circumstance. Observable characteristics such as age, functional tracks, other career experiences, education, socioeconomic roots, financial position, and group characteristics would all influence the strategic choices made by top management and leaders [96]. Undoubtedly, product innovation is one of the strategic choices that leaders make for improving firm performance [96]. As a remark, Carmeli *et al.* [64] argued that IL can improve strategic fit and further enhance the firm performance. IL is related to the innovative nature of organization leaders that ranges from emphasizing on teamwork, clarifying individual responsibility, providing clear feedbacks to employees, emphasizing on task orientation, encouraging initiatives, and developing trust among employees [64].

In an uncertain business environment under COVID-19, it is very difficult to forecast and plan activities. Disasters and pandemic situations exacerbate the uncertainty, and if leaders continue to work with the same approach used under normal circumstances, then their businesses will not survive the impact. Innovative leadership can be highly effective for managing business challenges during pandemic situations.

Applying innovative thinking to leadership tasks can spur employees to begin thinking in innovative ways and further use BDA to configure the HSC and pull the firm out of danger [60]. Learning and teamwork are required to improve environmental training and configure supply chains for sustainability outcomes [61], [62]. Training forms part of the Industry 4.0 delivery system and is important in sustainable development [63].

All of the abovementioned human resource factors are antecedents of IL [20]. IL improves organizational performance and contributes to a firm's strategic positioning within the business environment [64]. Importance of human resource management, involving IL and responsive management for supply chain sustainability, is highlighted in [12], which argued that the greater the IL, the more pronounced the effect of BDA information processing capabilities on building responsive HSC. Some other studies have demonstrated that leadership thinking based on extensive information will enhance configuration decisions [65], [66]. Therefore, we have the following hypothesis.

*Hypothesis H3: IL has a moderating effect on BDA capabilities and RSC.*

IL is essential for managing the same supply chain tasks in a new way [60]. Many important decisions must be made during disasters caused by the COVID-19 pandemic [4], and innovative leadership can foster innovative thinking by the team and result in innovative solutions that can be helpful for humankind. Unique solutions can involve deploying robots to

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screen for COVID-19 in the community, using drones to carry testing kits and essential drugs to remote places, producing PPE from alternative materials at low cost, using specialized logistics for distribution [109], protecting employees from infection, and changing supply chain processes [67].

The demonstration of innovative thinking by top management builds confidence in BDA application among other employees, and the data can be useful in supply chain innovation. The greater the IL in the organization, the greater is the activation of BDA information processing capabilities on SCI [20], [49]. Therefore, we propose the following hypothesis.

*Hypothesis H4: IL has a moderating effect on BDA capabilities and supply chain innovation.*

*3) SCI, Responsiveness, and Resilience:* During a pandemic such as COVID-19, the configuration of the HSC requires significant modifications to enable changes in business processes that can benefit patients and facilitate the economical distribution of essential medical goods and devices. It may be necessary to restructure old supply chain structures to transform them into new structures and develop innovative approaches and capabilities [68]. Changing suppliers and supply chain processes can enable the application of innovative technologies and thereby drive agile and responsive processes to counter changes. We, hence, have the following hypothesis.

*Hypothesis H5: SCI has a positive relationship with RSC.*

The HSC can be optimized by reconfiguring its resources to make the healthcare supply more resilient [4]. The ability to quickly configure the supply chain will enhance the ability of the HSC to become responsive and effectively fight against a pandemic, which will save time and efforts while using resources more effectively. This ultimately brings an added benefit to the society [4], [69]. Changing the supply chain configuration and quickly responding to market changes will help to reduce negative effects from repeated risk and improve supply chain resilience [11]. Therefore, we build the following hypothesis.

*Hypothesis H6: RSC has a positive relationship with SCR for pandemic response.*

An innovative supply chain design influences the choice of vendors and results in cooperation with important suppliers as well as impacting supply chain efficiency and quality-related practices [14]. Working in a collaborative manner with suppliers and integrating operations for improved efficiency can result in innovation [70]. In the HSC, innovation initiatives are important to meet increasing demands for better services in a timely manner for patients [71]. Innovation in the HSC can reduce the distance between warehouses and affected areas [72]. Innovation can also contribute to the cheaper manufacturing of products and make them available quickly based on demand. Only innovative approaches can make the HSC more resilient and help manage pandemic situations more effectively [11], [72]. Therefore, we have the following hypothesis.

