



The Structural Modeling of Significant Factors for Sustainable Cloud Migration

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Abstract: Cloud computing is a matured platform to host the information and communication technology (ICT) infrastructure and services. All the top leading companies have made investments in cloud infrastructure including US Department of Defence's contract of USD 10 Billion to Microsoft for cloud migration. Cloud computing helps in conserving the resources and improving the performance of ICT services, hence making the computing more sustainable. Migration to cloud needs careful planning, strong business case, credible migration strategy and robust migration frameworks. This research has reviewed the area of cloud computing migration to identify important factors. The author keywords of 299 research articles downloaded from the web of science database have been analyzed using co-word analysis and resulted in 10 most significant factors in the form of cloud migration tuple. This study applies the interpretive structural modeling (ISM) technique to study the interrelationship on these factors. Application of ISM followed by Matrice d'Impacts Croise's Multiplication Appliquée a UN Classement (MICMAC) analysis has categorized these factors into independent and dependent sets. The resultant model demonstrates that organizations need to incorporate the dimensions of service orientation, virtualization, multi utilization, dynamic allocation and mobile support into their data, application and security stacks. Migration of these stacks with sound strategy, policy and frameworks will lead to post-migration performance improvements in a synergistic fashion. The adoption of cloud migration tuple with understanding of interrelationships will help organizations make strategies and plan to migrate to cloud in an efficient manner.

Keywords: Cloud computing migration, Cloud migration tuple, Interpretive structural modeling (ISM), Matrice d'impacts Croise's Multiplication Appliquée a UN Classement (MICMAC), Sustainable cloud adoption.

1. Introduction

Cloud computing "offers scalable or elastic computing on virtually complete range of computing devices, supporting all existing and archaic software technologies and tools, and served through disparate network hence making it platform independent, portable and ubiquitous" [1]. Public cloud service revenue is growing in the areas of cloud application services or Software as a Service (SaaS), cloud business process services (BPaaS), cloud system infrastructure services or Infrastructure as a Service (IaaS), cloud application infrastructure services or Platform as a Service (PaaS), cloud management and security services [2]. And, leading companies with their cloud services are Microsoft (SaaS, IaaS and PaaS), Amazon (IaaS and PaaS), IBM (SaaS, IaaS and

PaaS), Salesforce (SaaS, PaaS) and SAP (SaaS, IaaS and PaaS) [3].

Cloud computing is deployed through public, private, community and hybrid clouds, and offered in service delivery models such as IaaS, PaaS, SaaS etc. It utilizes virtualization to offer unified interface and services from the numerous hardware resources through virtual machine monitors (VMM) or hypervisors. The type-1 or bare metal hypervisors work directly on the hardware to manage virtual machines (VM) such as XEN, Microsoft Hyper-V, Oracle VM Server, VMware ESX and ESXi. And type-2 or hosted hypervisors that run on top of an operating system such as Redhat KVM and VMware Workstation [4]. Whereas, cloud services are offered through web services designed on web services description language (WSDL) and simple object access protocol (SOAP) and universal description,

discovery, and integration (UDDI) industry standards [5]. And inside the cloud, they are managed and orchestrated through service-oriented architecture (SOA).

Similarly, containers virtualization technology is being used by large cloud providers such Google, IBM/Softlayer and Joyent [6]. Mostly containers utilize Linux kernel containment features, LXC. Containers share same host operating system (OS) therefore are lighter and hundreds of them can be run on single hardware machine. Whereas, on top of hypervisors, each VM can have its different OS. Containers provide the view of underlying OS to developers unlike VMs that have complete implementation of OS. Dockers help in the deploying Linux application inside containers. And Google's Kubernetes manages the cluster of docker containers.

Cloud computing also provides a new approach to application development and deployment known as cloud native. Cloud native approach among others ensures the stateless computing so that elasticity of cloud can be achieved in real-time and hence user traffic can be dynamically directed to any server regardless of their state of sessions. Cloud-native application (CNA) "is a distributed, elastic and horizontal scalable system composed of (micro) services which isolates state in a minimum of stateful components. The application and each self-contained deployment unit of that application is designed according to cloud-focused design patterns and operated on a self-service elastic platform" [7].

