

## Article

# Developing a Cloud-Based Mobile Learning Adoption Model to Promote Sustainable Education

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**Abstract:** Education plays a very significant role in the context of sustainability. As the world population is growing, providing education through the traditional classroom setting is not sufficient and not feasible to extend learning in professional life. Therefore, modern technology-mediated learning paradigms such as mobile learning are becoming increasingly popular. Mobile learning is said to integrate multiple contexts, learning types, mobilities and communications. As information and communications technology (ICT) plays a vital role in the delivery of mobile learning services, it is very essential to adopt sustainable IT resources to keep it viable. Cloud computing offers a range of affordable, scalable and on-demand solutions. This paper attempts to model important critical success factors (CSFs) in the area of cloud-based mobile learning using the interpretive structural modeling (ISM) technique. ISM helps in identifying the hierarchical inter-relationships between the variables of study with the help of experts in the field. Finally, Matrice d'Impacts Croisés-Multiplication Appliquée à un Classement (MICMAC) analysis is employed to classify the variables into dependent and independent variables. Management support has been identified as most rudimentary among sixteen CSFs identified through a literature review to establish a distinguished relative advantage. Further, the paper discusses the theoretical underpinning of all the constructs. This study will help organizations to implement mobile learning in sustainable ways.

**Keywords:** mobile learning; critical success factors (CSFs); interpretive structural modeling (ISM); Matrice d'Impacts Croisés-Multiplication Appliquée à un Classement (MICMAC); cloud-based adoption model

## 1. Introduction

The adoption of technologies in education has been posited as the major shift in education and is yet to be materialized in its full potential [1]. The latest advancements in information and communication technologies (ICT) are bridging the gaps at each level—social, technological and organizational—to make this transition feasible. The high penetration of internet-based services and especially social media has improved digital literacy globally. Currently, there are 4.33 billion internet users and 3.53 billion social media users [2]. Cloud computing, the Internet of Things (IoT), virtual reality, interactive touch screens, 3D printing, E-Learning solutions, mobile apps, open-source components and high-speed networks are all making ICT interactive, affordable and easy to use. Organizations are heavily dependent upon ICT in their business and operational transactions and relationships with stakeholders and partners. Similarly, universities and institutions also maintain an efficient ICT infrastructure.

Mobile learning has appeared to be the most mature and convenient type of technology-mediated or enhanced learning. Initially, it was projected as the extension of E-Learning on the mobile devices [3].

However, later as the phenomenon evolved, other important constructs such as context, communication, informal learning and mobilities (in physical, conceptual and social space, technology and time) also emerged [4]. Therefore, the relatively newer definition of mobile learning describes it as “learning in multiple contexts, through social and content interactions, using personal electronic devices” [5]. The significance of technology remains strong as the success of mobile learning rests upon the successful orchestration of ICT resources such as ICT infrastructure, mobile devices and apps, and security.

Mobile learning is supporting all forms of learning, such as formal, non-formal and informal. Children are gaining information from mobile devices at an unprecedented pace in different formats on virtually every domain. Mobile learning has provided a pervasive environment for learning at any time and anywhere to promote the cause of inter-generational education for sustainable development (SD). Sustainability is measured in three dimensions, i.e., economic, social and environmental, which are referred to as the triple bottom line (TBL) [6]. Education has been defined as one of the five indicators for social sustainability by the United Nations (UN) [7]. Mobile learning will support social sustainability by providing sustainable means for learning.

The implementation of mobile learning must provide a relative advantage over traditional means of learning by utilizing best-in-class ICT tools and resources. The implementation must be governed under the principles of sustainability, which asserts that the current utilization of resources should not compromise the capacity for future generations. Cloud-based ICT infrastructure serves the cause of sustainability and will provide required on-demand scalability, cost optimizations and innovative solutions. Cloud computing offers a robust ecosystem of software services, vendors and ICT resources. Initially, cloud services were offered in three basic modes, i.e., software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS) [8]. Later domain-specific services also started, such as business process as a service (BPaaS) [9]. Most of the ICT vendors provide their services on cloud platforms, including E-Learning service providers such as Blackboard. Similarly, open-source E-Learning solutions are also hosted on cloud platforms, such as moodlecloud, and offer mobile-friendly services.

Mobile learning implementation is a highly interdisciplinary area involving active participation from multiple domains. There are studies that tried to integrate the multiple domains in E-Learning [10], cloud-based E-Learning [11] and mobile learning [12]. Most studies have considered the constructs from the technical side and behavioral side. The technical side focuses on mobile learning system development including content design and interface design. Whereas the behavioral aspects being studied are satisfaction, behavioral intention to use and perceived benefits of mobile learning. Similarly, different theoretical frameworks such as SERVQUAL, an instrument to measure service quality [13], technology acceptance [14], diffusion of innovation [15] and hybrid and modified [16] models are used to correlate different constructs.