*Hypothesis H7: SCI has a positive relationship with SCR for pandemic response.*

## III. Research Methods[1]

A multimethod approach [73] is used in this study. Multimethod approaches are commonly utilized to validate findings in technology and operations management research [73]–[75]. This article was conducted in the following two phases: I) quantitative survey and testing of theoretical model using variance-based SEM and II) semistructured qualitative questionnaires and thematic analysis. Saunders *et al.* [104] pointed out a very important part of academic research, i.e., data collection. Data are linked with the answering the research questions. Therefore, "what type of data is required" and "what techniques are necessary to collect the data" are both critical decisions in any empirical research study. Saunders *et al.* [104] conceptualized the data collection process as the central part of the research onion. Selection of data collection techniques and analysis processes are critical to produce a good research output. We previously indicated that the multimethod approach was used to reach to the "centre of the onion," i.e., answer the central research questions. We did not simply peel off the important outer layers of the onion and thrown them away. We had carefully selected the techniques, with a combination of quantitative and qualitative techniques, in both data collection and analyses. The rationale behind using these methods is as follows: First, to overcome the limitation of empirical surveys (i.e., to have the triangulation effect). Second, to gain richer insights from the practitioner's perspectives. In the first phase, we used a structured questionnaire and further analyzed the theoretical model. In such a process, we established the links and contributed to the literature. However, the primary data/empirical survey did not provide rich and deeper insights about the underlying mechanism, which was made possible through the use of qualitative surveys with selected respondents (considered from the same sampling frame from phase 1). The qualitative analysis further provided understanding about the relationships to a greater extent that was not possible with quantitative study. Results of the qualitative study can also verify if the quantitative findings are valid or not. This enhances research rigors. The research flowchart is presented in Fig. 2. Note that this approach follows the philosophy proposed by Choi *et al.* [73].

### A. Construct Operationalization

The survey items were adopted from the existing literature. The five-item BDA construct was taken from Arunachalam *et al*. [47], the six-item SCI construct was adapted from Kwak *et al*. [11], the five-item RSC construct consisting of five items was adapted from Parmigiani *et al*. [68], the four-item IL construct was adapted from Yoon *et al*. [20] and the eight-item SCR for pandemic response construct was adapted from Sabegh *et al*. [4]; and Kwak *et al*. [11]. The details are provided in Table A1 (Online Supplementary Appendix A).

### B. Sampling and Data Collection

The target population for this article comprised general managers, senior managers, managers, junior managers, and other

[1]The authors sincerely thank a reviewer for reminding us the importance to clarify the idea behind the multimethod study.