The global cloud infrastructure causes latency and jitters and fog computing helps overcome it. Fog computing is defined as "an architecture that uses edge devices to carry out a substantial amount of computation, storage, communication locally and routed over the internet backbone" [8]. Fog computing is a standard that facilitates the edge computing and is highly desirable in the mobile computing and Internet of things (IoT) applications to overcome the problems of latency and jitter, context awareness and voluminous data.

Cloud computing helps in achieving the objectives of sustainable computing. Sustainability is a very holistic performance measure and defined as "development that meets the needs of the present without compromising the ability of future generations to meet their needs" [9]. Cloud computing allows for maximum resource utilization through virtualization and multitenancy. Still corporations see many challenges to migrate to the cloud due to issues related to security, data management, governmental regulations, cloud computing competency, migration strategy and recovery of ICT assets in times of disaster or switching the cloud service provider.

The adoption of cloud have been studied through antecedent approaches [10–12]. Also there exist studies that present cloud adoption toolkits that help in making decisions for cloud migration [13]. In the organizational context behavioural studies attempt to illustrate the process of cloud migration [14]. Similarly, migration theory has also been adopted to study the process of cloud migration [15]. There also exists cloud simulation tools such SimGrid (<https://simgrid.org>) that help in experimenting with cloud environment and adopted in some studies [16, 17].

The objective of this paper is to identify interrelationships between significant factors of cloud migration identified in cloud migration tuple [18]. The cloud migration tuple was arrived through literature review and author keyword analysis, utilizing the concept of co-word analysis as reported in [18]. This research applied interpretive structure modeling (ISM) technique to develop interrelationships between these factors with the help of experts. ISM is a computer assisted learning technique and is being applied in many IS and sustainability research [19, 20]. Also, MICMAC analysis has been carried out to get more understanding on the factors. Remaining of the paper is organized as research methodology, cloud migration tuple, article description, ISM and MICMAC analysis, discussions, and conclusion, limitation and future research.

2. Research methodology

The objective of this research is to develop the structural model of significant factors of cloud migration using state of the art literature and ISM. In order to collect the research articles in the area of cloud computing migration, Web of Science database was used. As this database contains the high-quality peer reviewed research papers. The query for the keyword "cloud computing migration framework" resulted in 299 research articles. Their details are given in the article description section.

Co-word analysis is a technique to analyze the significant words or keywords to study the conceptual structure of a research field [21]. In this research the authors' keywords of the 299 articles have been studied using concept of co-word analysis to identify the significant factors present in the context of cloud computing migration. Author keywords are extracted into the spreadsheet software and cluster of related terms are formed. Clusters having more than 10 items have been studied, defined and formed into a cloud migration tuple as illustrated in corresponding section.

ISM has been applied to develop model of interrelationships among elements of cloud migration

tuple. ISM is a computer assisted learning technique that uses Boolean matrix algebra and graph theory [22–26]. Certain number of decision makers (DMs) or domain experts compare pair-wise variables for one of the four possible relationships (such as for variables a and b) either a influences b, b influences a, a and b influence each other, or a and b don't influence each other. Based on the input of DMs further steps of ISM are carried out as explained in ISM application section. In the present study four DMs participated in the brainstorming session. They were all from academics having more than 10 years of experience, one associate professor, one PhD lecturer and two lecturers pursuing PhD.

ISM is generally coupled with MICMAC analysis. MICMAC analysis helps in classifying the variables into four categories autonomous, independent, linkage and dependent [27]. The analysis helps in setting prioritization for handling dependent variables as they will affect the independent variables.

3. Article description

The articles were between the time period of 2009 to 2018 as shown in Table 1. Maximum articles were published in the year of 2015. Table 2 shows the publishing sources having frequency count 5 or more.

Table 1. Year-wise Publication Frequency










Publication years	Article count	Bar chart
2018	37	
2017	46	
2016	55	
2015	60	
2014	34	
2013	29	
2012	24	
2011	12	
2009	2	

Table 2. High Frequency Publication Sources

Source of publication	Count
Lecture Notes in Computer Science	9
IEEE International Conf. on Cloud Computing	7
Future Generation Computer Systems	6
Journal of Network and Computer Applications	6
Communications in Computer and Information Science	5
IEEE Access	5
International Conf. on Cloud Computing Technology and Science	5
Journal of Supercomputing	5

4. Cloud Migration Tuple

Cloud migration tuple was identified through co-word analysis and clustering of author keywords present in 299 articles in the area of cloud migration [18]. There were total of 1263 keywords and 768 unique keywords. Clusters having 10 or more related terms were considered to derive most important dimensions. Ten such clusters were identified. The identified clusters of related terms are as follows virtualization, service orientation, data, multi utilization, dynamic allocation, mobile support, performance, security, application and migration [18]. These terms are explained in the context of cloud computing in the following paragraphs.

