Does the transcultural problem really matter? An integrated approach to analyze barriers to eHealth SMEs' development

Abstract

Purpose – In a competitive environment, eHealth SMEs' barriers to survival differ from those of large enterprises. Empirical research on barriers to eHealth SME's in less prosperous areas has been largely neglected. This study fills this gap by employing an integrated approach to analyze barriers to the development of eHealth SMEs.

Design/methodology/approach - We collected data through semi-structured interviews, and conducted thematic analysis to identify 16 barriers, which were used as inputs into total interpretive structural modeling (TISM) to build interrelationships among them and identify key barriers. Cross-impact matrix multiplication applied to classification (MICMAC) was then applied validate the TISM model and classify the 16 barriers into four categories.

Findings – This study makes significant contributions to theory by identifying new barriers and their interrelationships, distinguishing key barriers, and classifying the barriers into four categories. We identify that transcultural problems are the key barrier and deserve particular attention. eHealth SMEs originating from regions with cultural value orientations, such as hierarchy and embeddedness, that differ from the UK's affective autonomy orientation should strengthen their transcultural awareness when seeking to expand into UK markets.

Originality/value - By employing an integrated approach to analyze barriers that impede the development of eHealth SMEs in a less prosperous area of the UK, this study raises entrepreneurs' awareness of running businesses in places with different cultural value orientations.

Keywords: eHealth SMEs; Barrier analysis; Transcultural problem; Total interpretive structural modeling; MICMAC analysis

1. Introduction

The World Health Organization (2022) defines eHealth as "the cost effective and secure use of ICTs [information and communication technologies] in support of health and health-related fields, including health-care services, health surveillance, health literature, and health education, knowledge and research". This refers to ways in which healthcare services are delivered and healthcare information is accessed, exchanged, and managed among patients, organizations, and healthcare service providers (Pan *et al.*, 2019). Other terms, such as medicine 2.0, health 2.0, mobile health (mHealth), telecare, telehealth, digital health, and telemedicine are used interchangeably with eHealth across the literature (Ahern *et al.*, 2006; Boogerd *et al.*, 2015; Ballestar *et al.*, 2020; Scheibner *et al.*, 2021). eHealth technologies promise a range of benefits for activities such as information management, time management, patient monitoring, consultations, information gathering, health record maintenance, medical education and training, and clinical decision-making (Ventola, 2014; Zaman *et al.*, 2017; Gaspar and Lapao, 2021). For example, during the COVID-19 crisis, a patient education and monitoring app was developed and promoted across several countries (e.g., the Netherlands, Belgium, and Germany) to share timely COVID-related information on national guidelines and local measures in hospitals (Timmers *et al.*, 2020), to collect data to assist healthcare providers' and policymakers' decision making. Software-based health and fitness applications have been developed to improve sleeping habits, protect psychological health, and reduce harmful impacts of sedentary behaviours (Bokolo, 2021). Other applications, such as social network applications, mobile integrated healthcare programs, artificial intelligence-based decision-making applications, robotic technologies, and eHealth software platforms for outpatients, were all developed during and after the outbreak of COVID 19 (McCall, 2020; Torous *et al.*, 2020). eHealth technologies also offer new opportunities to help achieve the United Nations

Sustainable Development Goal (SDG) on good health and wellbeing. For example, integrating advanced ICTs, optimizing eHealth service design processes, and especially preparing users and healthcare professionals might enhance healthcare service delivery and healthcare outcome (Wyllie *et al.*, 2022). With this potential to improve the quality, accessibility, and affordability of healthcare, it is predicted that the global eHealth market will grow dramatically in the next few years, from $334 billion in 2022 to $657 billion in 2025 (Statista, 2021).

Small and medium-sized enterprises (SMEs) are major contributors to the eHealth industry (Li *et al.*, 2016; Demir *et al.*, 2022). It is estimated that at the start of 2021 there were approximately 5.6 million SMEs in the UK, including 5.5 million small enterprises with between 0 and 49 employees, and 35,600 medium-sized enterprises with 50 to 249 employees (Department for Business, Energy & Industrial Strategy, 2021). These SMEs employ 16.3 million people, and their turnover of £2.3 trillion accounts for 52% of the UK's GDP. SMEs are considered the backbone of the UK's economy and growth, but they have limited resources, weak financial structures, and limited business activities. These challenges have motivated researchers to investigate how to improve SMEs' overall managerial knowledge and competencies (Moeuf *et al.*, 2020; Beynon *et al.*, 2021; Olan *et al.*, 2022). Areas covered include risk management (Branicki *et al.*, 2018; Pezeshkan *et al.*, 2019), digital transformation (Upadhyay *et al*., 2022), internationalization (Chandra *et al*., 2020; Satyanarayana *et al*., 2022), and sustainability (Vuorio *et al*., 2018; Wahga *et al*., 2018). However, barriers that impede SMEs' development seem to have been neglected by scholars, particularly in relation to eHealth companies (McCann and Ortega-Argiles, 2016; Jaramillo *et al*., 2019). We focus on eHealth SMEs because with limited resources, they must prioritize which barriers to tackle.

This study analyzes barriers hindering the development of eHealth SMEs in Cornwall and the Isles of Scilly (CIoS). We selected this region for several reasons. First, CIoS is located in the extreme southwestern peninsula of England, and its rurality and sparse population make it an excellent testbed for eHealth technologies (Austin *et al*., 2021). Unlike other areas of the UK, such as Greater Manchester, London, and the South East, which have large and stable eHealth markets, the eHealth market of CIoS remains precarious (Asthana *et al*., 2019). Second, in 2020, 145,457 people in CIoS were aged 65 and older; thus, 25.3% of its population are elderly, compared with 19% in the rest of the UK. eHealth may offer a cost-effective solution to rising demand for high-quality healthcare services (Cornwall Council and Council of the Isles of Scilly, 2021). Third, we already had extensive connections with eHealth SMEs in CIoS, arising from several large eHealth-focused projects currently being delivered by our university's Centre for Health Technology. These projects, which aim to support local businesses in developing digital health solutions, provided us with opportunities to hold discussions with eHealth SMEs about factors impeding their development. Three research questions were formulated for this study: (1) what are the barriers that hinder the development of eHealth SMEs in CIoS; (2) how are these barriers interrelated; and (3) what are the key barriers that need to be tackled?

This study makes several contributions to the literature and managerial practice. Its first theoretical contribution is to extend the technology acceptance model (TAM) by adding transcultural problems to the external variables that may affect technologies' perceived usefulness and ease of use. Second, this study is one of the earliest to employ an integrated approach to analyze seven categories of barriers that may impede the development of eHealth SMEs from a less prosperous area of the UK. Several scholars have investigated obstacles to the development of SMEs in specific industries, such as high-tech, automotive, and manufacturing (Wang, 2016). For example, Hoppe *et al*. (2021) investigate cyber risk management in relation to various SMEs, and Moeuf *et al*. (2020) indicate that lack of expertise and a short-term strategic mindset are two major obstacles that SMEs must overcome in order to adopt industry 4.0. However, only limited research has focused on eHealth SMEs in CIoS.