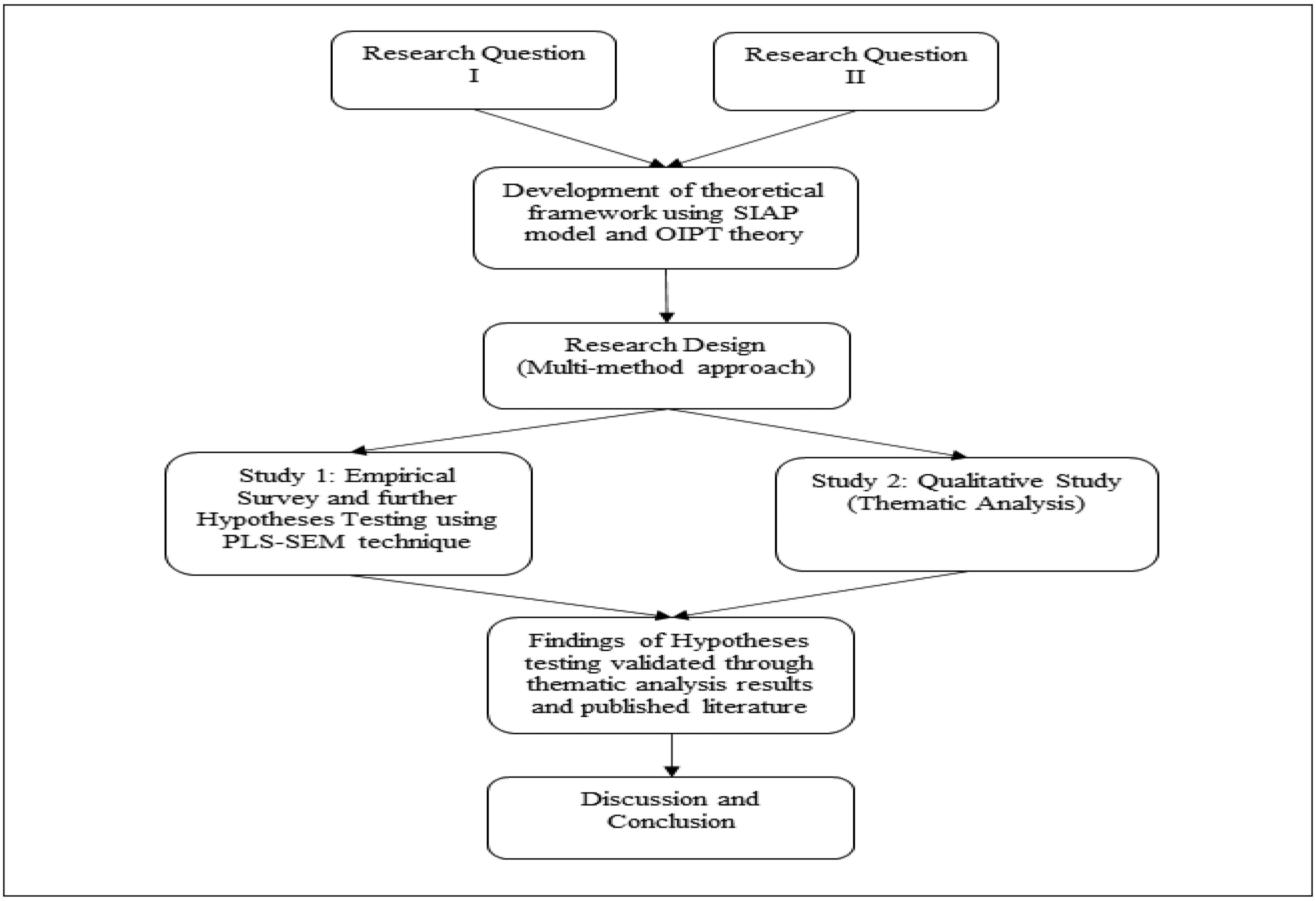


Fig. 2. Research flowchart.

healthcare sector professionals responsible for sourcing, manufacturing, logistics, distribution, research, and development. The companies were selected from among the most relevant databases in the context of our article, namely the "Innovation Pharmaceutical Association of South Africa," "Generic and Biosimilar Medicines of South Africa," and "BioPharmGuy." The total number of members listed in these directories combined is approximately 1200.

It was determined that 30 representative participants would be a reasonable minimum recommendation for a pilot study [76], [77]. The questionnaire was developed based on a five-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree). The questionnaire was e-mailed (using Google Forms) to 37 managers for a pilot survey assessment. After the responses and comments were received, seven questions were reworded before distributing the final survey.

Sampling targeted a total of 550 potential respondents, who were selected using random sampling technique, and the final questionnaire was sent (using Google Forms) to two respondents from each company. No incentive was offered or given to survey participants. After two rounds of follow-up, a total of 190 responses were received, representing a response rate of 34 percent. Questionnaires were received from 78 respondents were received at the end of April 2020, and after conducting follow-up, we received data from an additional 112 respondents at the end of May 2020. We did not receive any incomplete submissions, as the questionnaire was designed only to accept complete submissions.

The demographic profile of the survey participants is presented in Table A2 (Online Supplementary Appendix A). The highest number of responses was received from professionals working in the healthcare industry for over 15 years, and most responses were received from companies operating in South Africa for more than 20 years. Responses were received from pharmaceutical product and medical device manufacturers, biotechnology companies, medical product distributors, medical retailers, and clinical research institutes. The largest number of responses was received from biotech companies, followed by medical device manufacturers. The analysis also indicated that most responses were received from big companies with annual turnover of more than 50 million South African Rands.

### C. *Nonresponse Bias (NRB)*

Since data were received in two phases, we checked NRB by judging the first and second wave of responses, with the second wave (i.e., late responses) being regarded as a control group standing in for those who did not respond (for example, see [80]). Homogeneity of variance test was performed to determine if there was any difference between both sets of responses. The nonsignificant results indicated that our article was free from NRB.

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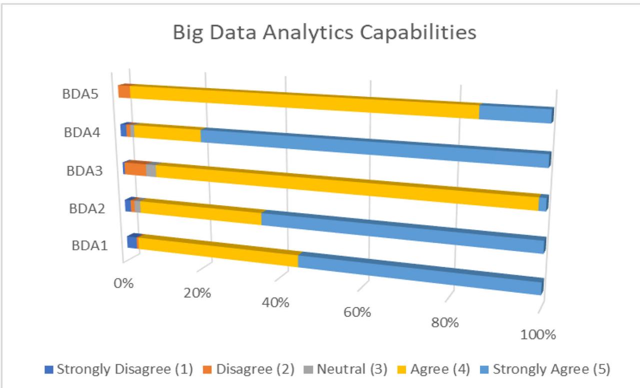


Fig. 3. BDA capabilities.

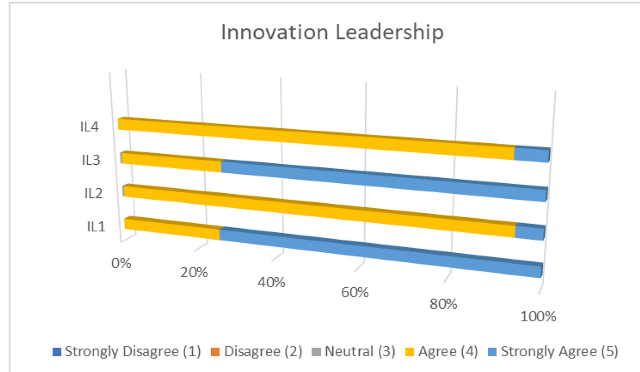


Fig. 4. Innovation leadership.