Virtualization: this term is very integral of cloud computing as the whole technology works on virtualization of resources. Similarly, the virtual machine (VM) related concepts and processes have also appeared in this cluster such as VM consolidation, migration, live migration, placement, provisioning, storage migration, scheduling and security [28–32]. Moreover, virtual network [33, 34] and virtual data center [35] also happen to fall under this cluster.

Service Orientation: it is also a unique characteristics of cloud computing as it is delivered as a service. Some important terms related are service orientation, availability, innovation, migration, portability and replication [36–38]. Service oriented architecture deserves a mention here as well. And service level agreements (SLA) are also one the most researched topic in this cluster and some related terms are SLA assurance and monitoring [37, 39].

Data: data is primary resource of information technology. Many important terms are mentioned with data such as locality, distribution, portability, migration, security, mining and deduplication [32, 40–42]. Data centers (DC) are the basic infrastructural component of cloud computing that contain data. Therefore DC networking and management also deserves mention here as well [43].

Multi Utilization: multi term has many-faceted implication in cloud computing. Most common of all is multi-tenant environment. Multi-Agent system (system of multiple interacting intelligent system) [44] has also become significant in the context of cloud computing. Similarly some underlying concepts that help in multi-utilization are replication and redundancy such as multicast [43], multi-cloud [45] and multi-gateway [46] system.

Dynamic Allocation: dynamic term is associated with real-time changes and requires application of advanced algorithms. For instance, to ensure elasticity, dynamic resource allocation capability of cloud native applications is important. Similarly, dynamism is desired for load balancing [47], consolidation [30], priority, resource migration and

scheduling [48]. This construct is also important for dynamic migration and consolidation of VMs, and dynamic structures [49].

Mobile Support: mobile support is provided by all the cloud service providers given the pervasiveness of smart phones and devices [50]. Within this concept mobile [50] and edge computing [51] become essential to solve the problems of jitter and latency. Additionally, the term mobile is used in conjunction with network [52], platform [53] and services [54].

Performance: this is the most important criterion for the success of cloud computing migration. This term has both, pre-migration importance such as performance matrix [55], modelling [56], prediction [57] and testing [58]. Similarly, in the post migration stage performance attributes [47], analysis [59], evaluation and management [60] is of great significance to assess migration success.

Security: security and privacy has been the most debated and stumbling block for migration to the cloud. Security is important in all the aspects such as migration, services and data. Security needs careful planning. Security requirements [61], metrics and measurements [62] should be well defined. This term is also used in combination with compliance [62] and transparency [63]. Security also needs to be maintained during live migration of VMs [64, 65].

Application: in the traditional sense software were said to be applications rather than services, and older applications are today termed as legacy applications. Application migration and offloading [50, 66] are important concepts in the cloud computing context. And for application or code offloading frameworks such as AppSpecCloudlet [67] for specific cloudlet selection are included in this cluster. Similarly, post-migration concepts of application adaptation and optimization are of great importance [68]. Some other important terms are application replication and application-aware allocation.

Migration: migration refers to moving organizations ICT infrastructure to the cloud infrastructure. Migration may follow on of the approach namely rehost, re-platform, re-factor or rebuild [69, 70]. Similarly, migration policy, methodology and framework need to be developed well in advance before migration process execution. Migration patterns [71] also assist in managing the migration.

There are some variables that are very innate of cloud computing environment such as virtualization, multi utilization and dynamic allocation. Whereas, cloud is service based architecture and encourages applications to migrate onto the service oriented or microservices architectures to achieve maximum performance [72]. Integration of mobile support is

easier in cloud infrastructure than in the traditional IT infrastructure by virtue of mobile cloud computing. Whereas, Data and security issues exists both in traditional and cloud computing infrastructure. Data and applications are supposed to be migrated to the cloud infrastructure in anticipation of performance enhancements. Therefore, set of variables logically represent all the important aspects of cloud computing migration.