The findings of this study contribute to the literature by revealing 16 barriers that affect eHealth SMEs' development in this region. Third, this study builds a hierarchical framework to highlight inter- and cross-relationships between the identified barriers, and reveals that the key barrier is transcultural problems. We contribute to the literature on risk management and internationalization of SMEs, particularly for SMEs originating from a cultural value orientation (e.g., hierarchy and embeddedness) that differs from the UK's affective autonomy orientation. Finally, this study helps to identify drivers and mediators by classifying the 16 barriers into four groups. In terms of contributions to managerial practice, this study will raise eHealth managers' awareness of different barriers that may impede their development, help them to allocate strategic resources to critical key barriers, and equip them with insights into the characteristics of and interrelationships between barriers.

In the remainder of this paper, Section 2 presents a review of the literature on barriers to the development of SMEs, analyses and typologies of eHealth SME barrier, and multi-criteria decision-making (MCDM) methods in eHealth contexts. We identify research gaps and propose a conceptual framework. In Section 3, we explain our research methods, including semi-structured interviews, thematic analysis, TISM, and MICMAC analysis. Section 4 explains the empirical data collection process, and Section 5 presents the data analysis and results. In Section 6 we discuss the findings, and in Section 7 we draw some conclusions, highlight our contributions to managerial practices, explain the limitations of our study, and suggest future research directions.

2. Literature review

2.1 Barriers to SMEs' internal processes and external environment

SMEs play critical national roles in generating income, increasing employment, and reducing poverty (Doern, 2011; Lin and Lin, 2016; Giotopoulos *et al*., 2022; Zhao *et al*., 2022b). However, approximately 50% of them close down within five years of their constitution, and a further 30% to 40% fail in the following five years (Parnell *et al*., 2015). This is due to a range of barriers that hindering or limiting their development (Rahman *et al*., 2017; Chandra *et al*., 2020) that prevail in their internal processes and external environment. Regarding the external environment, Asgary *et al*. (2020) identify over 30 economic, environmental, geopolitical, societal, and technological risks that may influence the development of manufacturing SMEs in Turkey. Of these, fiscal crises in key economies and high structural unemployment or underemployment have the greatest impact and likelihood of occurring. In Pakistan's manufacturing SMEs, environmental barriers such as unscheduled power failures, poor government support, political influence, seasonal effects, and stringent government regulations are more common (Haleem *et al.*, 2019). Other common external environmental barriers include limited access to finance, lack of economic incentive policies, and fierce competition (Bajo *et al*., 2012; Agyapong, 2021; Onjewu *et al.*, 2023). Various barriers also reside in SMEs' internal processes. For example, Italy's energy SMEs lack internal technical skills and personnel and managerial awareness (Trianni and Cagno, 2012). Poor management commitment and leadership are considered to be the most critical barriers, given rise to other barriers that hinder SMEs' the internal management processes (Yadav *et al*., 2019). As the literature reveals that SMEs face various industry-specific barriers, the next section reviews barriers specifically affecting to the development of eHealth SMEs.

2.2 Analysis of barriers and typologies of eHealth SMEs

Analysis of the barriers facing eHealth SMEs cover eHealth technology adoption relating to specific diseases, business challenges, and applications of eHealth technologies in various healthcare sectors. For example, Anderson (2007) finds that lack of access to capital, absence of relevant legislation, privacy concerns, and the complexity of eHealth applications are significant barriers. However, Schreiweis *et al*. ' (2019) analysis of 76 potential barriers to the adoption of eHealth services indicates that limited knowledge of eHealth, lack of necessary

devices, problems with financing eHealth solutions, cognition, and security are the top five barriers. Based on empirical research on eHealth SMEs in the wellness and healthcare sector, Jaring *et al*. (2013) propose that the main barriers are lack of capability to deploy new ICT solutions, weak customer awareness of eHealth, healthcare employees' lack of skills to pilot new eHealth technologies, the difficulty and expense of building ICT solutions, and the difficulty of determining which partners and channels to focus on. In Namatovu *et al*. ' (2021) view, the cost of data services, internet intermittency, and lack of training in using eHealth systems are the top three barriers to eHealth technology uptake. Kesse-Tachi *et al.* (2019) analyze factors influencing eHealth technology adoption from the perspective of managerial and institutional characteristics, and performance and effort expectancy. Their results reveal that eHealth technology adoption relates particularly to institutional characteristics, and to characteristics of healthcare managers characteristics such as their professional experience in healthcare and whether they received higher education. Other authors mention barriers such as limited knowledge of eHealth, inadequate financing, institutional corruption, and lack of economic incentive policies (Krasniqi, 2007; Shi *et al*., 2008; He *et al*., 2014; Wildenbos *et al*., 2017). Table 1 summarizes the barriers facing eHealth SMEs.

Insert Table 1

Various typologies are used to classify barriers to SMEs. For example, Shi *et al*. (2008) propose four categories: policy and market, financial and economic, technical and information, and managerial and organizational. Alternatively, barriers can be classified into internal and external barriers (Jaramillo *et al*., 2019). Internal barriers are those originating from the firm's internal environment, whereas external barriers relate to factors such as infrastructure, and cultural and economic environments (Al-Hyari *et al*., 2012). Extending this typology, Leonidou (2004) classifies internal barriers into three categories (informational, functional, and marketing). As Leonidou (2004) provides a relatively comprehensive analysis of barriers impeding SMEs' growth and SMEs' major concerns (Brustbauer, 2014; Dabic *et al*., 2020), we follow this classification to categorize the barriers identified in this study.

2.3 Multi-criteria decision-making methods for eHealth contexts

Since most eHealth firms are SMEs, they have limited resources to tackle internal and external barriers and facilitate growth. Hence, MCDM methods have been deployed to analyze and prioritize decision alternatives for finding an appropriate solution. For example, Faber *et al*. (2017) use structural equation modeling (SEM) to investigate factors influencing the adoption of eHealth by hospitals in the Netherlands. Their results indicate that hospital size, top management support, and organizational readiness are the three most influential factors. Shimizu *et al*. ' (2021) exploration of factors inhibiting the dissemination of telemedicine in Japan, using interpretive structural modeling (ISM), reveals that high implementation and operating costs, lack of research data, and risks to clinical safety are key factors. In developing countries such as Bangladesh, ease of use, and the usefulness of and trust in eHealth technologies are considered by patients to be the two most important factors influencing eHealth adoption (Hoque *et al*. 2017). Other MCDM methods adopted include the judgment-decomposition analytic hierarchy process approach (JD-AHP) to assess the suitability of smart eHealth technology applications (Chen and Wu, 2020), a combination of AHP and the technique for order of preference by similarity to ideal solution (TOPSIS) to evaluate and select mHealth applications (Rajak and Shaw, 2019), and the DEMATEL-based analytic network process (DANP) to identify key factors in consumers' adoption of intelligent medical terminals (Liu *et al*., 2017). A detailed analysis of the literature is shown in Table 2.