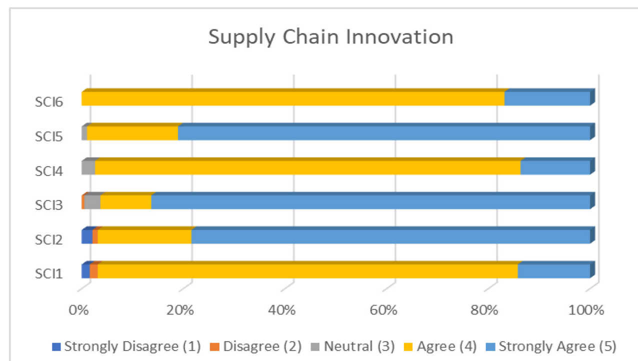


Fig. 5. Supply chain innovation.

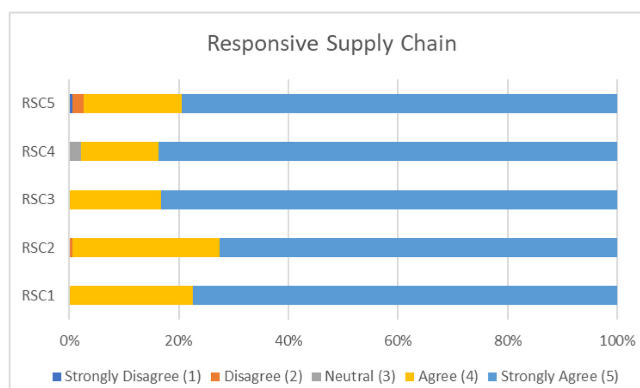


Fig. 6. Responsive supply chain.

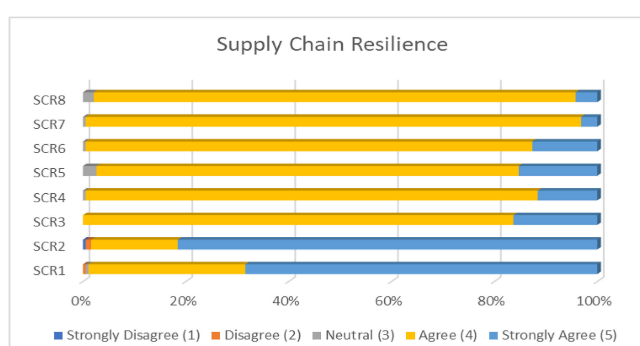


Fig. 7. Supply chain resilience.

### D. *Qualitative Study Methodology*

The semistructured, open-ended questionnaire (Online Appendix B) used to collect qualitative data was adapted from Sheng *et al*. [85] and consisted of the following two sections: the first section intended to capture the demographic profile of respondents, and the second section consisted of seven questions intended to capture the potential of BDA in developing resilient HSCs. To avoid any form of common method bias (CMB), a clear note at the top of the questionnaire explained that the data collection is purely for academic purpose and the names and personal details of the respondents will not be disclosed at any point of time. The number of questions was kept minimum to avoid respondents becoming bored or losing patience while answering such descriptive questions. The questionnaire was created on Google Forms and the link was emailed to 30 potential respondents who were part of the initial empirical survey performed during phase 1 of this article. The request to complete the questionnaire was sent at the end of January 2021, and all of the data was received by early February 2021. Responses were received from all 30 participants. Previous studies have used 20 samples; therefore, a sample size of 30 is acceptable for this study [86]. Finally, the thematic analysis acts as an input for the triangulation of the results obtained from the previous stage. Excel was used to perform the coding, followed by grouping under subthemes and extracting the main themes.

## IV. Data Analysis

The data obtained during the primary study in phase 1 is depicted in Figs. 3–7. Fig. 3 indicates that there are five items (BDA1, BDA2, BDA3, BDA4, and BDA5) that were used to measure the latent construct BDA capabilities. It also shows the responses received during the primary survey for instance if we look at the item BDA1, out of total 190 responses: 5 selected strongly disagree, i.e., 2.6%; 1 selected disagree, i.e., 0.52%, 0 neutral, 79 selected agree, i.e., 41.57%, 105 selected strongly agree, i.e., 55.26%.

Fig. 4 indicates that there are four items (IL1, IL2, IL3, and IL4) that were used to measure the latent construct IL. It also shows the responses received during the primary survey.

Fig. 5 indicates six items (SCI1, SCI2, SCI3, SCI4, SCI5, and SCI6) were used to measure the latent construct supply chain innovation. It also shows the responses received during the primary survey.

Fig. 6 indicates five items (RS1, RSC2, RSC2, RCS3, RSC4, and RSC5) were used to measure the latent construct responsive supply chain. It also shows the responses received during the primary survey.

Fig. 7 indicates eight items (SCR1, SCR2, SCR3, SCR4, SCR5, SCR6, SCR7, and SCR8) were used to measure the latent construct supply chain resilience. It also shows the responses received during the primary survey.