Cloud-based mobile learning will further increase the stakeholders and include cloud service providers, mobile learning solution providers, institutions and learners. The important dimensions of cloud computing, such as cloud data security, customizable service level agreements (SLA) and cloud services, play an important role in the adoption of mobile learning. The critical success factors (CSFs) approach [17] ensures the identification of limited mandatory areas to achieve relative success. In one of the previous studies [11], 12 CSFs were identified through a literature review in the cloud-based E-Learning paradigm in four categories, namely cloud service resilience, institutions' technology maturity, institutions' organizational readiness and cloud-based E-Learning imperatives. Furthermore, the study was extended in [18] by adding two more variables—cloud services (SaaS, PaaS and IaaS) and the design of innovative services. Additionally, the combinatorial approach of fuzzy analytical hierarchy process and group decision-making was applied to rank dimensions and individual CSFs. The current study attempts to extend the studies [11,18] to the cloud-based mobile learning environment. Two more variables, mobile device adoption and social media usage, have been added as explained in the literature review section in the mobile learning context. This study utilizes interpretive structural modeling (ISM) and Matrice d'Impacts Croisés-Multiplication Appliquée à un

Classement (MICMAC) techniques to identify the hierarchical relationships among the important factors in the context of cloud-based mobile learning.

Warfield [19–22] developed ISM technique in the 1970s and around the same time MICMAC [23] was also developed. ISM utilizes a very robust bottom-up approach for studying the system of variables. The pairwise comparison of variables allows the experts to study the sub-system in isolation; whereas the mathematically derived hierarchical model of interrelationships allows experts to study the phenomenon holistically. The research databases show the exponential growth of the adoption of the ISM technique in diverse fields. It has been applied in many studies in the area of ICT [24–26] and very extensively in the area of sustainability. It has also been applied in the area of E-Learning [10,27]. Similarly, studies [28,29] have used ISM for language learning and curriculum implementation modeling in the mobile learning context. Therefore, in essence, this research will attempt to answer the following research questions:

- What are the important CSFs for the cloud-based mobile learning adoption?
- What is the hierarchical structural model of relationships among these CSFs?

The article is organized into the following sections: literature review, research methodology, ISM and MICMAC analysis, model discussion, and conclusion, future research and limitations.

## 2. Literature Review

The cloud-based mobile learning area is a relatively newer field. Therefore, for the purpose of this study, literature was explored in the domains of cloud computing adoption in institutions and E-Learning, mobile learning and cloud-based mobile learning. Finally, CSFs in the field of cloud-based mobile learning have been aggregated.

### 2.1. CSFs for Cloud Computing in Institutions and E-Learning

The application of cloud computing in institutions and E-Learning is present in the literature from different perspectives. The general challenges that are faced in the adoption of cloud computing remain the same irrespective of the sector. The literature review shows that there have been researches to determine the major factors and challenges in the success of cloud computing [10,30–34]. These factors may be listed as cost-reduction, flexibility, virtualness, availability, collaboration, scalability, efficiency, redundancy and reliability, data management, service management, governance, product-process control and monitoring, infrastructure, system reliability, information and visualization security, data security and concerns over data transmission across anticipated broadband speeds. The authors of [34] categorized the migration risks into security-related and general migration risks. The authors of [35] proposed a theoretical framework for migration strategies

The role of cloud computing in educational institutions has also been the focus of research. Many studies report the growing trends of the adoption of cloud computing in educational institutions. The extant researches deal with the state of cloud computing adoption in the West [36,37]. There are also significant studies focusing on Arab countries [38,39]. These studies describe the cloud computing environment and its advantages in terms of cost, efficiency, reliability, portability, flexibility and security. They also list the major challenges in cloud computing, namely security, lock-in and unsolicited advertising.

The paper [11] presents a systematic literature review to ascertain the CSFs for effectively implementing cloud-based E-Learning. They identified twelve factors and clustered them along four dimensions, namely: “cloud service resilience, university technological maturity, university organizational readiness, and cloud-based E-Learning imperatives”. The authors of [40] added the “perception, attitude and intention of people towards the adoption of cloud computing” as the most important factors in adopting cloud computing. The authors of [41] found the major factors in implementing cloud computing by public universities in Nigeria as “data insecurity, regulatory compliance concerns, lock-in and privacy concerns”.

In terms of the migration to cloud computing by universities in Saudi Arabia, a framework was proposed by [32,42,43]. They identified a set of critical success factors from the studies on cloud migration, web-based learning and enterprise resource planning. The authors of [42] classified the critical success factors into technological factors and organizational factors. The technological factors included “reliability, interoperability, security and privacy, disaster recovery, and network bandwidth” whereas the organizational factors included “ministry of education policies, management support, user awareness, service level agreements, and degree of control”. Other studies have also reported factors that may be categorized within these broad factors [44–47].

## 2.2. CSFs Related to Mobile Learning

Research on mobile learning has increased in the recent past [48–50]. Two literature reviews related to the factors that affect mobile learning [12,51] noted that there has been a significant increase in the publications in this area in the recent past. The authors of [12] pointed out that there are not many studies that deal with an in-depth analysis of the CSFs of mobile learning. Research on mobile learning has focused on students [52–54], instructors and organizations [55]. From the perspective of instructors, [56] reported that instructors feel reluctant to adopt mobile learning.

