FRAMEWORK FOR EVALUATING AND SELECTING MOBILE-LEARNING APPLICATIONS USING MULTI CRITERIA DECISION MAKING TECHNIQUES

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Abstrak

Penggunaan aplikasi pembelajaran mudah alih (m-pembelajaran) meningkat secara mendadak dalam beberapa tahun kebelakangan. Aplikasi m- pembelajaran dipasang oleh pengguna melalui pelbagai platform mudah alih. Agar khalayak ramai dapat menerimanya, aplikasi ini mestilah stabil dan berkualiti tinggi. Keputusan untuk membeli aplikasi m-pembelajaran memerlukan garis panduan yang sistematik supaya pilihan yang sesuai dapat dipilih untuk memberikan penyelesaian yang efektif dan berkesan kepada organisasi pendidikan. Kebolehgunaan dalam aplikasi m- pembelajaran telah dilihat sebagai isu bukan-berfungsi (non-functional) dalam beberapa kajian sebelum ini. Pada hakikatnya, institusi pengajian tinggi Saudi masih kekurangan kerangka kerja yang sistematik, cekap, dan jelas untuk menilai dan memilih aplikasi m-pembelajaran kerana kurangnya kaedah pemilihan aplikasi m-pembelajaran yang boleh dipercayai. Oleh itu, kajian ini mengatasi jurang ini dengan mencadangkan kerangka kerja untuk menyokong dan meningkatkan proses penilaian dan pemilihan aplikasi m-pembelajaran yang dinamakan sebagai Rangka Kerja Penilaian dan Pemilihan Aplikasi Bergerak-Pembelajaran (MLA-ESF). MLA-ESF menyokong penilaian dan pemilihan aplikasi m-pembelajaran dan penyatuan keperluan berfungsi dan bukan-berfungsi serta menangani masalah ketidakserasian. Di samping itu, MLA-ESF dibangunkan untuk membantu dan membimbing pemaju dan organisasi pendidikan dalam memilih aplikasi m-pembelajaran yang diperlukan dengan lebih sistematik dan berulang. Tambahan lagi, kerangka MLA-ESF menyediakan garis panduan untuk penyelidikan masa hadapan, serta menjadi alat praktikal dan berguna dalam konteks sebenar. Kajian ini dilakukan dalam empat fasa utama: tinjauan dan wawancara pembuat keputusan dan pengguna untuk mengenal pasti kriteria penilaian, pembangunan kerangka berdasarkan Teori Penilaian, pembangunan teknik membuat keputusan baru dengan mengintegrasikan Proses Hierarki Analitik Fuzzy (FAHP), Teknik Urutan Keutamaan berdasarkan Kesamaan dengan Penyelesaian Ideal (TOPSIS), dan Analisis GAP (GA) untuk menangani ketidakserasian keperluan pengguna, dan pengesahan keberlakuan dan kebolehpercayaan MLA-ESF menggunakan tinjauan pakar, kajian kes dan pengesahan tolak. Kajian menunjukkan bahawa aspek yang dinilai dari MLA-ESF iaitu, input, tindakan, hasil, dapat dilaksanakan dan menunjukkan potensi dan kebolehgunaannya untuk diterapkan dalam konteks sebenar kerana 75% pakar menganggapnya berguna, 66.7% merasa senang untuk dilaksanakan, dan 75% mendapati tekniknya mencukupi dan melengkapi.

Kata kunci: Aplikasi Mudah-pembelajaran, Kebolehgunaan, Teori penilaian, Bukan-berfungsi.