5. ISM and MICMAC analysis

Interpretive structural modeling is a computer assisted learning tool. The first step is to identify the factors in the domain of study and carried out through literature review and co-word analysis on the author keywords as explained in the previous section. In the second step, a brainstorming session is conducted with the help of four domain experts for the pair-wise comparison of variables to establish contextual relationships. One of the four symbols V, A, X and O were placed in the structural self-interaction matrix (SSIM) for two variables a and b indicating one of the four relations, a influences b, b influences a, a and b influence each other, or a and b don't influence each other respectively Table 3. For example, as per experts' verdict virtualization will influence migration, application, security, performance, mobile support and data; will mutually influence dynamic allocation and multi utilization; and will be influenced by service orientation. Accordingly, V, X, and A symbols have been entered in the first row of Table 3. Likewise, for all constructs, symbols have been entered as per experts' opinions. SSIM servers the basic input for other steps of ISM such as reachability matrix, final reachability matrix incorporating transitivity, level partitioning, conical matrix, diagraph and final model. For developing reachability matrix, V, A, X and O symbols are replaced with binary digits 0 or 1 based upon following rules.

Let m_{ij} be the element of SSIM and r_{ij} be the element of reachability matrix where i and j represent row and column index.

if $m_{ij} = V$ then $r_{ij} = 1$ & $r_{ji} = 0$

if $m_{ij} = A$ then $r_{ij} = 0$ & $r_{ji} = 1$

if $m_{ij} = X$ then $r_{ij} = 1$ & $r_{ji} = 1$

if $m_{ij} = O$ then $r_{ij} = 0$ & $r_{ji} = 0$

Hence obtained reachability matrix is further checked for transitive reachability meaning if x leads to y and y leads to z then x will also lead to z. All the transitive relations are represented by 1* and the resultant matrix is called final reachability matrix Table 4. This table also shows the driving and

dependence powers by adding non-zero rows and columns respectively.

Following step estimates the ranks or levels of the variable through level partitioning. For each variable reachability and antecedent, and their intersection sets are calculated. Variables corresponding to non-zero row elements including variable gives the reachability set and similarly column for antecedent set. For any variable if intersection set matches with the reachability set then that variable is given top level or Level I and removed for the next iteration from all the sets. Iteration continues until all variables are assigned the levels. In this case, within four iteration all variables were assigned level from I to IV, Table 5.

In the next step, the conical matrix is formed after sorting the final reachability matrix based on the levels of variables row and column wise. Conical matrix helps in making diagraph that is drawn by representing nodes corresponding to variables and directed edges based on non-zero cells in conical matrix. Finally, the diagraph is converted into final model by removing unnecessary transitive links and

replacing node ids with corresponding variable details Fig. 2.

Matriced’ Impacts Croise’s Multiplication Appliquée a UN Classement (MICMAC) analysis helps in categorizing variables into autonomous, dependent, linkage and independent classes. Based on the dependence and driving power (Table 4), all variables are mapped onto two by two matrix Fig. 2.

Table 3. Matrix Indicating Structural Self-Interaction

No	Elements	10	9	8	7	6	5	4	3	2
1	Virtualization	V	V	V	V	V	X	X	V	A
2	Service Orientation	V	O	V	V	V	V	V	V	
3	Data	V	V	A	V	A	O	A		
4	Multi Utilization	V	O	V	V	V	A			
5	Dynamic Allocation	V	O	O	V	V				
6	Mobile Support	V	V	V	V					
7	Performance	A	V	A						
8	Security	A	A							
9	Application	A								
10	Migration									

Table 4. Final reachability matrix

S. No.	Elements	1	2	3	4	5	6	7	8	9	10	Driving Power
1	Virtualization	1	0	1	1	1	1	1	1	1	1	9
2	Service Orientation	1	1	1	1	1	1	1	1	1*	1	10
3	Data	0	0	1	0	0	0	1	1*	1	1	5
4	Multi Utilization	1	0	1	1	1*	1	1	1	1*	1	9
5	Dynamic Allocation	1	0	1*	1	1	1	1	1*	1*	1	9
6	Mobile Support	0	0	1	0	0	1	1	1	1	1	6
7	Performance	0	0	1*	0	0	0	1	1*	1	1*	5
8	Security	0	0	1	0	0	0	1	1	1*	1*	5
9	Application	0	0	1*	0	0	0	1*	1	1	1*	5
10	Migration	0	0	1*	0	0	0	1	1	1	1	5
	Dependence	4	1	10	4	4	5	10	10	10	10	