Many studies were found to deal with the advantages of mobile learning [57–60]. These advantages may be categorized from the perspectives of different stakeholders. Flexibility, cost, social interactivity, reliability, technical advantages, ease of use and pedagogical advantages are some of the major benefits reported in the studies. Researchers have defined mobile learning in terms of physical characteristics [61,62], mobility [57], type of learning [63] and different locations [4]. The specific challenges in the adoption of mobile learning have been highlighted in the research too. These challenges pertain to the teaching methods and the academic context [64], poor screen display [65], problems related to cognition and usage [66], interest of students [57], security concerns [54], cost [12] and obsolescence of mobile devices and technologies [67].

In order to successfully adopt mobile learning in educational institutions, several factors have been listed in the studies. These factors may be listed as technical competence of learners, user-friendly design, learner community development and platform accessibility [54,68–73]. The authors of [68] focused on the mobile social media framework. They called them mobile social media CSFs that included six factors, namely “pedagogical integration of the technology into the course and assessment, lecturer modeling of the pedagogical use of the tools, creating a supportive learning community, appropriate choice of mobile devices and web 2.0 social software, technological and pedagogical support, and creating sustained interaction that facilitates the development of ontological shifts, both for the lecturers and the students”. The authors of [61] proposed guidelines on the implementation of mobile learning technology that included ten major factors. The authors of [74] uses a socio-technical approach to study the adoption of mobile learning. They categorized the CSFs into four domains namely “organization, people, pedagogy, and technology”. The authors of [75] explored the CSFs of mobile learning and classified them in six dimensions, namely “Learner’s characteristics, Instructor’s Characteristics, System Quality and Mobile Learning Environment, Institution and Service Quality, Course and Information Quality, and Motivation”. The authors of [76] identified one CSF of mobile learning as the most important and that is the “pedagogical integration of technology into course criteria and assessment”.

## 2.3. CSFs for Cloud-Based Mobile Learning

There are limited studies in the area of cloud-based mobile learning (CBML) as mentioned earlier. The study [77] proposed to use CBML to manage the huge amount of data by using cloud-based Big Data capabilities and also offloading the heavy computing needs to the cloud. Further, the application of the localized technology acceptance model (TAM) in the study proved that personal innovativeness was found to be an influential factor for mobile learning adoption in addition to ease of use, external motivation from family and friends and financial factors. Nonetheless, the model does not holistically

include the aspects of cloud computing. The paper [78] explored auto-scaling techniques for CBML applications in order to scale the cloud resource for optimal performance. Similarly, paper [79] proposed the interface for the CBML systems. Paper [80] proposed a very rudimentary architectural layout of cloud-based mobile learning. The authors of [81] developed a mobile cloud-based learning platform to teach practice-oriented courses such as sports in a blended format. Two applications were developed for teacher and learner with almost similar modules, and learning and assessment contents were in video formats hosted on YouTube, whereas a cloud server containing student and course information was also used. Survey results prove that the platform supports the top four factors in sports education, namely: accessibility to expert coaching; learning at your own pace; course performance using the platform; and freeing coach time. The authors of [82] performed a literature review on the existing CBML frameworks and concluded that most of them focused on technical issues, ignored other stakeholders and were designed for specific contexts.

The article [83] surveyed 40 undergraduate students for both traditional and mobile cloud modes of courses. It was identified that course outcomes for the mobile cloud mode were better than the traditional mode of learning. Similarly, study [84] also demonstrated the increased adoption of mobile cloud in Jordan and better results in mobile cloud mode over the traditional mode of education. Study [85] identified that CBML has a significant impact on both perception of innovative environments and creative performance, based on a survey from 127 students in a Taiwanese university, where perception of innovative environments is correlated with creative performance. Hence CBML is very effective to boost the creative performance of learners. Study [86] has proposed a mobile cloud framework for blended flexible learning that consists of access management, support for personalized, collaborative and micro learning, multimedia content, learner modeling, a student progress tracker and parent involvement. The framework does not incorporate the technical implementation aspects.

CBML implementation will require active participation of a cloud service provider, a mobile learning solution provider, institutions, content writers, instructors and learners. The important dimensions of cloud computing, such as cloud data security, customizable service level agreements (CSLA) and cloud services play a very dominant role in the adoption of cloud-based mobile learning. There are extant frameworks in E-Learning adoption such as Khan's framework [87]. It helps to evaluate the readiness of an institution for E-Learning and includes an institutional dimension, a management dimension, a technological dimension, a pedagogical dimension, an ethical dimension, an interface design dimension, a resource support dimension and an evaluation dimension. Similarly, [88] identified CSFs in the adoption of E-Learning and proposed a framework comprising of five dimensions, namely technology, content, students, professors and educational institutions. Additionally, [89] compared the perspectives of students and academic staff for evaluating the CSFs for E-Learning. They proposed six clusters of factors responsible for success of E-Learning. These are "instructor characteristics, student characteristics, technology infrastructure, E-Learning systems and online learning resources, and support and training". The authors of [90] compiled seventy-four CSFs into four main categories, namely: instructor; student; information technology; and university support.