Abstract

The use of mobile learning (m-learning) applications in education has increased dramatically in recent years. M-learning applications are installed by users through a variety of mobile device distribution platforms. For a wide audience to accept them, these applications must be stable and of high quality. The decision to purchase m-learning applications needs systematic guidelines so that the appropriate one can be selected to provide a viable and effective solution to educational organizations. Usability in m-learning applications has been studied as a non-functional problem in several previous studies. In reality, Saudi tertiary institutions still lack a systematic, efficient, and well-defined framework for evaluating and selecting m-learning applications due to the lack of reliable m-learning application selection methods. Therefore, this study addresses this gap by proposing a framework to support and improve m-learning applications evaluation and selection process named as Mobile-Learning Application Evaluation and Selection Framework (MLA-ESF). MLA-ESF supports evaluation and selection of m-learning applications and integration of functional and non-functional requirements as well as addresses mismatch problems. In addition, the MLA-ESF is developed to assist and guide developers and educational organizations in selecting the required m-learning application in a more systematic and repeatable manner. Moreover, the MLA-ESF framework provides a guideline for future theoretical research, as well as being a practical and usable tool in real contexts. The study is conducted in four main phases: a survey and interview of decision-makers and users to identify the evaluation criteria, development of the framework based on the Evaluation Theory, development of a new decision-making technique by integrating Fuzzy Analytical Hierarchy Process (FAHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and GAP Analysis (GA) to handle user requirements mismatches, and validation of the applicability and reliability of MLA-ESF using experts review, case study and yardstick validation. The study shows that the evaluated aspects of MLA-ESF namely, inputs, actions, outcomes, are feasible and demonstrate their potential and applicability to be applied in the real environment as 75% of the experts found it as useful, 66.7% find it easy to implement, and 75% find the techniques are adequate and sufficient.

Keywords: Mobile-learning applications, Usability, Evaluation Theory, Non-functional requirements.

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List of Abbreviations

MLA	M-learning Application
STACE	Social-Technical Approach to commercial off the shelf Evaluation
DC	Developing Country
CR	Consistency Ratio
COTS	Commercial-Off-The-Shelf
MBS	M-learning -Based Systems
OTSO	Off-The-Shelf Option
PORE	Procurement-Oriented Requirements Engineering
MEC	M-learning Application Evaluation Criteria
JAD	Joint Application design
WSM	Weighting Scoring Method
AHP	Analytical Hierarchy Process
FAHP	Fuzzy Analytical Hierarchy Process
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
CEP	Comparative Evaluation Process
CF	Confidence Factor
CI	Consistency Index
RI	Random Index
ISO	International Organization for Standardization
MCDM	Multi-Criteria Decision Making
CI	Consistency Index
RI	Random Index
ISO	International Organization for Standardization
MCDM	Multi-Criteria Decision Making
API	Application Programming Interface
NFR	Non-Functional Requirements
IRC	Identifying mismatches Resolution Constraints
CRC	Considered Resolution Constraint
ISO/IEC	International Organization for Standardization and International Electro Technical Commission
SPSS	Software Package for Social Sciences
JAD	Joint Application Design

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Since mobile technology has developed significantly, most students now have their own smart phones. These machines have a potential benefit in the use of education technology because they are smaller than laptops and desktops (Traxler, 2010).

Wang et al. (Han, 2011) reported that cell phones used to give university students on-line courses. However, (Prensky, 2010) questioned why these devices should be used in education and stressed that students should read.

New opportunities have arisen with the introduction of technology in educational standards; for instance, with the rise of the internet, the ability to access and manage the knowledge base, that comprises online classes, and learning tools, has changed greatly.

A dynamic approach to learning, called electronic learning (e-learning), which could be individual or collective, has been launched(Honeyman, 1993; Parsons & Ryu, 2006)

The cooperation approach encourages people to communicate and exchange learning documents; e-learning, for example, enables students to interact within the framework of e-learning platforms with staff, practitioners and experts (Di Cerbo, Dodero, & Papaleo, 2010). In addition, e-learning allows people to choose activities and material according to their background.

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APPENDIX A

Related Work For Questionnaire Development

Section I: Demographic Data				
Variables	Sources	#	Items	Sources
Respondents details	Kunda, 2002 Gerea, 2006 Yahaya, 2006	1	Main job function	Yahaya, 2006 Kunda, 2002 Gerea, 2006
		2	Respondents' experience	Yahaya, 2006 Kunda, 2002
		3	Respondent's role or activity in system development	Kunda, 2002
Organization details	Kunda, 2002, Gerea, 2006 Yahaya, 2006	4	Organization's business	Yahaya, 2006 Kunda, 2002 Gerea, 2006
		5	The number of employees	Yahaya, 2006 Kunda, 2002 Gerea, 2006
		6	The experience with building systems from COTS software	Kunda, 2002
Section II: Overview of Development Process				
Variables	Sources	#	Items	Sources
General Information About MLA	Kunda, 2002 Gerea, 2006	7	The number of COTS software products	Kunda, 2002, Gerea, 2006
		8	The kind of used COTS software	Kunda, 2002 Gerea, 2006
Process For Building Systems Using MLA	Kunda, 2002	9	The current approaches	Kunda, 2002
MLA Benefits and Risks	Kunda, 2002	10	Benefits	Kunda, 2002
		11	Risks	Kunda, 2002
Section III: MLA Evaluation and Selection				
Variables	Sources	#	Items	Sources
Overview of Evaluation and Selection Process	Kunda, 2002	12	The major problems	Kunda, 2002
		13	The current selection method	Kunda, 2002
		14	The ad-hoc manner	Kunda, 2002