### *A. SEM Applying the Partial Least Squares Technique*

Two types of SEM techniques are commonly applied, they are namely: 1) the covariance-based method, and 2) the partial least squares method. PLS-SEM is widely used by researchers in various fields [79]. Many research papers are available that critically examined the pros and cons of PLS-SEM [100]–[102]. In this article, we followed the guidelines of Hair *et al.* [103]. When the objective of this article is mainly on "prediction and explanation," then PLS-SEM is recommended. For the case with "reflective model specification," both PLS-SEM and CB-SEM can be used. For smaller sample sizes, PLS-SEM is recommended. Keeping in mind all these points, we opted for the PLS-SEM technique. The software WarpPLS (version 6.0) was applied for conducting the SEM analysis. We do understand that no single method is perfect. There are pros and cons of each method. To enhance research rigors, we have adopted the multimethod approach (see Fig. 2).

### *B. Common Method Bias*

The problems associated with the effect of method bias have long been highlighted in the literature [97]–[99]. In many cases, the instructions at the beginning of a questionnaire can influence responses in a particular way (e.g., by implying the desirability of certain responses), thereby introducing common variation among the indicators and contaminating key results by inflating path coefficients due to the introduction of multicollinearity.

Following the guidelines of MacKenzie and Podsakoff [98], we carefully designed the questionnaire. First, to ensure the questions could be easily understood, we pretested the questions in our preliminary trial survey. Second, we selected respondents who had the necessary experience about BDA in the healthcare industry. Third, we avoided the use of highly complex and abstract questions. Fourth, we took away "item ambiguity" by using a clear and concise language. Fifth, we did not keep any double-barrelled questions. Sixth, we refocused questions to ask about the current pandemic states because this would minimize efforts required for retrieval of information.

In addition, we performed Harman's single-factor test on all the constructs [108]. We conducted the standard exploratory factor analysis by selecting the principal component. We further checked the unrotated factor solution to determine the number of factors. The findings did not produce any individual dominating factor which indicates nonexistence of CMB.

Lastly, the research team checked whether CMB was present by applying a full collinearity test to examine both vertical and lateral collinearities [78], [79]. If the variance inflation factors (VIFs) are above 3.3, the collinearity issues exist and the model suffers the CMB problem. This is a highly sensitive CMB criterion that tends to identify CMB where other methods provide false negatives [78]. In the current study, the VIF values were all found to be lower than 3.3, and we can, therefore, conclude that our model does not suffer the CMB problem.

### *C. Measurement Model*

*1) Validity and Reliability:* The internal consistency of the latent constructs was checked, and Cronbach's alpha test was used to check the reliability of the instrument. All Cronbach's alpha values except IL (0.658) and RSC (0.621) were higher than 0.70 (BDAC: 0.868, SCI: 0.893, SCR: 0.749, IL∗BDAC: 0.912). Since the measurement of these constructs was sensitive to the number of items in the respective scales, the research team also checked the composite reliability of all latent constructs. Composite reliability is a preferred alternative to Cronbach's alpha test in the context of the data analysis method employed, and composite reliability values above 0.60 are acceptable in social science research. The results indicate acceptable reliability (BDAC: 0.908, IL: 0.793, SCI: 0.920, RSC: 0.771, SCR: 0.812, IL∗BDAC: 0.929). Average variances extracted (AVEs) were calculated to assess convergent validity based on the widely used threshold of 0.50 [81], [82]. The values obtained (BDAC: 0.670, IL: 0.598, SCI: 0.662, RSC: 0.505, SCR: 0.599, IL∗BDAC: 0.542) suggest that our measurement model displays acceptable convergent validity.

Using square roots of AVEs for the latent constructs in combination with latent construct correlations, the research team also investigated discriminant validity by following the Fornell–Larcker criterion, i.e., for any latent variable, the square root of the AVE must be higher than its correlation with any other latent variable [81], [82]. The results are showcased in Table A3 (Online Supplementary Appendix). These results suggest that our measurement model displays acceptable discriminant validity.

*2) Model Fit and Quality Indices:* The quality of the research model was checked using both classic model fit indices and more modern causality assessment indices, as outlined in the following. The classic model fit indices used were the average path coefficient (APC), average R-squared (ARS), average adjusted R-squared (AARS), average block variance inflation factor (AVIF), and average full collinearity VIF (AFVIF) [83].

It is recommended that the $p$ values for APC, ARS, and AARs be less than or equal to 0.05, and these conditions were met (APC $= 0.514$, $p < 0.001$; ARS $= 0.472$, $p < 0.001$; and AARS $=$ $0.466$, $p < 0.001$). In addition, it is recommended that both AVIF and AFVIF be less than or equal to 3.3, especially in models where the variables are measured by more than one indicator (as is the case in our study) [78]. All these conditions were met, suggesting good model-data fit.