The paper [91] demonstrated an intensive literature review of CSFs of mobile learning and found that five CSFs are the most common, including "technology availability, support of the concerned institution, network connectivity, assimilation with study curriculum, student experience, or real life, and technology ownership by learners". The authors of [74] categorized the CSFs into four domains, namely Organization, People, Pedagogy and Technology. In one of the previous studies [11], 12 CSFs were identified through a literature review in the cloud-based E-Learning paradigm and categorized into the following: cloud service resilience, institutions' technology maturity, institutions' organizational readiness and cloud-based E-Learning imperatives. Furthermore, the study was extended in the article [18] by adding two more variables—cloud services (SaaS, PaaS and IaaS) and design of innovative services. Literature on mobile learning necessitates addition of two more variables, namely mobile device adoption and social media usage. Table 1 gives the details of all the 16 CSFs, such as dimensions, brief description and references.



**Table 1.** List of Variables.

Dimensions	Variables	Brief Description	References
Cloud Service Resilience	Cloud Data Security	Security of data in execution, transit and storage.	[12,32,34,38,41–43,54,92]
	Availability and Reliability	Availability and reliability of mobile learning services at the promised time, place, device and load.	[30,32,38,42]
	Customizable Service Level Agreement	The customizability of service level agreement to address the specific technological or organizational needs, and compliance with regulations.	[32,41,92]
	Cloud Services	Cloud services in different delivery (SaaS, PaaS and IaaS) and deployment (private, public and hybrid) models.	[59,93–97]
Institutions' Technology Maturity	Network Bandwidth	The capacity of network bandwidth to efficiently support wired and wireless access to mobile learning services.	[32,42];
	Technological Compatibility	The technological maturity to exploit cloud services.	[30,39,41]
	Mobile Device Adoption	Pervasiveness and ubiquity of mobile or smart devices.	[12,65–68,98]
	Technical Support	Technical support for cloud migration, and electronic service development and adoption.	[32,60,63,65,68,73,92]
Institutions' Organizational Readiness	Management Support	The management financial and organizational commitment.	[39,43,45,55,73,99]
	Human Readiness	The technical skills of staff and digital literacy of end users.	[40,45,47,55–57,92]
	Social Media Usage	Flourishing online communities.	[12,57,58,68]
	Utilization Complexity	The degree of difficulty in delivering mobile learning services.	[38,45–47,54,100]
Cloud-Based Mobile Learning Imperatives	Cost Flexibility	Cost as you go.	[30,38,43,59]
	Ease of Use	The degree of ease, users experience in using the mobile learning services.	[12,38,45–47,54,65,66,100]
	Relative Advantage	The relative advantage afforded to the community of learners over previous learning paradigms.	[12,39,45–47,59,61,62,66,100]
	Design of Innovative Services	The innovative and integrative mobile learning services.	[12,30,54,57,65,67]

### 3. Research Methodology

This paper has identified critical success factors (CSFs) for cloud-based mobile learning through a literature review in the first phase. Firstly, cloud computing adoption in institutions and E-Learning were explored. Secondly, the CSFs of mobile learning have been explored to ensure the inclusion of context in the model. Thirdly, literature was explored for cloud-based mobile learning to illustrate the current state of the field. The literature review section presents discourse on these studies and a gap in the holistic approach presented in this study, and the list of identified CSFs along with their brief descriptions.

In the second phase with the help of decision-makers (DMs), interpretive structural modeling (ISM) has been employed to establish relationships between the CSFs identified in first phase. ISM has several steps, such as the development of a structural self-interaction matrix (SSIM), a reachability matrix (RM), a final reachability matrix (FRM), level partitioning, a conical matrix formation, a digraph

and an ISM model. Each of these steps is explained in the analysis section. There were three DMs, as the literature suggests that there may be as few as two DMs [101,102]. All the DMs had decades of academic experience and almost ten years of technology-mediated learning experience. One of the DMs had played a leadership role in the migration of mobile/E-Learning services to the cloud platform. DMs compared pairs of variables, such as  $x$  and  $y$ , for one of the possible relationships, namely  $x$  influences  $y$ ,  $y$  influences  $x$ ,  $x$  and  $y$  influence mutually or  $x$  and  $y$  do not influence each other; these are represented by the symbols V, A, X and O, respectively. The assigned relationships for all pairs of variables in group decision-making are registered in the SSIM and thereafter mathematical steps guide through the whole analysis.

MICMAC analysis is also carried out almost always in conjunction with ISM. MICMAC helps in classifying variables into four categories based on the dependence and driving power of the individual variable. The ISM model and MICMAC diagram help in assessing the conceptual validity of the model. The whole exercise may be repeated until the experts or DMs are satisfied with the final ISM model. In this study it was revised two times to the satisfaction of the DMs. Additionally, the model has been discussed to illustrate the identified relationships and theoretical underpinning of the constructs.