		15	Using tools support	Kunda, 2002
		16	The main processes/activities of the evaluation and selection COTS software	Kunda, 2002
Defining The Evaluation Criteria	Kunda, 2002	17	The techniques for specifying the requirements	Kunda, 2002
MLA Alternatives Searching		18	Searching techniques	Kunda, 2002
MLA Alternatives Evaluation		19	Data collection techniques	Kunda, 2002
		20	Synthesis or analysis technique	Kunda, 2002
MLA Selection	Kunda, 2002 Yahaya, 2006	21	The COTS mismatches consideration	Kunda, 2002 Yahaya, 2006
		22	The importance of the COTS mismatches	Kunda, 2002 Yahaya, 2006
		23	COTS mismatches techniques	Kunda, 2002 Yahaya, 2006

Section IV: Overview of Criteria For Evaluation and Selection MLA				
Variables	Sources	#	Items	Sources
General Information	Yahaya, 2006 Kunda, 2002	24	Considering the non-functional aspects for COTS software	Yahaya, 2006
		25	The important of the non-functional aspects	Yahaya, 2006 Kunda, 2002
Quality	Yahaya, 2006 Kunda, 2002	26	Quality aspects	Yahaya, 2006 Kunda, 2002
Domain		27	Domain aspects	Yahaya, 2006 Kunda, 2002
Architectural		28	Architecture aspects	Yahaya, 2006 Kunda, 2002
User Organization		29	User organization aspects	Yahaya, 2006 Kunda, 2002
Vendor Organization		30	Vendor organization aspects	Yahaya, 2006 Kunda, 2002

APPENDIX B

The Questionnaire

EVALUATING AND SELECTING M-LEARNING APPLICATIONS QUESTIONNAIRE:

The purposes of these questionnaires are:
1. To investigate current practices of M-learning applications evaluation and selection processes, evaluation criteria, and other relevance issues.
2. To determine the importance of the theoretical processes, evaluation criteria, and other issues in the M- learning domain.
3-it consist of 5 sctions with 22 questions (approx 5 minutes to complete).

* Required

General Informations

1. Please check the category that best describes your main job function in your institute. *

- ◯ 1-Management
- ◯ 2-Academic or Researcher
- ◯ 3-Application or systems programming
- ◯ 4-Operations
- ◯ Other:

2-Please Select your Orgnization Name *

Choose

ocs.google.com/forms/d/e/1FAIpQLSefjMYq4fL1fTpA5dfOMEjtcJofhhaLosNlilOdwelmCCRZew/viewform

3. How long have you experienced dealing with M-learning applications: *

- ○ 1-Less than 3 years
- ○ 2-3 to 10 years
- ○ 3-11 to 20 years
- ○ Other:

4. On what activities do you currently involved in? (Please check all that apply) *

- ☐ 1-Requirements engineering
- ☐ 2-M-learning applications Selection
- ☐ 3-Evaluation criteria definition
- ☐ 4-M-learning applications purchasing
- ☐ Other:

Next

EVALUATING AND SELECTING M-LEARNING APPLICATIONS QUESTIONNAIRE:

* Required

OVERVIEW OF M-LEARNING APPLICATIONS DEVELOPMENT PROCESS

5. Please indicate the number of M-learning applications you are using in your institute *

- ○ 1.0-5
- ○ 2.6-10
- ○ Other:

6. Please check the box(s) that describe the approaches of using M-learning applications.(select ALL applicable) *

- ☐ 1-We purchase M-learning applications and use it without adapting or extending it.
- ☐ 2-We purchase M-learning applications and then adapt or extend it.