The causality assessment indices employed (see [82]) were the Simpson's paradox ratio (SPR), R-squared contribution

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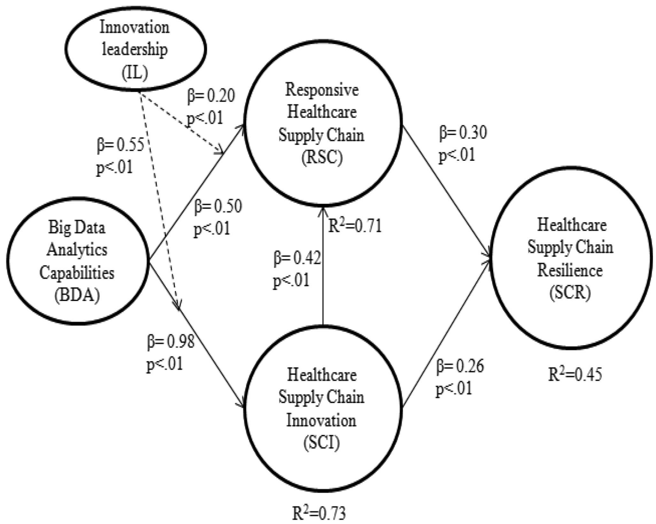


Fig. 8. Theoretical model after PLS-SEM analysis.

ratio, statistical suppression ratio (SSR), and nonlinear bivariate causality direction ratio (NLBCDR). The SPR value was found to be 0.714, which is above the recommended threshold of 0.70. This means that at least 70% of the paths in this model are free from Simpson's paradox (whereby path coefficients and correlations paradoxically have different signs) [84]. The SSR value was found to be 0.857, and thus, above the threshold of 0.7, and the NLBCDR value was found to be 0.786, above the recommend threshold of 0.7 and, thus, acceptable. This latter value means that in at least 78% of paths in our model, support for the reverse hypothesised direction of causality is weak.

Taken together, these causality assessment results suggest that our hypothesised network of cause-and-effect relationships fits well with the empirical data that was collected and analyzed.

### D. Structural Model Analysis

The software WarpPLS (version 6.0) was applied for analysis [82]. Five steps were followed in the SEM analysis. A $p$ value of 5% is considered to be the cut-off value for significance (i.e., 1%–95%). Hypothesis tests were performed, and the path coefficients and $p$ values were obtained for each hypothesised path in the tested model. As Fig. 8 illustrates, all hypotheses are supported.

### E. Results of Thematic Analysis

The demographic details of respondents are presented in Table A4 (Online Supplementary Appendix A). To maintain confidentiality, we have assigned the respondents numbers from R1 to R30. The subthemes and main themes are presented in Table A5 (Online Supplementary Appendix A), and the main themes have been further elaborated.

*1) Understand the Benefits of BDA in Healthcare HSC:* Many respondents indicated that BDA enables healthcare companies to use large datasets from clinical trials as well as reshape their global supply chain network. For example, Respondent R2 mentioned that

> Business analytics can be useful for companies to identify the threats and opportunities which can be used by management to make key decisions pertaining to work conditions in the plant and supply chain network design.

Many respondents also indicated that BDA can be immensely helpful for managing work conditions and employees. As Respondent R22 stated:

> BDA is useful for analysing large datasets and further using the rich data for HSC data. These days, descriptive analytics (past events), predictive analytics (future events), and prescriptive analytics (actions to be taken) are gaining popularity among supply chain professionals. Companies like Microsoft, Tableau, Qlik, SAP, and IBM are offering various data analytics tools that are user friendly. BDA software can be used for strategic workforce planning, including remote workforce planning and flexible contracts.

*2) Understand the BDA Capabilities on Improving Responsiveness and SCI:* Respondents highlighted the opportunities that BDA can create for enhancing HSCs, noting that large datasets can be useful for identifying various patterns and trends and more quickly meeting customers' needs. Respondents elaborated that big data can power digital manufacturing technologies such as additive manufacturing/3-D printing, CNC machines, 3-D scanners, and 3-D printing technologies to accelerate research and development activities and more rapidly meet market demands. For instance, Respondent R1 asserted:

> To cope up in any pandemic situation we need to focus on responsive supply chains as they have the ability to meet the changing customer needs quickly. BDA can be useful for developing responsive HSC especially during pandemic situation by identifying opportunities and threats, assessing market dynamics, and developing a plan to respond to them quickly.

Similarly, Respondent R1 mentioned that

> Innovation has gained significant importance in this contemporary business world. Innovation increases the chances of firm's survival in this competitive world. Technology, particularly big data and AI, has been a critical resource for firms to enhance the effectiveness of product innovation related activities.

*3) Overcome the Critical Barriers of BDA:* Respondents indicated that healthcare companies willing to leverage BDA must overcome the critical barriers through effective trainings to the staff/employees, effective orientation, investing in cloud-enabled IT infrastructure, and improving cyber security protocol. As Respondent R3 stated, Implementing business analytics in healthcare requires effective trainings to the staff/employees. Effective orientation is really missing. Similarly, Respondent 22 noted that Cloud-enabled IT infrastructure, including an enhanced cyber security protocol is required to leverage on big data technologies.