#### 4. ISM and MICMAC Analysis

This section illustrates the steps of ISM and MICMAC analysis.

##### 4.1. Structural Self-Interaction Matrix (SSIM)

This matrix represents relationships identified by the DMs in the group decision-making. The pair of variables are compared and assigned one of the possible relationships, such as first influencing second, second influencing first, mutually influencing or no relation, which are shown with the letters V, A, X or O, respectively. This step of ISM is most crucial, as the following mathematical steps are dependent upon this matrix. For instance, Cloud Data Security will influence Relative Advantage, Utilization Complexity and Availability and Reliability. Whereas Technical Support, Smart Device Adoption, Cloud Services and Customizable Service Level Agreement will influence Cloud Data Security. Furthermore, no relationships are identified with the rest of the variables. The results of the careful study of isolated effects of 120 pairs of variables are summarized into an SSIM as shown in Table 2.

**Table 2.** Resultant pairwise comparison matrix showing structural self-interaction. SLA: service level agreements.

S. No.	Elements (CSFs)	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	Cloud Data Security	O	V	O	O	V	O	O	O	A	A	O	O	A	A	V
2	Availability and Reliability	O	V	V	O	V	O	O	O	A	A	A	A	A	A	
3	Customizable SLA	V	V	O	V	V	O	O	A	O	O	O	V	V		
4	Cloud Services	V	V	O	V	V	O	O	A	A	V	V	O			
5	Network Bandwidth	O	O	O	O	O	V	O	A	O	V	O				
6	Technological Compatibility	V	V	V	O	V	O	O	A	A	V					
7	Smart Device Adoption	V	V	V	O	V	V	V	A	O						
8	Technical Support	V	V	V	O	V	O	V	A							
9	Management Support	O	V	O	V	O	O	V								
10	Human Readiness	V	V	V	O	V	A									
11	Social Media Usage	V	O	V	O	V										
12	Utilization Complexity	V	V	O	O											
13	Cost Flexibility	O	V	O												
14	Ease of Use	A	V													
15	Relative Advantage	A														
16	Design of Innovative Services															

##### 4.2. Reachability Matrix (RM)

The next step is to develop the RM. Firstly, all the letters of the SSIM are replaced with 0 or 1 based on the following logic, where  $i$  and  $j$  represent the row and column indexes, respectively. The resultant initial RM is shown in Table 3.

If SSIM (i, j) = V, then RM (i, j) = 1 and RM (j, i) = 0;  
 If SSIM (i, j) = A, then RM (i, j) = 0 and RM (j, i) = 1;  
 If SSIM (i, j) = X, then RM (i, j) = 1 and RM (j, i) = 1;  
 If SSIM (i, j) = O, then RM (i, j) = 0 and RM (j, i) = 0.

**Table 3.** Initial reachability matrix (RM).

S. No.	Elements (CSFs)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Cloud Data Security	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
2	Availability and Reliability	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0
3	Customizable SLA	1	1	1	1	1	0	0	0	0	0	0	1	1	0	1	1
4	Cloud Services	1	1	0	1	0	1	1	0	0	0	0	1	1	0	1	1
5	Network Bandwidth	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0
6	Technological Compatibility	0	1	0	0	0	1	1	0	0	0	0	1	0	1	1	1
7	Smart Device Adoption	1	1	0	0	0	0	1	0	0	1	1	1	0	1	1	1
8	Technical Support	1	1	0	1	0	1	0	1	0	1	0	1	0	1	1	1
9	Management Support	0	0	1	1	1	0	1	1	1	1	0	0	1	0	1	0
10	Human Readiness	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1
11	Social Media Usage	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1
12	Utilization Complexity	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
13	Cost Flexibility	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
14	Ease of Use	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
15	Relative Advantage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
16	Design of Innovative Services	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1

Thereafter the transitive relations are identified, for instance, if any variable a influences b and b influences c then a also influences c. Similarly, higher-order transitive relations such as a influencing b through two or more variables are identified. These relations are represented with 1\*, as shown in the final RM or FRM (Table 4). This table also shows the driving and dependence powers of each variable; those are counts of non-zero cells of rows and columns for each factor.