Insert Table 2

2.4 Research gaps and conceptual framework development

Our literature review reveals several research gaps.

First, the literature is fragmented and focuses on a variety of issues, including factors determining the success and failure of eHealth adoption at system, community, organizational, and professional levels (Hardiker and Grant, 2011; Li *et al*., 2013; Schreiweis *et al*., 2019; Beynon *et al*., 2021), evaluation and integration of eHealth solutions into healthcare (Faber *et al*., 2017; Negro-Calduch *et al*., 2021), and eHealth technology improvement and optimization (Broekhuis *et al*., 2019). eHealth is a new domain of research, and many areas of eHealth have developed in the last two decades. However, few studies have investigated barriers to the development of eHealth SMEs, despite SMEs' increasing importance to national economies (Ballestar *et al*., 2020; Oderanti *et al*., 2021).

Second, various MCDM methods have been used in the field of eHealth, such as PLS-SEM, DEMATEL-based ANP, AHP, TOPSIS, JD-AHP, Delphi, and ISM-MICMAC (Cross-impact multiplication applied to classification), as shown in Table 2 (Hoque *et al*., 2017; Chen and Wu, 2020; Almathami *et al*., 2022). However, interrelationships and interdependencies between barriers have seldom been analyzed. Mitigation of one barrier may escalate others (Zhao *et al*., 2020); thus, investigating the joint impact of various barriers may lead to better management of eHealth SMEs than treating each barrier in isolation (Ho *et al*., 2015). Therefore, this study employs TISM-MICMAC to analyze interrelationships among barriers, and to distinguish drivers, mediators, linkages, and dependencies. This integrated approach provides us with a better understanding of the barriers.

Third, there is a trend for analyzing factors that determine the success or failure of eHealth adoption globally. For example, Austin *et al*. (2021) explore barriers and facilitators to delivering eHealth from a university-industry collaboration perspective, and Jang-Jaccard *et al*. (2014) summarize barriers to delivering telehealth in rural Australia. In the UK in 2020, SMEs accounted for 36% of eHealth industry employment and 22% of eHealth industry turnover. Approximately 56% of eHealth industry practitioners are located in Yorkshire and Humber, London, and the South East, whereas the South West, including CIoS accounts for only 6% of eHealth industry practitioners across the UK (Office for Life Sciences, 2020). Empirical research investigating barriers to the development of eHealth SMEs from the perspective of the less prosperous area of CIoS is acutely lacking. Investigating this topic in a less prosperous area of a developed country will thus generate new findings and interesting insights.

To guide our research, we developed a conceptual framework (see Figure 1) that has three sections; identifying barriers, establishing interrelationships among the barriers, and prioritizing key barriers.

Insert Figure 1

3. Research methodology

We adopted an integrated approach to analyze barriers hindering the development of eHealth SMEs in CIoS (see Figure 2). This included data collection through semi-structured interviews, thematic analysis to identify barriers, TISM to build interrelationships between barriers and prioritize them by allocating them into different layers, and MICMAC analysis to validate the TISM model and identify the key barriers.

Insert Figure 2

3.1 Data collection method

Semi-structured interviews are considered to be a useful technique for gaining in-depth understanding of participants' experiences and how they interpret them (Schultze and Avital, 2011). We used semi-structured interviews to collect data because they enable probing questions to seek further information or clarification (Barriball, 1994), and because eHealth practitioners may have differing professional, educational, and personal backgrounds precluding use of a standardized interview schedule. Other data collection methods, such as questionnaires, would not have enabled us to gain a deep understanding of interrelationships between barriers, for which open-ended questions were required (Saunders *et al*., 2015). Furthermore, questionnaires might elicit incorrect or illegible answers, which would inevitably influence the quality of the data collected (Rowley, 2014).

3.2 Data analysis methods

Thematic analysis was used to identify and describe barriers emerging from the interview data. This method was selected for several reasons: it is a well-structured approach for analyzing qualitative data and helping to generate clear and evidence-based themes (Holloway and Todres, 2003); it allows for high flexibility and contextual modification (Braun and Clarke, 2006); and it generates unanticipated insights by highlighting similarities and differences across different datasets (Nowell *et al*., 2017).

TISM is a widely used modelling technique to build interrelationships and interpret links among variables, and prioritize them by allocating them to different layers (Jena *et al*., 2017). Its key advantage over ISM is to provide interpretations of both links and nodes in the structural model (Sushil, 2012). Hence, TISM facilitates answers to "what", "why" and "how" questions in theory building. Other methods, such as Delphi, AHP, analytic network process (ANP), ELECTRE, simple additive weighting (SAW), data envelopment analysis (DEA), and DEMATEL, all have drawbacks that precluded their application in this study. For example, the Delphi technique does not afford sufficient time for participants to elaborate on their views, and requires continuous commitment from participants (De Meyrick, 2003). AHP fails to consider interactions and dependencies among the criteria used to rank alternatives (Saaty, 2008). ANP may be inapplicable to tackling practical problems, as it derives a weighted super matrix by weighting each cluster equally (Kou *et al*., 2014). The process and outcomes of ELECTRE are obscure from a layperson's perspective, and estimates from SAW do not always reflect real situations (Velasquez and Hester, 2013). DEA has the capacity to handle multiple inputs and outputs, but assumes that all of these are precisely known (Ji and Lee, 2010). DEMATEL ranks variables based on interdependent relationships between them, but ignores other criteria in decision-making problems (Si *et al*., 2018). Thus, TISM was used to build interrelationships between and prioritize the barriers.

Finally, MICMAC analysis was utilized to identify key barriers driving the whole system by analyzing the driving power and dependence power of each barrier. TISM and MICMAC are well-established methods and have been widely applied in various areas, including supply chain management (Zhao *et al*., 2022a) and organizational management (Singh and Dhir, 2022). TISM enables barriers to be allocated to different layers, but key barriers cannot be distinguished solely from these layers. Thus, MICMAC analysis complements TISM in providing a clearer understanding of drivers, mediators, linkages, and dependent barriers in the system. The theory underlying MICMAC analysis is the multiplication properties of matrices (Sharma *et al*., 1995).

4. Empirical data collection

An interview guide was developed through discussions with two research fellows in eHealth and one business support manager (see Appendix 1). This was used to help direct conversations toward the research topic during the interviews (Cridland *et al*., 2015). The interview guide has three sections: a warm-up section on general information relating to participants and their companies, a follow-up section on barriers impeding their companies' development, and a final

section on methods adopted to tackle these barriers. To confirm the coverage and relevance of the content, three pilot tests were conducted with a research fellow in a digital health testbed, a research fellow in eHealth, and an eHealth business support manager. These were selected because they had been working with eHealth companies for more than three years and had significant knowledge of eHealth. Valuable guidance on critical information for the interview guide and the wording and arrangements of questions helped us to improve the guide.