*4) Develop Resilient Healthcare Models:* The healthcare sector was not prepared to fight against COVID-19 pandemic. In many countries healthcare industry policies are not sufficiently robust enough in terms of policies, and the HSC faced enormous challenges as the virus's spread accelerated. Supply–demand gaps, damage to HSCs, economic disruption as small suppliers and transporters struggled to run their businesses, and stress on

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medical producers, distributers and stakeholders all profoundly impacted the HSC.

Many respondents highlighted that HSCs need to build resilience to sustain any pandemic situations. For instance, R2 argued that Resilience is important to be able to bounce back to original situation after temporary disruptions. Global supply chains must be able to quickly recover and meet customer demands in pandemic situations. Similarly, R23 stated that Value creation for customers is extremely important to survive in this competition. Nevertheless, companies need to show more agility and resilience in changing environmental conditions.

*5) Critical Roles of Leaders:* The role of leaders increased substantially during COVID pandemic; however, their main responsibility remains to assess internal and external risks and create strategies to mitigate them without affecting the sales and profitability of the company.

Respondents highlighted the importance of focus toward innovation. As Respondent R1 stated:

> COVID-19 since this pandemic has impacted the lives of every human on this earth. Therefore, leaders have a big role to play in this pandemic situation. Since healthcare firms cater to essential goods supply and cannot close their operations during pandemic; therefore, leaders need to develop plans to ensure all workers get a safe environment to work during pandemic without getting being infected by the corona virus. Leaders need to take care of the mental/psychological wellbeing of each and every employee working in the firm.

In the same vein, R4 argued that leaders are the engine for the organisation. They lead the team from the front. Leaders must hold hands of their team members to march forward and win this pandemic battle. R27 noted that Covid-19 situation presented both challenges and opportunities for the leaders. Traits like empathy, clarity, authenticity, and agility are becoming more important during this pandemic.

*6) Strengthening Collaborative Relationships Among Supply Chain Partners:* Respondents noted that strengthening collaborative relationships with supply chain partners, developing logistics and procurement integrity, cultivating local supply sources, and changes in inventory stocking norms can help a healthcare company to survive this pandemic battle. For example, R19 argued that:

The establishment and strengthening of collaboration relationships is very critical to survive in this pandemic. The importance of logistics and procurement integrity is also critical. Continuous monitoring of supply chain partners can help in minimising the supply chain risks. Trust building and sharing of resources among supply chain partners is important. More focus is needed towards waste reduction and material circularity approach.

## V. Discussions

### A. Theoretical Implications

BDA is gaining importance in the domain of supply chain management. However, relatively few studies had explored the application of BDA toward improving supply chain responsiveness in healthcare contexts. In this article, we explored the problem from the OIPT and SIAP perspectives to explain the impacts of BDA capabilities on RSC and innovation during the COVID-19 pandemic.

The SEM results from study 1 indicates that the “BDA and RSC” path is significant, which clearly reveals that an information technology strategy is important to (i) enhance information processing capability and (ii) result in changes of the supply chain configuration to build responsiveness. The significance of the “BDA and SCI” path resonates with Wamba *et al.* [44], who pointed out that business strategy alignment is critical for enhancing BDA to improve firm performance. The study of Dubey *et al.* [107] previously indicated that visibility and information sharing are key antecedents of resilient supply chains.

The thematic analysis results support the above findings. Respondents in fact highlighted the usefulness of BDA for building a responsive and innovative HSC. Rapid responsiveness is needed to meet the market demand of medical supplies and thereby save human lives. Health care supply chain managers need to look for opportunities to leverage BDA and enhance responsiveness. However, they must also be aware of and overcome barriers to achieve effective BDA applications. One important aspect is that BDA will help in the preparedness and adaptation stages and we know that both are important dimensions in configuring resilience of firms [106].

The SEM analysis also indicates that IL demonstrates a significant moderating effect on both the “BDA and RSC” and “BDA and SCI” paths. Again, these findings were supported by the qualitative study, as respondents had clearly indicated that leaders had to play a critical role during the COVID-19 pandemic. Organizations are recognizing that strong IL enables them to enhance their responsiveness and innovativeness. For instance, leaders who have sustained their organizations during the pandemic have adopted innovative approaches such as adopting a mixture of online and offline business models, including focusing on local supply sources, strategic relationship building with supply chain partners and leveraging smart technologies. The importance of developing collaborative relationships with supply chain partners have been highlighted in the literature as well (e.g., [105]). Only strong innovative leaders will focus on collaborative aspects and culture in the organization.

Finally, the “RSC and SCR”, and “SCI and SCR” paths were all found to be significant. In the literature, Akter and Wamba [87] suggested that BDA can prove to be an invaluable asset when managing disasters. SCM plays a key role in ensuring timely supplies of medicine and other items and saving lives [88]. Overcrowding might impact the resilience of healthcare facilities, which creates enormous stress in the health care supply chain [89]. Supply crises, supplier bankruptcy and supply chain disruption have been common events during the pandemic [90], which have imposed serious threats to the healthcare sector’s ability to serve customers [91]. BDA can ameliorate such problems by enhancing supply chain agility, adaptability and performance [15]. Moreover, the findings of our thematic analysis indicate that strategic collaborations with supply chain partners would be critical for developing supply chain responsiveness. This calls for the special attention of the related stakeholders in HSCs.