7. Indicate your strength of agreement for each statement that consider as the benefits of using M-learning applications.(Ranking:1= Not considered 2 = low 3 = Average 4 = High 5 = Very High Consideration) *

	1	2	3	4	5
1-Decrease in training costs	○	○	○	○	○
2-Reducing the time and effort for training	○	○	○	○	○
3-Continuous and situated learning support	○	○	○	○	○
4-Improving levels of literacy, participation in education.	○	○	○	○	○
5-Multimedia content delivery and creation options.	○	○	○	○	○

8. Indicate your strength of agreement for each statement below that consider the risks associated with using M-learning applications.(Ranking:1= Not considered 2 = low 3 = Average 4 = High 5 = Very High Consideration) *

	1	2	3	4	5
1-Incompatibility between M-learning applications and other components in the system.	○	○	○	○	○
2-periodic releases of M-learning applications.	○	○	○	○	○
3-Difficult to discover the actual technical Capabilities of M-learning applications.	○	○	○	○	○
4-Lack of support of M-learning applications provider	○	○	○	○	○
5-Difficult to select from vast array of M-learning applications.	○	○	○	○	○

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EVALUATING AND SELECTING M-LEARNING APPLICATIONS QUESTIONNAIRE:

* Required

M-LEARNING APPLICATIONS EVALUATION AND SELECTION.

OVERVIEW OF EVALUATION AND SELECTION PROCESS.

9. Please check the box(s) that describe the major problems that you face when evaluating and selecting M-learning applications. Select ALL applicable. *

- [ ] 1-No formal process for evaluating and selecting M-learning applications (ad-hoc manner)
- [ ] 2-Difficult to identify and resolve the mismatches between M-learning applications and organization requirements.
- [ ] 3-Lack of handling non-functional requirements (e.g. efficiency, reliability, vendor reputation, vendor stability)
- [ ] 4-Lack of learning from past evaluating and selecting experiences and knowledge collecting
- [ ] Other:

10. What is the method(s) or approach(s) that your organization is using through evaluation and selection M-learning applications? Select ALL applicable. *

- [ ] 1-Heuristic Evaluation
- [ ] 2-Cognitive walkthroughs
- [ ] 3-User Test
- [ ] 4-Off-the-shelf-option method (OTSO)
- [ ] 5-Plan, Establish, Collect, and Analyze (PECA)
- [ ] 6-Don't use any specific method (please specify by answering the next question (Q 18))
- [ ] Other:

11. If you don't use any specific method, what is the ad-hoc manner is using in your institute when selecting M-learning applications? Select ALL applicable. *

- [ ] 1-Selecting the M-learning applications based on the experiences of development team.
- [ ] 2-Selecting the M-learning applications based on the experiences of manager.
- [ ] 3-Selecting the M-learning applications based on the intuition.
- [ ] 4-Selecting the M-learning applications based on the relationship with particular supplier
- [ ] Other:

12. What are the main processes/activities of the evaluation and selection M-learning applications in your institute? Indicate your strength of agreement for each activity below.(Ranking:1= Not considered 2 = low 3 = Average 4 = High 5 = Very High Consideration) *

	1	2	3	4	5
a. Defining the evaluation criteria	○	○	○	○	○
b. M-learning application searching	○	○	○	○	○
c. M-learning application screening	○	○	○	○	○
d. M-learning application evaluation	○	○	○	○	○
e. M-learning application selecting	○	○	○	○	○
f. Documentation	○	○	○	○	○
g. Planning the evaluation (team forming, identifying stakeholders)	○	○	○	○	○

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EVALUATING AND SELECTING M-LEARNING APPLICATIONS QUESTIONNAIRE:

* Required

M-LEARNING APPLICATIONS ALTERNATIVES EVALUATION

13. Please indicate the data collection techniques and tools you use when estimating M-learning applications. *

- [ ] 1-Documents Analysis
- [ ] 2-Experimentation user group advice
- [ ] 3-M-learning applications demonstrations Attending
- [ ] 4-Questionnaires
- [ ] 5-Algorithms for benchmarks testing
- [ ] 6-checklists
- [ ] 7-templates