Purposive sampling was used to identify participants who would be most likely to yield useful information and deepen our understanding (Palinkas *et al*., 2015). This was based on a need to include specific kinds of people that we assumed might hold valuable knowledge, important information, and different views on barriers hindering the development of eHealth SMEs in CIoS (Robinson, 2014; Campbell *et al*., 2020). Several criteria were applied to recruit suitable participants: they must come from SMEs in the CIoS eHealth industry; they must hold senior roles in the company (e.g., founder, product manager, technical director) to ensure high-level expertise and knowledge; and the selected eHealth SMEs must have collaborative relationships with our university's Centre for Health Technology to enable us to acquire sufficient information and discuss sensitive issues with participants. Based on the criteria, 20 eHealth SMEs were selected and agreed to participate in this research. These included SMEs using apps to record physical activities, support mental health wellbeing, empower general practitioners (GPs), and manage epilepsy and diabetes, as well as firms developing AI-based voice technology and mass vaccination booking platforms. Detailed information on each SME is shown in Table 3, including their expertise and products, standard industrial classification (SIC), and technological readiness levels (TRLs), as well as interviewees' positions. The TRLs ranged from TRL1 Basic principles to TRL9 Operations (Nuclear Decommissioning Authority, 2014). SIC codes are used to describe SMEs' nature of business.

Insert Table 3

Interviews with eHealth SMEs were conducted online between January and April 2022. We secured time slots by sending enquiry emails to potential participants. A copy of the interview guide was sent to interviewees three days in advance to ensure their familiarity with the topic, structure, and process of the interviews. Pre-project training was conducted with the interviewers on the purpose of the research, how to store and use information, how to elicit answers from participants, and informed consent. Each interview lasted between 30 and 40 minutes, and interviewees were given sufficient time to clarify their answers and express their ideas. All interviewees were given permission for recording. Probing questions were asked to ensure that sufficient information was elicited. A research fellow in digital health was invited to participate in these meetings to take notes.

5. Data analysis and results

Three data analysis methods were used in this study: thematic analysis, TISM, and MICMAC analysis. The data analysis process is described in detail in the next sub-sections.

5.1 Generation of barriers through thematic analysis

The thematic analysis adopted in this study consisted of four steps: transcribing, coding, categorizing, and presenting (see Figure 3).

Insert Figure 3

The first phase was transcribing. Interview audio files were uploaded to Otter, a professional transcription package that supports speech-to-text transcription. Each audio file was transcribed word-for-word to ensure that we did not miss any elements emerging from the

interviews with eHealth industry practitioners. After immersive and repeated reading of the transcripts, irrelevant data were removed, resulting in a cleaned-up transcript for the next step.

The second phase was coding. The main aim was to identify interesting sections, sentences, paragraphs relating to barriers hindering the development of eHealth SMEs. We used qualitative data analysis software (NVivo 13) for the coding process. Codes extracted from the transcripts were then collapsed into themes, which were labelled using established constructs from existing literature (e.g., SMEs' risk management). An iterative approach was adopted to refine codes and themes by moving back and forth between relevant literature and theories (Inkpen and Tsang, 2005).

In the third phase, we classified the barriers (themes) into categories used in previous research (Leonidou, 2004), and linked these with relevant codes.

Finally, we presented our findings using King and Horrocks' (2010) framework in terms of: (1) descriptive coding (first-order codes), which involved extracting data from the transcripts relevant to the research questions, and allocating descriptive codes across the whole transcript; (2) interpretive coding (second-order themes), which involved categorizing descriptive codes with similar meanings and creating an interpretive code to represent these; and (3) defining overarching themes (aggregate dimensions), which involved identifying overarching themes characterizing key concepts in the analysis. Table 4 summarizes the coding structure of this study.

Thematic analysis was also used to identify the data saturation point. There is no universally accepted rule on how many interviews should be conducted. For example, Guest *et al*. (2006) propose that data saturation occurs within the first 12 interviews, whereas others, such as Fusch and Ness (2015), argue that it emerges after between six and 12 interviews. Having analyzed 17 interviews with eHealth industry practitioners, we found that barriers such as "lack of access to funding", "skills gap", and "poor staff support" appeared frequently in our data, and little new information was emerging. Thus, we decided to conduct three additional interviews to confirm the data saturation point (Morse *et al*., 2014). These revealed no new themes, indicating that data saturation had been reached. Thus, the sample size of this study was 20 interviews.

Through the thematic analysis, 16 barriers were identified (see Table 4) that might impede the development of eHealth SMEs in CIoS. These were categorized into seven groups: informational, functional, marketing, environmental, procedural, task, and governmental. Barriers seldom identified in previous research included lack of links in National Health Service (NHS) procurement, limited re-innovation capability, transcultural problems, lack of specific digital skills, and limited product scalability (Kim and Xie, 2017; Alshahrani *et al*., 2019; Shaheer and Li, 2020). For example, several eHealth SMEs involved in this study were running their apps successfully in other countries, such as China, India, Greece, Finland, and Norway, but were experiencing problems in the UK owing to transcultural issues, a topic largely neglected in previous research (Jaramillo *et al*., 2019; Schreiweis *et al*., 2019).

Insert Table 4

5.2 Prioritizing and building interrelationships between barriers through TISM

In this study, TISM was used to build interrelationships among barriers and prioritize them. This involved nine steps (Sushil, 2012; Zhao *et al*., 2020).

- Step I was to identify and define elements to be modelled. Elements can be identified from existing literature, through brainstorming sessions, or using other ideas generation techniques (Jena *et al*., 2017). In this study, the 16 barriers to the development of eHealth SMEs generated from the interviews with experienced eHealth practitioners across CIoS were used as inputs into the process TISM.

- Step II was to determine contextual relationships between the barriers. Thus, the contextual relationship between two barriers could be: "barrier A will cause barrier B".
- Step III was to interpret the relationships to gain a deeper understanding. The opinions of three experts (two research fellows in digital health and one business support manager) were captured by asking - whether barrier A would cause barrier B, and if so, how.
- Step IV, an interpretive logic knowledge base was developed for pairwise comparison of the 16 identified barriers. In the paired comparisons, the i*th* barrier was compared individually to all barriers from the (i+1)*th* to the n*th* barrier. This was because each pair of barriers (i,j) might have two possible directional links: barrier i might cause barrier j, or barrier j might cause barrier i. If a study has n elements that need to be modelled, there will be n×(n-1) rows in the knowledge base. Thus, the knowledge base in our study contained 16×(16-1)=240 rows.
- Step V involved developing a reachability matrix and conducting transability testing. An initial reachability matrix was developed based on the interpretive logic knowledge base: "Y" and "N" entry codes were converted to values of 1 and 0, respectively, in the initial reachability matrix (see Appendix 2), based on the relationship between the barriers. For example, if barrier A causes barrier B, a "Y" entry code will be presented in the interpretive logic knowledge base. We then prepared for transability checking. The transability rule is that if barrier A relates to barrier B and barrier B relates to barrier C, then barrier A necessarily relates to barrier C. Based on this rule, we transformed the initial reachability matrix into the final reachability matrix (see Appendix 3).
- Step VI, level partitioning was implemented using the final reachability matrix to determine the level-wise placement of elements (Warfield, 1973). This step ended when the levels of all 16 barriers were determined (see Appendix 4). Several concepts are important in implementing the level partitioning process. For example, in this study, the reachability set for a particular barrier consisted of the barrier itself and any other barriers at the same level that the barrier might cause, whereas the antecedent set consisted of the barrier itself and any other barriers that might cause it. The intersection set was determined from the reachability and the antecedent sets. Identical barriers in the two sets of indicated the top level in the TISM hierarchy. Thus, barriers were removed from the element set, and the same procedure was performed until all levels were determined.
- Step VII involved developing a digraph (see Appendix 5) by allocating the barriers to levels and drawing direct links, as shown in the final reachability matrix. Important transitive links were also added to the digraph through a brainstorming session with the experts involved in this research.
- Step VIII, a binary interaction interpretive matrix was developed based on the final digraph, depicting all interactions by "1" in the respective cells. For each cell with a "1" entry, the corresponding interpretation was picked from the interpretive logic knowledge base to form the interpretive matrix.
- Step IX, a TISM model of barriers hindering the development of eHealth SMEs was constructed, based on the digraph and the interpretive matrix. The nodes in the digraph were substituted with interpretations of the barriers placed in boxes. The interpretations in the cells of the interpretive direct interaction matrix were depicted alongside the respective links in the structural model.