**Table 4.** Final reachability matrix (FRM).

S. No.	Elements (CSFs)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Driving Power
1	Cloud Data Security	1	1	0	0	0	0	0	0	0	0	0	1	0	1*	1	1*	6
2	Availability and Reliability	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	1*	5
3	Customizable SLA	1	1	1	1	1	1*	1*	0	0	1*	1*	1	1	1*	1	1	14
4	Cloud Services	1	1	0	1	0	1	1	0	0	1*	1*	1	1	1*	1	1	12
5	Network Bandwidth	1*	1	0	0	1	0	1	0	0	1*	1	1*	0	1*	1*	1*	10
6	Technological Compatibility	1*	1	0	0	0	1	1	0	0	1*	1*	1	0	1	1	1	10
7	Smart Device Adoption	1	1	0	0	0	0	1	0	0	1	1	1	0	1	1	1	9
8	Technical Support	1	1	0	1	0	1	1*	1	0	1	1*	1	1*	1	1	1	13
9	Management Support	1*	1*	1	1	1	1*	1	1	1	1	1*	1*	1	1*	1	1*	16
10	Human Readiness	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	5
11	Social Media Usage	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1*	1	6
12	Utilization Complexity	0	0	0	0	0	0	0	0	0	0	0	1	0	1*	1	1	4
13	Cost Flexibility	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
14	Ease of Use	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
15	Relative Advantage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
16	Design of Innovative Services	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
	<b>Dependence Power</b>	8	9	2	4	3	5	7	2	1	9	8	12	5	14	16	13	

\* represents the transitive relation.

### 4.3. Level Partitioning

The partitioning is a higher complexity function that organizes variables in vertical order. It is an iterative function that repeats until the level of each variable is identified. For each of the variables two sets of variables are identified, the variables that it can reach to and the variables that reach it, called reachability and antecedent sets, respectively. Thereafter the intersection of these two sets is calculated. Variables having a reachability set and intersection equal are assigned the highest available level and are removed for the next iteration. The process ran for 11 times and assigned 11 levels to the 16 variables. The level assigning row of each iteration is shown in Table 5, sorted with element id.



**Table 5.** Level partitioning iterations summary.

Elements (Mi)	Reachability Set R(Mi)	Antecedent Set A(Mi)	Intersection Set $R(Mi) \cap A(Mi)$	Level
1	1	1, 3, 4, 5, 6, 7, 8, 9	1	6
2	2	1, 2, 3, 4, 5, 6, 7, 8, 9	2	5
3	3	3, 9	3	10
4	4	3, 4, 8, 9	4	9
5	5	3, 5, 9	5	8
6	6	3, 4, 6, 8, 9	6	8
7	7	3, 4, 5, 6, 7, 8, 9	7	7
8	8	8, 9	8	10
9	9	9	9	11
10	10	3, 4, 5, 6, 7, 8, 9, 10, 11	10	5
11	11	3, 4, 5, 6, 7, 8, 9, 11	11	6
12	12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	12	4
13	13	3, 4, 8, 9, 13	13	2
14	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16	14	2
15	15	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	15	1
16	16	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 16	16	3

#### 4.4. Conical Matrix, Digraph and Final ISM Model

The conical matrix is a horizontally and vertically sorted form of FRM as per the levels of variables. This matrix helps in developing the digraph. The digraph is a directed graph that shows the nodes with variable identifiers and edges as per the relationships between them. The digraph has many redundant transitive links that are removed as per the DMs' input from the ISM model. Furthermore, the ISM model is drawn by replacing the digraph oval nodes with rectangles and variable identifiers with names to improve readability. The ISM model is further analyzed for comprehensive validity by the DMs. Unsatisfactory models warrant re-evaluation of the SSIM and a rerun of the complete analysis. In this study, the whole analysis was revised twice and the final ISM model is shown in Figure 1.

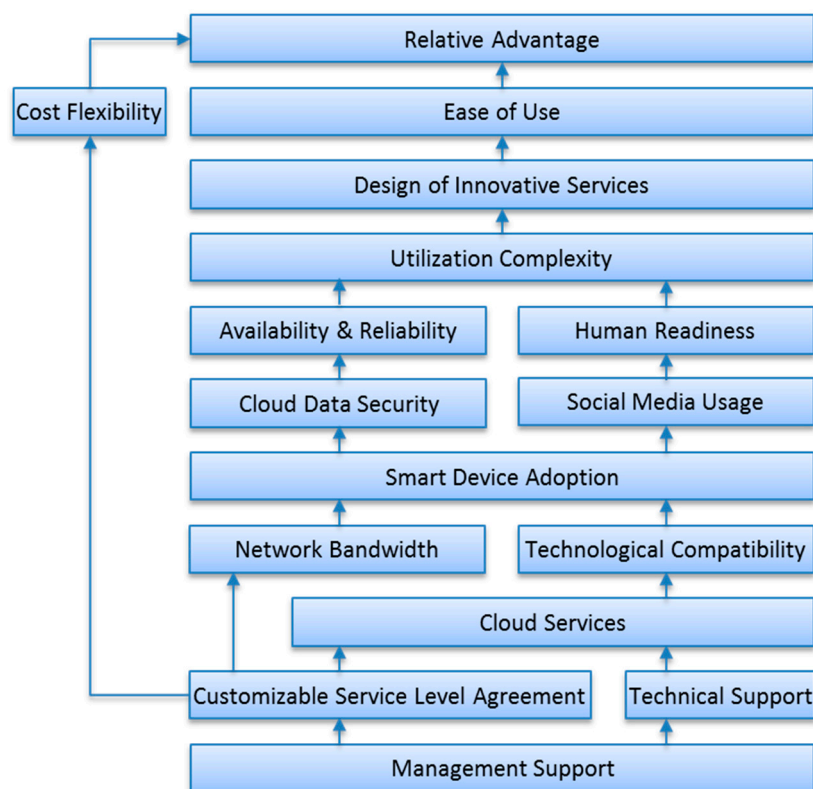


Figure 1. Cloud-based mobile learning adoption model.