Our articles tested and validated unique paths that will bridge the gap between theory and practice. BDA will offer a strategic competitive advantage to the HSC during the current COVID-19 pandemic situation. Healthcare organizations hence need to work on enhancing their information processing capabilities and developing greater supply chain responsiveness. In addition, a focus on supply chain innovation is needed to build SCR that is more robust and resilient to negative impacts [4], [11]. The findings of our thematic analysis suggests that the mixed online and offline models are most effective during the post-COVID-19 era. New healthcare business models supported by videos and e-prescriptions will also be helpful. Hospitals can conduct follow-up appointments remotely, and healthcare service providers can link with online pharmacies to deliver medicines. This is a specific action plan that is suggested based on our findings.

If we compare our article with the extant literature, in particular with two recent important studies of by [94], [95] (which had advanced the supply chain resilient literature to a great extent from the information systems perspective), our article actually focuses on IL and hence contributes to the literature from another perspective. We argued that the role of innovative leadership is critical to fight against the COVID-19 pandemic because it is indirectly related to BDA capability development and SCR.

### B. Practical Implications

This article adds to research highlighting the need for organizations to focus on resources to build up BDA. First, managers must develop information processing capabilities and analyse connections within the business environment. Situations are volatile during the current pandemic, and organizations must avoid focusing too narrowly on resources and capabilities in order to avoid risks. Managers must have an overview of all available resources and capabilities, and more importantly, they should understand how each of these resources and capabilities interacts with the others and under what conditions each of them maintains or loses importance.

Second, emphasis must be placed on supply chain responsiveness and innovation capabilities. During a pandemic, it is essential to create market-responsive HSCs with flexible suppliers and frequent new product launches to cope with stochastic demands. Additionally, it is critical to have HSC creativity driving continuous innovation in core supply processes.

Third, the moderating role of IL influencing the relationship between BDA and responsive supply chain must not be forgotten. Leaders must foster innovation among personnel to find new ways to structure supply chains.

Finally, managers need to make their HSC management resilient to improve their pandemic response. Crisis situations are natural in any pandemic scenario, especially in the case of COVID-19, when the virus spreading the infection is new to researchers, scientists and healthcare workers. In such situations, shortages of medical supplies are likely to occur, as everyone is working on an emergency basis to save the lives of infected patients. The demand for essential medical supplies like PPE, testing kits, drugs and medical equipment in such a situation is likely to rise sharply. Companies may struggle to accomplish timely manufacturing and distribution due to improper planning, poor supply, inflexible suppliers and resource unavailability, thereby leading to shortages and abnormal increases in the costs of essential medical goods. The current article demonstrates that only a data-driven HSC can absorb such shocks during pandemic times and create a resilient HSC.

### C. Policy Implications

Policy makers at all levels must set up digital platforms with special apps that the public and use to submit necessary health information, which can be further used by analysts to examine trends. However, traceability and visibility can be misused; therefore, policymakers need to be careful with the privacy and security aspects of public information. Clear digital policies are very important, and the public should be made aware of these policies so that they can submit the appropriate information. Governments needs to ensure that the infrastructure is regularly upgraded and that connectivity is able to support the massive use of digital technology applications, and digital solutions must be user friendly. Governments should also prepare the healthcare ecosystem with a strong infrastructure, drugs and medical equipment to fight against COVID-19. Finally, governments should create awareness about resilience and prepare for recovery to the next new normal.

## VI. Conclusion

This article is a novel attempt to examine the effects of BDA on RSC, innovation and resilience during the COVID-19 pandemic. In the first phase of the article, we developed a theoretical framework linking BDA with SCR and statistically tested via PLS-SEM our model using data from 190 respondents (who are competent in BDA and working in HSC). In the second phase of the article, we conducted a qualitative analysis using inputs collected from a semi-structured questionnaire completed by 30 executives working in healthcare. The findings suggest that BDA would play a pivotal role in improving SCI and building a responsive HSC during the COVID-19 pandemic situations. In turn, SCI and responsiveness lead to the development of SCR during uncertain times. An additional important finding from this article is that high IL in healthcare firms strengthens the effect of BDA on SCI and responsiveness.

Limitations of this article include the use of cross-sectional data for the analysis. Additionally, we have not compared the results with those of developed countries. Readers should hence note these limitations when they interpret our results. Future research can involve improving the model by incorporating the intertwined supply network construct recently proposed by Ivanov and Dolgui [92], which can improve supply chain resilience in pandemic situations. Future studies can also use the digital twin model developed by Ivanov and Dolgui's [93] for supply chain mapping and visibility improvements, which can be immensely useful during the course of COVID-19 pandemic and in postpandemic situations.

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