Insert Figure 4

The final TISM model (see Figure 4) has seven levels. For example, limited product scalability (E8) occupies level I in the TISM hierarchy, whereas other barriers, such as limited re-innovation capacity (E4), problems in user experience evaluation (E13), and the other 13 barriers, occupy levels II to VII. Barriers at the lowest level of the TISM hierarchy act as drivers of the system and have the capability to trigger other barriers, whereas barriers at the highest level have less impact on the system and rely on other barriers for their achievement. For example, transcultural problems (E7), located at the lowest level of the TISM hierarchy, may directly and indirectly cause nine other barriers in the system. Limited product scalability (E8), located at the highest level of the TISM hierarchy, may be elicited by the other 15 barriers.

Transcultural problems (E7) may cause difficulties in accessing funding (E3) owing to eHealth SME managers' limited knowledge of local grant opportunities. In particular, some managers are either migrants from other countries (e.g., India and China), or are seeking to exploit UK markets, such as SMEs originating from Greece, Finland, and Norway. The problem common to all these managers is that they are unfamiliar with local grant opportunities, such as the National Institute of Health and Care Research's i4i Funding at the Speed of Translation (FAST) awards and funding opportunities from the Cornwall Council and Council of Isles of Scilly. External funding is critical for eHealth SMEs' development, particularly for SMEs with fewer than 10 employees, as they are unable to secure external finance from banks (Enterprise Research Centre, 2016). Thus, labour shortages (E2) were a common problem for the eHealth SMEs that participated in this research, as they had limited budgets for hiring new employees. They had tried to tackle this problem by forming university-industry collaborations and offering student internships.

The eHealth SMEs in this study had been established for various reasons. For some, the founder or co-founder had survived illness (e.g., diabetes, brain cancer, mental ill health, or nutritional problem), and therefore wanted to share their successful experiences or build tools to help more patients. For others, the founder or co-founder had expertise in areas such as machine learning, artificial intelligence, blockchain technology, sleep training, and epilepsy management, and therefore had a vision of using cutting-edge technology to produce positive effects for patients. These SMEs might be equipped with knowledge, experience, skills, or technology, but seemed to neglect the important role of "soft power" for businesses, such as business networking, strategic strategy, and cultural issues. Most of the SMEs involved in this study identified lack of links with NHS procurement (E1) as an issue, even though the majority had mature products. This would cause limited investment in staff training programmes and lack of knowledge of their end-users and routes to market (E14), which in turn would cause lack of marketing expertise and knowledge. Missing links with NHS procurement and knowledge of marketing would also elicit other adverse effects, such as lack of knowledge of product promotion (E9) and poor staff support (E5). In particular, reskilling and upskilling employees is critical in the digital age, such as training on data analytics (e.g., R or Stata, Big Data, and data science). However, limited budget makes it difficult for eHealth SMEs to implement training programmes. Insufficient programming and data analytic skills will hamper innovations on existing platforms or mobile applications, which will cause limited product scalability (E8).

Amongst other barriers, problems with user experience evaluation (E13) will mean that eHealth SMEs cannot collect sufficient user experience feedback; and lack of specific digital skills (E12), such as programming language and data modelling, may cause limited product scalability (E8). User experience evaluation is a particularly widespread problem for eHealth SMEs in CIoS. We assumed that weak public awareness of eHealth (E10) result in these companies being unable to recruit sufficient qualified users.

The TISM analysis also generated interesting new insights. For example, the results show that transcultural problems (E7) should be given critical attention, particularly for those

running eHealth businesses successfully in countries with different cultural value orientations from that of the UK, such as Finland, Norway, Greece, India, and China, that have ambitions to exploit UK markets. Schwartz (2006) identifies seven cultural value orientations: egalitarianism, intellectual autonomy, affective autonomy, mastery, hierarchy, embeddedness, and harmony. In this study, one of the eHealth SMEs originated from India, which has a hierarchical cultural value orientation. It had wanted to expand into the UK market using the same eHealth app, but had been unsuccessful due to transcultural problems. In a hierarchical environment, people are encouraged to prioritize the collective rather than pursue their unique ideas and aspirations, whereas in an affective autonomy environment like the UK, people are encouraged to pursue affective experiences for themselves, such as pleasure, excitment, and variety (Schwartz, 2006). Thus, cultural conflicts between the UK and India require Indian managers to tolerate differences, understand varied expressions, collaborate with peers, and enhance their interpersonal and psychological skills. Data privacy must also be considered, particularly by eHealth managers from countries such as China and India. For example, India does not have a unified privacy law, whereas the UK's the General Data Protection Regulation (GDPR), established in the Data Protection Act 2018, requires information to be used fairly, lawfully, and transparently.

5.3 Categorization of barriers and validation of the TISM model through MICMAC analysis

MICMAC was implemented because it was not possible to identify key barriers based on each barrier's TISM hierarchy level. In particular, several barriers were located at the same levels of the TISM hierarchy. Thus, MICMAC analysis was performed to validate the TISM model and classify the 16 identified barriers into four categories. These were based on the driving power and dependence power of each barrier (see Figure 5), relating to whether a barrier has the power to drive the system or is dependent on it. Each barrier's driving power and dependence power were calculated by summing the "1" entries of each row and column in the final reachability matrix, respectively (see Appendix 3). For example, the driving power of transcultural problems (E7) is 10, meaning that this may cause ten other barriers, whereas its dependence power is 1, indicating that only one barrier can elicit transcultural problems. Thus, we classified the 16 barriers into four categories: independent, linkage, autonomous, and dependent variables.