Table 5. Variables’ levels through iteration I – IV

Elements (Mi)	Reachability R(Mi) set	Antecedent set A(Ni)	Intersection set, R(Mi)∩A(Ni)	Level
1	1, 4, 5,	1, 2, 4, 5,	1, 4, 5,	III
2	2,	2,	2,	IV
3	3, 7, 8, 9, 10,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10,	3, 7, 8, 9, 10,	I
4	1, 4, 5,	1, 2, 4, 5,	1, 4, 5,	III
5	1, 4, 5,	1, 2, 4, 5,	1, 4, 5,	III
6	6,	1, 2, 4, 5, 6,	6,	II
7	3, 7, 8, 9, 10,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10,	3, 7, 8, 9, 10,	I
8	3, 7, 8, 9, 10,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10,	3, 7, 8, 9, 10,	I
9	3, 7, 8, 9, 10,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10,	3, 7, 8, 9, 10,	I
10	3, 7, 8, 9, 10,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10,	3, 7, 8, 9, 10,	I

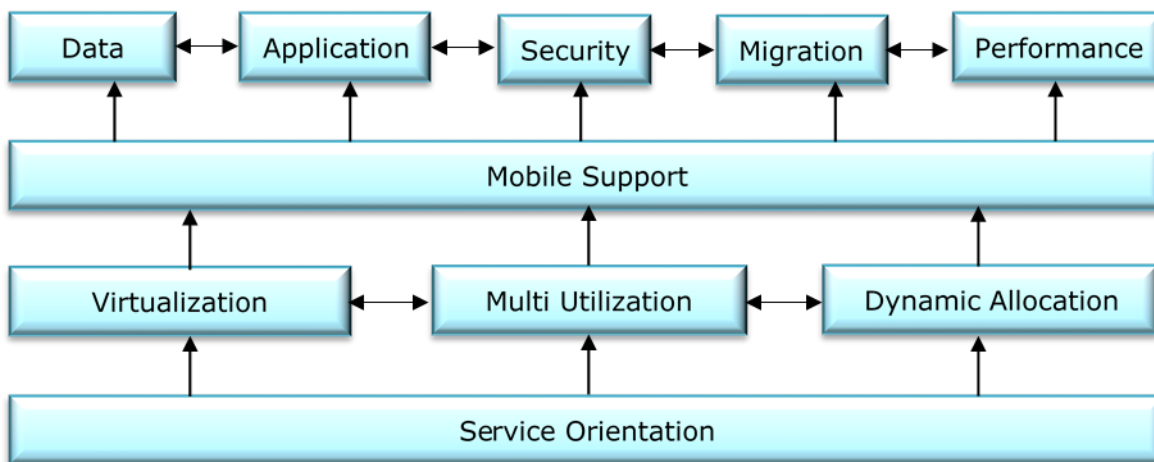


Figure. 1 ISM based model for cloud computing migration

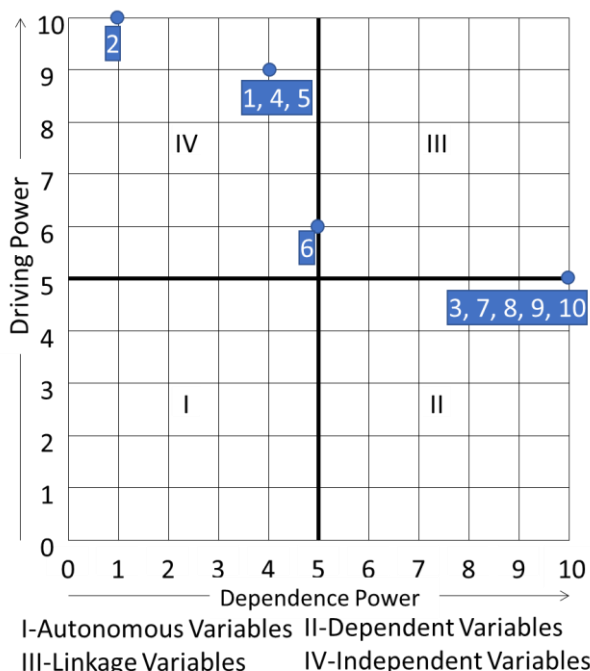


Figure. 2 Driving power and dependence diagram

6. Discussion

Cloud migration is on the top of agenda for most of the corporations. Cloud computing brings in sustainability in the IT services and operations, due to optimal utilization of resources. Organizations needs to be aware of the technological evolution behind cloud computing so as to make informed decision to adopt it. Cloud computing trends section illustrates upon the hypervisor, container, cloud-native and fog computing.

Traditionally cloud offered compute and storage services through virtualization without any care for bandwidth. To solve this issue, the concept of virtual network and data centres is gaining momentum. Recent research is focusing more onto developing

algorithms and mechanisms to migrate VMs into different data centres for energy and bandwidth optimizations. Another emerging research area is application offloading, essential in the context of mobile cloud computing. Similarly, frameworks such as organizational sustainability modelling are useful tools for organizations to assess their investments in the cloud.

There exist numerous frameworks and tools to assist in cloud migration. This research provides ten most significant dimensions that need careful consideration for successful cloud computing adoption. These dimensions are service orientation, virtualization, multi utilization, dynamic allocation, mobile support, data, application, security, migration and performance. The list is in order of independent to dependent variables as per the outcome of ISM and MICMAC analysis.

ISM model and MICMAC analysis gives the interaction among identified factors in the context of cloud computing migration. Service orientation is the core of cloud computing in design, delivery and development. Therefore, organizations can't ignore migration of their IT artefacts into service model to utilize maximum benefit in the journey to cloud. For instance, legacy application migrated onto IaaS mode will sit on top of cloud rather being imbibed into the cloud infrastructure. Secondly the innate nature of the cloud is virtualization, multi-utilization and dynamic allocation of resources. These three dimensions influence each other in a synergistic fashion. And these primitive features of cloud also greatly influence cost, energy and security measures.