#### 4.5. MICMAC Analysis

The MICMAC analysis, based on multiplication properties of matrices, categorizes the variables into four classes, namely autonomous, dependent, linkage and independent variables as per their driving and dependence powers [103]. The autonomous variables are weak variables and have low driving and dependence power, such as Cost Flexibility in this model (Figure 2). By contrast, linkage variables are unstable variables and have a high driving and dependence power, and there is no such variable in this model. All of the variables except Cost Flexibility have been categorized into the dependent or independent quadrants II and IV, respectively.

### 5. Discussion of Cloud-Based Mobile Learning Adoption Model

The resultant model has incorporated important constructs from organizational, technological and mobile learning contexts. The model includes technological and contextual dimensions of cloud-based mobile learning expansively and leads to the theoretical framework of diffusion of innovation [104]. Management support is the most important factor to achieve success in any innovative initiative in organizations. This CSF has been identified in many ICT-based adoption studies [105]. This study also identifies it to be at the root of the cloud-based mobile learning adoption model. The Management support directly or indirectly influences all the constructs. On the technological side, the management role is very essential in defining customizable SLA, a document with which to agree upon the cloud services, specifications, quality standards, data ownership, security, privacy and costs. Cloud service providers must provide customizable SLA to address the unique requirements of mobile learning. Similarly, the management role will be very helpful in establishing the optimum level of technical support.

The Cost flexibility factor can only be influenced by Customizable SLA and will influence the relative advantage perceived by the users. It is the only factor that has come out to be autonomous due to the lack of association with the rest of the variables. Nonetheless, the perceived cost has been identified

in many studies to negatively influence innovation adoption, such as in mobile banking [106] and smart watches [107]. Management support can mitigate the negative influence of cost by incorporating cost flexibility in mobile learning services. It may also decide to provide mobile devices, as happens in many institutions that provide laptops on the day of admissions, or tablet are provided during centralized exams.

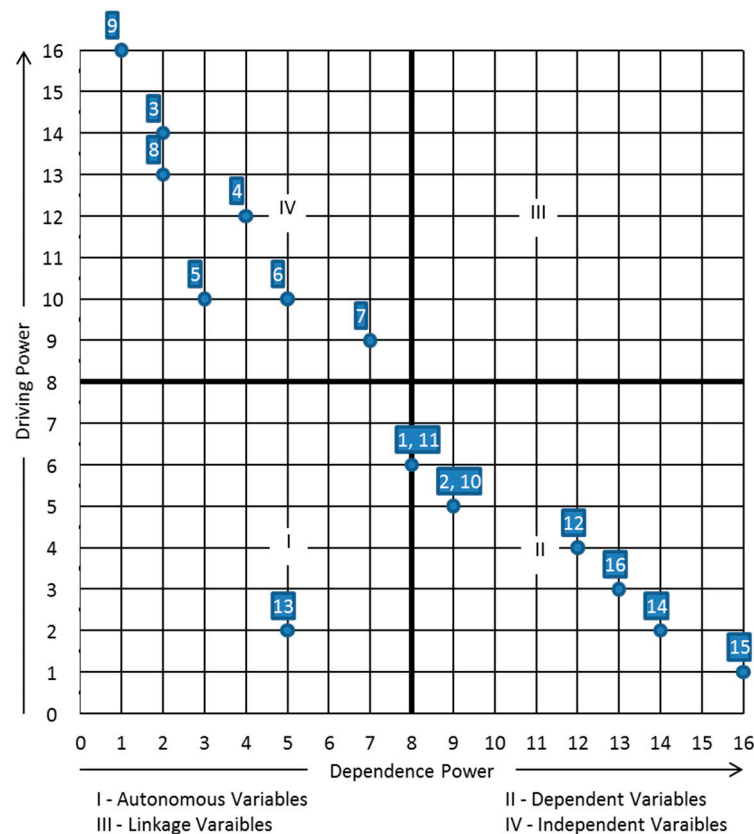


Figure 2. MICMAC diagram showing driving and dependence powers.

Cloud-based mobile learning services may be configured off-the-shelf in the SaaS Cloud Services mode, such as with moodelcloud. It may also be developed in the cloud using ICT software tools provided by the cloud in the PaaS mode. The third IaaS mode gives complete virtualized control over ICT resources. It allows to migrate the existing off-cloud mobile learning solutions to the cloud and provide support for mobile learning. The technological maturity requirement will increase from SaaS and PaaS to IaaS mode [35]. Moreover, the important cloud computing features such as cloud-native, microservices and multi-agent systems are best utilized in SaaS or PaaS mode [108]. Cloud computing also provides unlimited data storage capacity and inbuilt support for analytics, such as Big Data support. It also supports the vibrant ecosystem of services based on the latest technologies provided by different vendors.