- Independent barriers, characterized by strong driving power and weak dependence power, are the drivers of the system. In this study, we identified 11 barriers that act as drivers of the system, including transcultural problems (E7), lack of links with NHS procurement (E1), difficulty in accessing funding (E3), and lack of adequate infrastructure (E16). In particular, transcultural problems (E7), located at the lowest level of the TISM hierarchy, have the strongest driving power and weakest dependence power. Therefore, they should be tackled as a priority because, unlike other barriers, they may elicit most of the other barriers in the system.
- Linkage barriers have both strong driving power and strong dependence power, and act as links in the system. They are normally found in the middle of a TISM hierarchy. However, none were identified in this study, meaning that independent barriers may elicit other barriers directly without mediators. For example, the impacts of COVID-19 may cause poor staff support due to sequelae of COVID-19, such as lung and neuronal injury (Wang *et al*., 2020).
- Autonomous barriers have both weak driving power and weak dependence power, and are considered to have little influence on the system (Zhao *et al*., 2020). The only autonomous barrier identified in this study is weak public awareness of eHealth (E10). Its limited influence on the system was identified for two reasons. First, CIoS is an ideal testbed for eHealth innovations, as much of the population lives in rural areas with

limited access to primary care (Cornwall Trade and Investment, 2020). Second, the populations of CIoS has positive attitudes towards new eHealth technologies, such as virtual assistants (Buckingham *et al*., 2022). Weak public awareness of eHealth exists widely among residents of CIoS, but eHealth technology is the only feasible choice for people living in rural areas.

- Dependent barriers are identified as having strong dependence power and weak driving power, and are located at the top levels of the TISM hierarchy. This means that they can only be addressed by tackling other barriers, rather than tackling them directly. In this study, four dependent barriers were identified: limited re-innovation capability (E4), poor staff support (E5), limited product scalability (E8), and problems with user experience evaluation (E13). These issues cannot be resolved instantly, but only through long-term knowledge and skills accumulation. In particular, limited product scalability (E8) is located at the highest level in the TISM hierarchy and can be elicited by the other 15 barriers in the system. Therefore, it should be tackled in various ways, such as hiring new employees, reskilling and upskilling existing employees, and becoming involved in bid applications.

Insert Figure 5

6. Discussion

This empirical study focuses on barriers hindering the development of eHealth SMEs in CIoS, as an ideal testbed for new eHealth technologies. By conducting interviews with experienced eHealth SME managers and adopted an integrated approach to data analysis, this study generates interesting insights into the barriers identified and makes several contributions to existing knowledge, while answering the three research questions outlined in Section 1. In addressing the first research question, we find empirical evidence of 16 barriers that may impede the development of eHealth SMEs in CIoS, and categorized these into seven categories. In relation to the second research question, we identify interrelationships among the 16 barriers through TISM, and determine that the key barrier is transcultural problems. To address the third research question, we classify the 16 barriers into four groups based on their dependence and driving power, which provides a better understanding of the role of each barrier in the system, in terms of drivers, mediators, linkages, and dependent barriers.

This study also contributes to the literature as follows.

First, it has the potential to contribute to the TAM. TAM originally developed by Davis (1989) based on the Theory of Reasoned Action (TRA). This has since been extended and used in different disciplines to inform practitioners in a range of industries about measures they might adopt prior to implementing technologies (Surendran, 2012; Sagnier *et al*., 2020). In the area of eHealth, various external variables in the TAM model have been investigated, such as social demographics, subjective norms (e.g., image, job relevance, output quality, result demonstrability, and computer anxiety), propensity to innovate, enabling conditions, and social participation, as summarized by several literature reviews on TAM (Rahimi *et al*., 2018; Kavandi and Jaana, 2020). Researchers have also investigated the impact of cultural issues on technology acceptance. For example, Hoque and Bao (2015) suggest that culture-related factors, such as power distance, masculinity, and restraint, have significant impacts on intentions to use eHealth technologies in Bangladesh, whereas other factors, such as uncertainty avoidance, collectivism, and pragmatism, have no significant impact. In Middle Eastern countries, such as Jordan and Syria, cultural issues (e.g., doctor and patient resistance) also influence eHealth technology acceptance levels (Alajlani and Clarke, 2013). Recent reviews of the literature on factors influencing eHealth technology adoption clearly indicate that technical issues, cultural issues, and demographic characteristics of older adults influence eHealth technology

acceptance (Peek *et al*., 2014; Bastoni *et al*., 2021). Our study contributes to the external variables of the TAM model by reinforcing that eHealth SMEs managers' cultural value orientations may impact significantly on their companies' management and product development processes, particularly for eHealth managers operating companies with different cultural value orientations.

Our second contribution is to identify several new barriers that may impede the development of eHealth SMEs. For example, previous studies (e.g., Shi *et al*., 2008; Bocken, 2015; Falkner and Hiebl, 2015; Goldenstein *et al*., 2019) identify that lack of understanding of the market, lack of industry 4.0 infrastructure, lack of technical training, ignorance about regulation, rapid technological development, and weak public awareness are obstacles to SMEs' development (see Table 1). Our study confirms that barriers such as lack of knowledge about end-users, routes to market, and product promotion, difficulty in accessing funding, weak public awareness of eHealth, lack of specific digital skills, lack of adequate infrastructure, poor staff support, poor leadership, and problems in eHealth policy dissemination are all problems in the context of eHealth SMEs. Other barriers, such as transcultural problems, problems with user experience evaluation, lack of links with NHS procurement, and limited product scalability, are seldom mentioned in previous research. For example, transcultural issues are a challenge for healthcare staff working in clinics and hospitals (Amiri *et al*., 2016), and are frequently mentioned in research on nursing and healthcare (Shahzad *et al*., 2021); however, from a business perspective, their effects seem to be neglected, particularly for migrants with different cultural backgrounds running businesses in the UK. Iyer *et al*. (2005) highlight the relationship between product scalability and the performance of web applications. This connection is reinforced by our finding that limited product scalability may cause unsatisfactory performance by eHealth SMEs. There are several ways for eHealth SMEs to access NHS procurement channels, such as selling products directly to trusts or primary care organizations, through NHS supply chains or collaborative purchasing arrangements, or through national framework collaborations and government tenders (National Health Service, 2018). However, the complicated certification process makes it difficult for eHealth SMEs to participate in the NHS procurement process, particularly for those unfamiliar with the local public procurement market (Akenroye *et al*., 2020). For example, sales of products or goods with a value of over £172,514 require competitive dialogue or negotiations, or innovation partnership. A further "light touch" is required to fulfil transparency and equal treatment if the value of health services or goods exceeds £625,050 (National Health Service, 2016).