14. Please indicate the data analysis techniques you use to evaluate and select M-learning applications *

- [ ] 1-Attend demonstration by M-learning applications providers
- [ ] 2-Non-Functional Requirements (NFR) framework
- [ ] 3-Analytic Hierarchy Process (AHP)
- [ ] 4-Weighting Score Method (WSM)
- [ ] Other:

15. Do you consider the mismatches between M-learning applications features and requirements during the M-learning applications selection? *

- ○ 1-Yes
- ○ 2-No

16. How important will the mismatches between M-learning applications features and requirements during the selection M-learning applications? *

- ○ 1-Very important
- ○ 2-Somewhat important
- ○ 3-Unimportant
- ○ 4-Somewhat Unimportant
- ○ 5-Not sure

17. If you consider the mismatches between M-learning applications features and requirements, how do you identify and estimate the cost of those mismatches? (Please check ALL that apply) *

- ☐ 1-Using gap analysis technique
- ☐ 2-Using Fulfilment technique
- ☐ 3-Using the negotiations between user and vendor
- ☐ 4-Don't use any method or technique

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EVALUATING AND SELECTING M-LEARNING APPLICATIONS QUESTIONNAIRE:

* Required

OVERVIEW OF CRITERIA FOR EVALUATION AND SELECTION M-LEARNING APPLICATIONS

Non-functional aspects defined as a general set of attributes or requirements that used for describing the M-learning applications that classified into quality attributes, architecture attributes, domain attributes, organization attributes, and vendor attributes.

18. Do you consider the non-functional aspects of the M-learning applications prior to selection for purchase? *

- ○ 1-Yes
- ○ 2-No

19. How important will the non-functional aspects during the evaluation and selection M-learning applications? *

- ○ 1-Very important
- ○ 2-Somewhat important
- ○ 3-Somewhat Unimportant
- ○ 4-Unimportant
- ○ 5-Not sure

a.Quality Requirement

20.How do you rank the level of consideration of the quality factors that are commonly used for evaluating and selecting M-learning applications? (Ranking:1= Not considered 2 = low 3 = Average 4 = High 5 = Very High Consideration) *

	1	2	3	4	5
a.Efficiency	○	○	○	○	○
b.Usability	○	○	○	○	○
c. Expand-ability	○	○	○	○	○
d.Functionality	○	○	○	○	○
e.Intra-operatability	○	○	○	○	○
f.Maintainability	○	○	○	○	○
g.Reusability	○	○	○	○	○
j.Reliability	○	○	○	○	○
k.Safety	○	○	○	○	○
l.Verifiability	○	○	○	○	○

b.ARCHITECTURE REQUIREMENTS

Architecture Requirements are the set of attributes that describe the integration between components and their interactions and distinguish between independence and cooperation of these components.

21.How do you rank the level of consideration of the architecture requirements when evaluation and selection the M-learning applications? (Ranking:1= Not considered 2 = low 3 = Average 4 = High 5 = Very High Consideration) *

	1	2	3	4	5
a.integrity	○	○	○	○	○
b.Portability	○	○	○	○	○
c.Flexibility	○	○	○	○	○
d.Evolvability	○	○	○	○	○
e.Scalability	○	○	○	○	○
f.Interoperability	○	○	○	○	○
g.Composability	○	○	○	○	○

c.VENDOR REQUIREMENTS

Vendor Requirements are the set of requirements that are required by the users on the vendor organization.

22. How do you rank the level of consideration of the vendor requirements when evaluating and selecting the M-learning applications? Please tick at the appropriate box according to the ranking given below.(Ranking:1= Not considered 2 = low 3 = Average 4 = High 5 = Very High Consideration) *

	1	2	3	4	5
a. Vendor reputation	○	○	○	○	○
b. Vendor stability	○	○	○	○	○
c. Vendor support	○	○	○	○	○
d. Vendor experience	○	○	○	○	○
e. Vendor's popularity	○	○	○	○	○
f. Contract practice	○	○	○	○	○
g. Vendor certification	○	○	○	○	○
h. Vendor's Sustainability	○	○	○	○	○

Thank you for completing the questionnaire. Your assistance is much appreciated.

Back Submit

APPENDIX C

The Questionnaire of the Experts Review

Expert Questionnaire Related to the Framework for Mobile-Learning Application (MLA) Evaluation and Selection

This work is part of Ph.D research. It is designed to the professional developers and decision makers in the organizations to validate the applicability and suitability of the framework for MLA evaluation and selection.