Network Bandwidth is also very essential for having a responsive and engaging environment for mobile learning. It requires having management support to ensure high bandwidth and a multi-channel efficient network throughout. Customizable SLA will define the network bandwidth at the cloud. Cloud-based solutions enjoy inbuilt cross-platform compatibility that boosts the technological compatibility. Together, network bandwidth and technological compatibility will directly influence smart device adoption. Smart devices are a precondition for mobile learning. As of now, more than 50% of internet traffic originate from mobile devices (smartphones and tablets) [109], showing good adoption of these devices. Nonetheless, as mentioned earlier, management may facilitate these devices as well.

Social media usage has been a great boon to bridge the digital divide in many dimensions—age, gender, social strata and culture. Computer-mediated communities are formed around these social media websites. The motivations to join these communities are information exchange, friendship and social support among others [110]. Therefore, social media usage is going to influence positively towards human readiness to adopt mobile learning. Furthermore, the integration of social media features with mobile learning services will directly enhance the learning experience.

Cloud data security is also an important factor to develop trust or reliability in ICT-based solutions. The data must be secured at all stages including processing, transit and storage. The cloud-based mobile computing environment presents increased challenges for data security in all dimensions due to multi-tenant execution at the cloud, and the pervasiveness and heterogeneity of mobile devices. Moreover, it will influence the availability and reliability of mobile learning services. The availability is influenced due to certain restrictions placed by regulatory agencies in lieu of the security and privacy of data. Some countries, under the pretext of data sovereignty, enforce data localization policies and mandate citizens' specific data to reside inside the nation in order to safeguard citizens and national interests.

The human readiness and availability and reliability of ICT infrastructure and services will assist in easing the utilization complexity. Four factors identified in the present context—relative advantage, ease of use, technological compatibility and utilization complexity—can be traced back to the diffusion of innovation theory [104], which originated from sociology. Furthermore, these constructs were redefined for the individual acceptance of information technology innovation [111]. In this model, utilization complexity is oriented towards mobile learning system developers and instructors, meaning the degree of ease to utilize ICT infrastructure and services to design innovative mobile learning services.

Mobile learning emphasizes unified and pervasive learning from multiple contexts, people and contents through mobile devices. Therefore, all services and solutions must be designed on this basic premise of integrated mobile learning. Similarly, innovation is key to the success of mobile learning and all possible avenues must be explored for it. The possibilities would include solutions such as a magnet app that allows employees to reserve the company's office spaces based on relevant people's proximities on a specific project, so as to improve productivity and develop a professional network [112]. Such innovative and integrative services will bring in the utmost ease of use for the learners and hence boost the perception of the relative advantage of the mobile learning paradigm. The established relative advantage, "the degree to which an innovation is perceived as being better than its precursor" [111], of the mobile learning system will give great impetus to all stakeholders to adopt and use it.

## 6. Conclusions, Limitations and Future Research Directions

The mobile learning paradigm is a very promising technology-mediated learning environment. The pervasive adoption of mobile devices, social networking and increased digital literacy have made mobile learning a credible means to educate the growing world population. As mentioned in the literature review section, it is even being used successfully in teaching practice-oriented courses such as sports in a blended format. The adoption of cloud computing is essential to support the exponentially growing needs of ICT resources in order to make mobile learning sustainable. The literature shows that there is a lack of a holistic framework or model that can guide through the adoption of cloud-based mobile learning. This study identified sixteen CSFs in the area of cloud-based mobile learning and categorized them into four dimensions. Thereafter, with the help of three decision-makers the interrelationships between these CSFs were identified through pairwise comparison. Finally, the ISM and MICMAC techniques were applied to develop a hierarchical model and classification of CSFs into dependent and independent sets.

The resultant cloud-based mobile learning adoption model consists of constructs from cloud computing, organizational, technological and mobile learning domains. Similarly, constructs have been

traced to important theoretical frameworks, such as diffusion of innovation and technology acceptance. Management support has come out to be the most independent variable influencing all the constructs directly and indirectly. Alternatively, relative advantage is the most desirable outcome to be perceived by the community of learners to adopt mobile learning vis-à-vis other paradigms. Except for cost flexibility, all constructs have been identified as either independent or dependent. Cost flexibility has come out to be autonomous, meaning disconnected from the system of variables.

In an outcome-based educational environment, active learning, collaborative and cooperative learning have become paramount. Mobile learning can provide the best platform to realize collaborative and cooperative learning. The cloud-based mobile learning adoption model developed herein, with the help of the expertise of decision-makers, may have a bias. The model may further be improved for reliability through statistical validation using survey-based study and structural equation modeling (SEM). This model will help policymakers, practitioners and communities of learners to adopt mobile learning in sustainable ways and help in sustainable development.

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