Third, this study allocates the 16 barriers to seven layers by conducting TISM, and identifies transcultural problems as the key barrier. Rana *et al*. (2019) highlight that perceived risk is the key barrier to m-commerce adoption by manufacturing SMEs, whereas Alawamleh and Popplewell (2011) identify four risk sources critical to virtual organization: geographic location, cultural differences, ontology differences, and heterogeneity of partners. Our study produces the interesting new insight that transcultural problems may elicit various barriers, and should therefore be given critical attention. In this study, SMEs from other countries such as Finland, Norway, Greece, India, and China, had all encountered transcultural issues when seeking to exploit UK eHealth markets. This is because these countries' cultural value orientations differ that of the UK. For example, the cultural value orientations of China and India are extremely high in hierarchy and embeddedness and low in autonomy, so eHealth managers from these countries exhibit characteristics such as obeying the expectations of authority (Gopalan and Rivera, 1997). In particular, eHealth managers from the Chinese Confucian culture of hierarchy and obedience may expect employees to work in a "996" regime and violate labour rights due to the power differential between managers and subordinates (McLaren *et al*., 2019; Wang, 2020). This culture may force UK employees to leave. Closer cultural value orientations between managers and employees will accelerate knowledge sharing

and technology innovation, particularly in a collectivist culture (Dwyer *et al*., 2015). However, the UK's cultural value orientation emphasizes affective autonomy, which encourages individuals to pursue their own ideas and positive affective experiences (Street, 2011). Differing cultural value orientations between India, China, and the UK pertain to barriers such as poor staff support, poor leadership, labour shortages, and limited re-innovation capacity. The cultural value orientations of Finland and Norway are high in egalitarianism, intellectual autonomy, and harmony. Although these are similar to the UK, they show some differences. eHealth managers from Finland and Norway are characterized by responsibility and loyalty to their work, whereas UK employees may show less loyalty, as they tend to pursue more self-serving lives (Schwartz, 1999; Kirca *et al*., 2009). Loyalty issues may cause workforce mobility, and further induce knowledge loss, and shortages of skills and talent at the organizational level (Massingham, 2018). Greek eHealth managers show diverse cultural value orientations, but demonstrate relatively high embeddedness and low autonomy (Schwartz, 2006). In countries that focus on embeddedness, fulfilling collective activities is more important than pursuing one's own unique ideas. Thus, eHealth managers with a cultural value orientation of embeddedness may limit their organizations' capacity for innovation, as novel ideas and inspirations are not encouraged. Differences in these countries' cultural value orientations impact on managers' leadership style, behaviour, and cultural-personal traits, potentially resulting in more barriers for their SMEs. Most of the SMEs in this study had internationalized their firms by engaging in different types of learning (Ruzzier *et al*., 2006) and cross-cultural schemas (Ivanova-Gongne, 2015). Based on Andersson's (2000) research, a firm's international behaviour depends on two factors: how the manager treats individual learning, and characteristics of top managers. Our results offer a reminder that transcultural issues cannot be ignored by eHealth SMEs, and are a potential direction for further research.

Finally, MICMAC analysis of the 16 barriers provides a clearer understanding of the nature of each barrier, such as whether it acts as a linkage or a driver in the system. In this study, 11 barriers (68.75%) were identified as independent barriers, four (25%) as dependent barriers, one (6.25%) as an autonomous barrier, and none as linkage barriers.

7. Conclusions, implications, and future research directions

This study explored barriers impeding the development of eHealth SMEs in CIoS in the UK. An integrated approach was adopted, including semi-structured interviews, thematic analysis, TISM, and MICMAC analysis. We conducted 20 semi-structured interviews with experienced eHealth SME managers, followed by thematic analysis to generate 16 barriers. We then used TISM to build interrelationships among the identified barriers and distinguish the key barrier, and applied MICMAC analysis to categorize the barriers and validate the TISM model. The findings highlight that transcultural problems should be given critical attention, particularly by eHealth managers originating from countries associated with different cultural value orientations from that of the UK, such as those with a cultural background of hierarchy and embeddedness.

7.1 Implications for managerial practice and policy

This study makes several contributions to managerial practice. First, it raises eHealth SME managers' awareness of transcultural problems. For eHealth managers originating from China and India seeking to exploit the UK market, we suggest that they should enhance their self-awareness and reflection skills, facilitate their acceptance of different views, values, practices and norms, be prepared to cooperate. This is because the UK's cultural value orientation is based on affective autonomy, whereas those in China and India are based on hierarchy.

Second, this study shows that eHealth SMEs in CIoS face a range of barriers, including functional, marketing, environmental, governmental, and other barriers. Their limited budgets and resources make it difficult for them to develop capabilities to improve their competitive advantage. A feasible way to tackle barriers is to engage in university-industry collaborations.

Universities have advanced facilities, knowledge, and experienced researchers, as well as funding (e.g., knowledge transfer partnerships) for which eHealth SMEs across CIoS should consider applying.

Third, managers should allocate budgets to reskill and upskill their employees, since digital skills are critical for eHealth SMEs' development. This is because dependent variables such as poor staff support, limited re-innovation capacity, and limited product scalability all relate to lack of knowledge and skills in various ways. Thus, training programmes should be provided for all employees to ensure that they master basic digital skills (e.g., productivity software). With regard to senior level employees, training programmes such as online courses should equip them with sufficient understanding of the latest trends in eHealth. For critical technicians, specific digital skills such as programming languages, computer and networking support, and data analytic skills should be delivered through online courses and scenario-based learning.

Finally, regional and national governments should allocate funding to improve the information and communication infrastructure of rural areas and nurture SMEs. For example, increased broadband speeds would significantly benefit people living in rural areas by enabling them to access high-quality eHealth services. SMEs play a critical role in providing efficient, effective, and affordable eHealth services, and are vital to the UK economy. Thus, funding to nurture eHealth SMEs will help people to access affordable services, and contribute to achieving the SDG of good health and wellbeing.

7.2 Limitations and future research directions

This study has some limitations. First, it focuses on eHealth SMEs in CIoS, a less prosperous area of UK, which narrows the scope of the results. To generalize the findings, future research might draw on a larger sample of countries, for instance by conducting international surveys with eHealth SME managers in at least seven countries, which is the minimum of number suggested to support credible international generalizations (Franke and Glenn Richey Jr, 2010).

Second, in this study we focus on barrier analysis, such as barrier identification, categorization, and assessment. We tangentially propose some strategies that may have positive effects in tackling these barriers, but our results fall short of providing a systematic way to do so. Thus, from an organizational resilience perspective, a holistic framework to the tackle barriers would be a valuable future research direction (Lengnick-Hall *et al*., 2011; Hillmann and Guenther, 2021).

Third, this study reveals that transcultural problems are a key barrier that may give rise to other barriers. eHealth SMEs originating from other countries, including Finland, Norway, Greece, India, and China, run their businesses in CIoS. However, this study does not go into detail on the obstacles caused by different cultural value orientations. For example, eHealth businesses transferring from cultural value orientations of egalitarianism (Finland and Norway), hierarchy (India and China), or embeddedness (Greece) to affective autonomy (UK) might be investigated more systematically (Schwartz, 2006). Comparative cross-country analysis of transcultural issues is a valuable future research direction and that will generate practical guidance for businesses seeking to expand their international markets.

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Appendix 1 Interview guide

I. Introductory questions

a) Interviewee information

1) What is your current designation?
2) Can you give me a brief overview of your job within the company operations?
3) How many years have you been working in this company?

b) Company information

1) Can you give me a brief overview of your company, for example expertise and products?
2) How many employees are working for the company?