The framework was developed to help the organizations in selecting the fitness MLA in systematic way. It provides new data synthesis technique based on addressing the mismatches between MLA features and user's requirements, and proposes set of evaluation criteria that called MLA Evaluation Criteria (CEC). So, we need your help to read the proposed framework description to fill out the following questionnaire.

This questionnaire consists of three parts:

- **Part One**: To verify the feasibility and applicability of the proposed framework's processes, activities, and techniques.
- **Part Two**: To verify the validity of the proposed data synthesis technique.
- **Part Three**: To verify the CEC in term of its comprehensive, understandability, correctness, and coherence.

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Part One

The Proposed Framework (Processes, activities, and techniques)

The proposed framework consists of related processes and activities that are performed in order to achieve the evaluation objectives.

Planning Process

Description

The framework is started by the planning process. It is an important process because the effort spent in the planning can save countless hours of confusion and rework in the subsequent processes.

Inputs	*Activities*	*Used Technique*	*Outputs*
➢ Evaluation target ➢ Stakeholders ➢ Project constrains (budget, time, etc)	1. Defining the evaluation target 2. Forming the evaluation team 3. Creating the Work Breakdown Structure (WBS)	Joint Application Design (JAD)	➢ Evaluation team ➢ WBS

Notes

- Defining the evaluation target plays an important role to identify the potential evaluators who can deal with the target MLA, as well as to help estimating the project constraints (e.g. budget and time).
- The evaluation team should have the management or leader, Expert in the domain, several technical people, and the end-user.
- The WBS is created by the evaluation team to define the scope, aims, and constraints of the evaluation project.
- ***The Joint Application Design (JAD)*** is a technique that allows the users group to work together to identify, develop, and manage the evaluation target and system requirements.

Preparation Process

Description

It is also known as the pre-evaluation process, which refers to the preparing and providing required information for carrying out further evaluation in the subsequent process. In this process, the functional requirements are gathered, the MLA alternatives are identified and the yardstick that represents the ideal and lowest values of the attributes in CEC are defined.

Inputs	*Activities*	*Used Technique*	*Outputs*
➢ Functional requirements sources (user requirements, system requirements, project constrains, etc).	1.Defining functional requirements	➢ JAD, Document review	➢ Functional requirements ➢ List of MLA alternatives

➢ MLA sources	2.Searching MLA alternatives	➢ Inventories search, market surveys, internet search	➢ Yardstick ideal & lowest values
➢ Yardstick	3. Defining the yardstick (ideal & lowest values) by evaluation team	➢ JAD	

Notes

- ❖ Defining the functional requirements aims to identify the functional requirements that will support the identification of the MLA alternatives during the search activity.
- ❖ The search criteria are included as the required main functionality of the MLA searching as well as some of the key constraints.
- ❖ Defining the yardstick is the activity of assigning the ideal and lowest value for each attributes in the proposed evaluation criteria (that discussed in the part 3). The ideal values defined by this activity play a vital role in identifying the MLA mismatches levels in order to calculate the final score for each MLA alternative while the lowest values are used to filter out the MLA alternatives that fail to achieve these values.

Evaluation & Selection Process

Description

It is performed to estimate the satisfaction between the MLAalternatives and the evaluation criteria. The process aims to collect, synthesize, and consulate the data in order to estimate each MLA alternatives and rank them based on their fitness scores.

Inputs	*Activities*		*Used Technique*	*Outputs*
➢ MLAlist. ➢ Yardstick values (ideal & lowest values). ➢ Proposed MLA Evaluation Criteria (CEC)	1. Data collection and filtering	*Level1*: MLA and user organization documents.	Document review & JAD	1. The fitness MLA software. 2. List of MLA alternatives ordered based on their fitness. 3. Feedback (MLA Information) for the adaptation and integration phases. 4. Feedback to vendors about the weakness of their products.
		Level2: experimental group of users	Evaluation form	
		Level3: vendor.		
		Level4: MLA demonstration.	MLA demonstration participation	
	2. Decision making		The proposed Data synthesis technique	