Mobile support has been achieved at a very mature level through mobile cloud computing. Organizations must have clear strategies to harness mobile cloud computing to extend IT services to the mobile devices. Post-migration performance will be greatly affected

by incorporating mobile cloud computing. MICMAC analysis puts all these five factors as independent variables for the successful cloud migration.

Rest of the five factors, data, application, security, migration and performance are classified as dependent factors in the same level and influencing each other. Data, application and security stacks are migrated onto the cloud through different migration policies, strategies and frameworks. Such as lift and shift migration strategy (infrastructure as a service) will have implications on performance outcomes. Similarly, performance will impact the migration of data and application to the cloud. Security requirements will also dictate data and application, migration and performance. Therefore, these five dimensions needs to be managed in coordinated style.

7. Conclusion, limitations and future research

Cloud computing has become a norm of the day and all the leading organization commercial or government of different size and domain are adopting it, recent being the US Defence. Cloud computing technology is maturing day by day with hypervisors, containers, cloud native applications, fog computing, edge computing and cloudlets to become a robust platform to host complete range of information technology services. Cloud computing in the current state of the art is moving towards virtual network and data centres to solve bandwidth issues. Similarly, application offloading algorithms and frameworks have become recent research topics to support mobile cloud computing.

In this study, with the help of expert opinion and application of ISM and MICMAC analysis the constructs of cloud migration tuple are interrelated and grouped into independent and dependent categories. The independent variables are service orientation, virtualization, multi utilization, dynamic allocation and mobile support. Whereas, the dependent variables are data, application, security, migration and performance.

The results of this study illustrate that organizations need to incorporate the dimensions of service orientation, virtualization, multi utilization, dynamic allocation and mobile support into their data, application and security stacks. Migration of these stacks with sound strategy, policy and frameworks will lead to post-migration performance improvements in a synergistic fashion. Though a comprehensive, Web of science database was considered, in future more databases may be considered. In order to identify most significant factors only bigger clusters have been explained

whereas, smaller cluster may shed lights to more niche areas. The model arrived may also be tested using some cloud simulation tools such as SimGrid.

Conflicts of Interest

The authors declare no conflict of interest.

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