II. Barriers that impede the company's development

1) How would you describe any informational barriers relating to information inefficiencies?
2) How would you describe any functional barriers relating to enterprise functions, such as human resources, production, and finance?
3) How would you describe any marketing barriers relating to the enterprise's product, pricing, and promotional activities?
4) How would you describe any environmental barriers relating to the economic, political-legal, and sociocultural external environment?
5) How would you describe any procedural barriers relating to the operating aspects of transactions?
6) How would you describe any task barriers relating to the enterprise's customers and competitors?
7) How would you describe any governmental barriers relating to action or inaction by the local government?

III. Relationships between barriers

1) What does the term "relationships between barriers" bring to your mind?
2) How would you describe the relationships between different barriers? For example, governmental barriers may cause functional and marketing barriers.

IV. Barrier mitigation strategies

How would you describe any strategies or measures that have been adopted to mitigate:

(1) Informational barriers;
(2) Functional barriers;
(3) Marketing barriers;
(4) Environmental barriers;
(5) Procedural barriers;
(6) Task barriers;
(7) Governmental barriers

Appendix 2 Initial reachability matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16
E1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0
E2	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0
E3	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0
E4	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
E5	0	0	0	1	1	0	0	1	0	0	0	0	1	0	0	0
E6	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
E7	0	0	1	0	0	0	1	1	1	0	0	0	1	1	0	0
E8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
E9	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
E10	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
E11	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0
E12	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0
E13	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
E14	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0
E15	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0
E16	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	1

Appendix 3 Final reachability matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	**Driving power**
E1	1	1	0	1*	1*	0	0	1	1*	0	0	1	1*	0	0	0	8
E2	0	1	0	1	1	0	0	1*	1	0	0	0	1*	0	0	0	6
E3	0	1	1	1*	1*	0	0	1	1*	1	0	0	1*	0	0	0	8
E4	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	2
E5	0	0	0	1	1	0	0	1	0	0	0	0	1	0	0	0	4
E6	0	0	0	1*	1	1	0	1*	0	0	0	0	1*	0	0	0	5
E7	0	1*	1	1*	1*	0	1	1	1	1*	0	0	1	1	0	0	10
E8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
E9	0	0	0	1*	1	0	0	1*	1	0	0	0	1*	0	0	0	5
E10	0	0	0	0	0	0	0	1*	0	1	0	0	1	0	0	0	3
E11	0	0	0	1*	1	0	0	1*	0	0	1	0	1	0	0	0	5
E12	0	0	0	1	1	0	0	1	0	0	0	1	1*	0	0	0	5
E13	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	2
E14	0	0	0	1*	1*	0	0	1	1	0	0	0	1*	1	0	0	6
E15	0	0	0	1*	1*	0	0	1*	0	1	1	0	1*	0	1	0	7
E16	0	0	0	1*	1	0	0	1	0	1	1*	0	1*	0	1	1	8
Dependence power	1	4	2	13	12	1	1	16	6	5	3	2	14	2	2	1	

Note: * represents transability

Appendix 4 Partitioning the reachability matrix into different levels

Variable	**Reachability Set (RS)**	**Antecedent set (AS)**	**RS ∩ AS**	**Level**
Iteration 1				
E1	1,2,4,5,8,9,12,13	1	1	
E2	2,4,5,8,9,13	1,2,3,7	2	
E3	2,3,4,5,8,9,10,13	3,7	3	
E4	4,8	1,2,3,4,5,6,7,9,11,12,14,15,16	4	
E5	4,5,8,13	1,2,3,5,6,7,9,11,12,14,15,16	5	
E6	4,5,6,8,13	6	6	
E7	2,3,4,5,7,8,9,10,13,14	7	7	
E8	8	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	8	**Level I**
E9	4,5,8,9,13	1,2,3,7,9,14	9	
E10	8,10,13	3,7,10,15,16	10	
E11	4,5,8,11,13	11,15,16	11	
E12	4,5,8,12,13	1,12	12	
E13	8,13	1,2,3,5,6,7,9,10,11,12,13,14,15,16	13	
E14	4,5,8,9,13,14	7,14	14	
E15	4,5,8,10,11,13,15	15,16	15	

E16	4,5,8,10,11,13,15,16	16	16	
Iteration 2				
E1	1,2,4,5,9,12,13	1	1	
E2	2,4,5,9,13	1,2,3,7	2	
E3	2,3,4,5,9,10,13	3,7	3	
E4	4	1,2,3,4,5,6,7,9,11,12,14,15,16	4	**Level II**
E5	4,5,13	1,2,3,5,6,7,9,11,12,14,15,16	5	
E6	4,5,6,13	6	6	
E7	2,3,4,5,7,9,10,13,14	7	7	
E9	4,5,9,13	1,2,3,7,9,14	9	
E10	10,13	3,7,10,15,16	10	
E11	4,5,11,13	11,15,16	11	
E12	4,5,12,13	1,12	12	
E13	13	1,2,3,5,6,7,9,10,11,12,13,14,15,16	13	**Level II**
E14	4,5,9,13,14	7,14	14	
E15	4,5,10,11,13,15	15,16	15	
E16	4,5,10,11,13,15,16	16	16	
Iteration 3				
E1	1,2,5,9,12	1	1	
E2	2,5,9	1,2,3,7	2	
E3	2,3,5,9,10	3,7	3	
E5	5	1,2,3,5,6,7,9,11,12,14,15,16	5	**Level III**
E6	5,6	6	6	
E7	2,3,5,7,9,10,14	7	7	
E9	5,9	1,2,3,7,9,14	9	
E10	10	3,7,10,15,16	10	**Level III**
E11	5,11	11,15,16	11	
E12	5,12	1,12	12	
E14	5,9,14	7,14	14	
E15	5,10,11,15	15,16	15	
E16	5,10,11,15,16	16	16	
Iteration 4				
E1	1,2,9,12	1	1	
E2	2,9	1,2,3,7	2	
E3	2,3,9	3,7	3	
E6	6	6	6	**Level IV**
E7	2,3,7,9,14	7	7	
E9	9	1,2,3,7,9,14	9	**Level IV**
E11	11	11,15,16	11	**Level IV**
E12	12	1,12	12	**Level IV**
E14	9,14	7,14	14	
E15	11,15	15,16	15	
E16	11,15,16	16	16	
Iteration 5				
E1	1,2	1	1	
E2	2	1,2,3,7	2	**Level V**
E3	2,3	3,7	3	
E7	2,3,7,14	7	7	
E14	14	7,14	14	**Level V**
E15	15	15,16	15	**Level V**
E16	15,16	16	16	
Iteration 6				
E1	1	1	1	**Level VI**
E3	3	3,7	3	**Level VI**
E7	3,7	7	7	
E16	16	16	16	**Level VI**
Iteration 7				
E7	7	7	7	**Level VII**

Appendix 5 Digraph showing significant transitive links