Notes

- **Data collection and filtering activity** aims to collect the data of the MLA Evaluation Criteria (CEC) that are related to the identified MLA alternatives and estimate them based on the thresholds values (lowest values), which are defined in the yardstick, in order to determine which of these MLA alternatives will be continued with more detailed evaluation and which of them will be eliminated.
- In this activity, the data collection is combined with the MLA alternatives filtering that aim to decrease the number of the identified MLA alternatives. Therefore, it is become more efficient in term of time and effort besides accelerating the evaluation process.
- The four levels of data collection and filtering have been determined based on the set of MLA data sources (MLA & user Organization Documents, Other experimental MLA users, Vendors, and MLA demonstration).
- **The decision making activity** aims to synthesize and consulate the data from the previous activity and aggregate the weights of the CEC to make the decision of selecting the appropriate MLA alternative.
- The data synthesis technique has important role in synthesizing the identified mismatches and mismatch's solution constraints (cost, effort, time, and risk) in order to compute and provide the accurate final score for the MLA alternative.

This part is established to verify the feasibility and the effectiveness of the proposed framework (processes, activities, and techniques) in the real environment. Therefore, could you please answer the following questions by selecting your answer from the following choices?

1. Yes without modifications
2. Yes with modifications (please write your suggestions)
3. No (please write your suggestions)

#	Question	Tick your Answer			Suggestions
		Yes without Mod.	Yes with Mod.	No	
1	Does the framework implementation (processes, activities, and techniques) is perceived usefulness?				
2	Do the processes and their activities clear and understandable?				
3	Do the processes and their activities cover all the required stages of the MLA evaluation and selection?				
4	Comparing with other methods of MLA selection, does the framework appropriate for task (the fitness MLA selection), cost-effectiveness, clear and illuminate the process?				
5	Regarding to the framework's presentation, does it readable and useful format, internal consistency, well organized, and appropriate for audience?				
6	Does the framework easy to implement?				
7	Does the framework allow users to participate?				
8	Does the integration of data collection and MLA alternatives filtering is correct and cost-effectiveness?				
9	Do the used techniques in each process are adequate and sufficient?				
10	In term of the framework's outputs, Do they provide the expected results (select the desired MLA) and completed information?				

Part Two

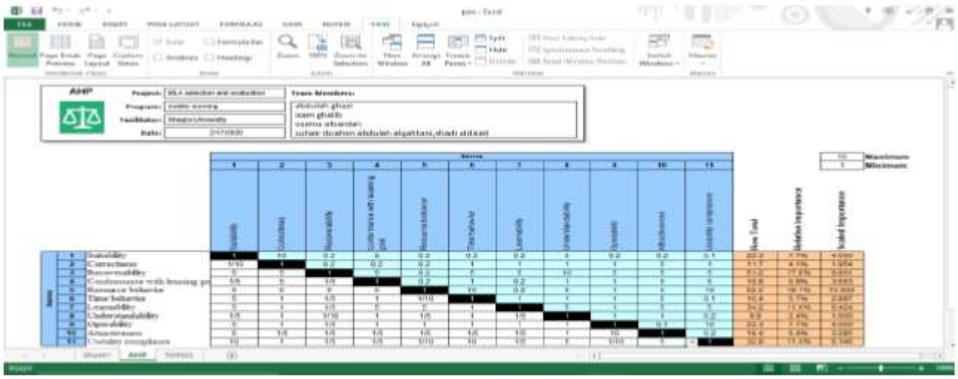
The Proposed Data Synthesis Technique

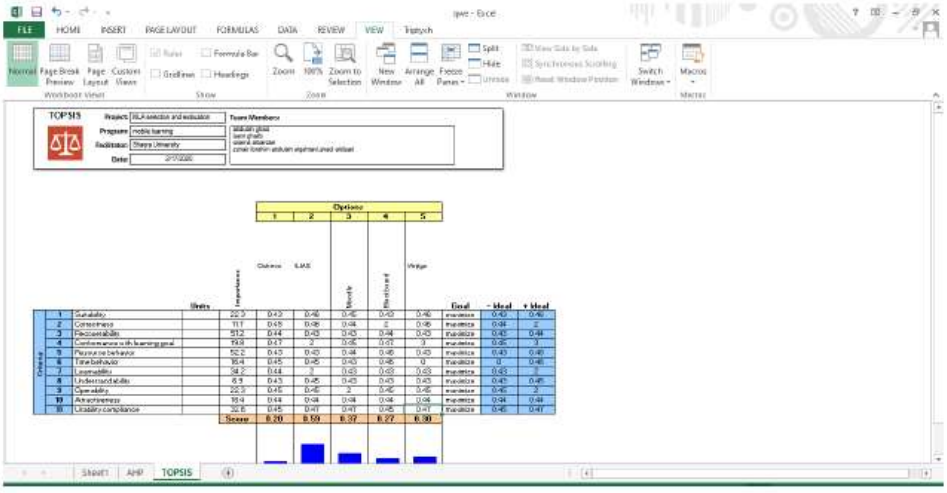
The synthesis techniques should be applied to synthesize all data and compare against the CEC in order to select the fittest MLA software. The main steps of the proposed technique are shown as following:

<table>
<tr><td>Inputs</td><td colspan="3">➢ The collected data from previous activity (data collection & filtering activity)
➢ MLA alternatives list (after filtering)
➢ Yardstick values (Ideal & lowest values)
➢ MLA Evaluation Criteria (CEC)</td></tr>
<tr><td rowspan="6">Steps</td><td>(1) Assigning the weights for CEC</td><td>1. Constructing the pairwise matrix
2. Perform the judgments of pairwise comparisons at each matrix
3. The pairwise comparison synthesis at each matrix
4. Performing the inconsistency test at each matrix</td><td>Relying on Analytic Hierarchy Process (AHP) method to assign the weights (Saaty, 1980)</td></tr>
<tr><td rowspan="5">(2) Scoring MLA alternatives</td><td>1. Measuring the Matching Level (ML) for MLA at each attribute in CEC</td><td>$ML_{(X_i, c_j)} = \begin{cases} 1 & X >= \text{ideal value in the yardstick} \\ aX+b & \text{lowest value} =< X < \text{ideal value} \\ 0 & X < \text{lowest value} \end{cases}$
Alves et al., 2005
where “a” and “b” represent the constants, which can be calculated as the following:
$a = 1/(I_{ci} - L_{ci})$, $b = -L_{ci} / (I_{ci} - L_{ci})$
where “I” is the ideal value of criterion (c_j), and “L” is the lowest value of criterion (c_j) defined in the yardstick. “X” is the MLA value at criterion (c_j).</td></tr>
<tr><td>2. Measuring the Mismatch Level (MML)</td><td>The used equation:
$MML_{(f_i, c_j)} = 1 - ML$</td></tr>
<tr><td>3. Measuring the Final Mismatching Level (FMML) for the MLA at each attribute in order to provide accurate selection decision in choosing the appropriate MLA.</td><td>The used equation:
$FMML_{(f_i, c_j)} = (MML_{(f_i, c_j)} * (c + t + e + r) / 4) / 5$
where,
FMML: the final mismatch level for the MLA feature (f_i) and the criterion (c_j)
MML: the mismatch level between the MLA feature (f_i) and the criterion (c_j)
“c”: the costs; “t”: the required time; “e”: the required efforts; and “r”: the level of potential risk of resolution action for solving the mismatch between the MLA feature (f_i) and the criterion (c_j).</td></tr>
<tr><td>4. Calculating the final matching level (FML) of the MLAat each criterion</td><td>The used equation:
$FML_{(f_i, c_j)} = 1 - FMML_{(f_i, c_j)}$</td></tr>
<tr><td>5. Calculating the Final Fitness Score (FFS) for each MLA alternative against the CEC.</td><td>$\text{Parent-Score} = \frac{\sum_{i=1}^{n} Wi * FMLi}{\sum_{i=1}^{n} Wi}$ where, “n” is the number of siblings that share the same parent; “W_i” is the weight of criterion (c_i); and “FML_i” is the final matching level at (c_i).
*It is applied starting from the low level in CEC and aggregating the weighted scores upwards until reaching the root to get FFS for each MLA alternative.</td></tr>
<tr><td colspan="2">The second step is repeated for all MLA alternatives in the list.</td></tr>
<tr><td>Outputs</td><td colspan="3">➢ The fitness MLA(the highest FFS value)
➢ List of MLA alternatives ordered based on their fitness against CEC.
➢ Feedback information such as mismatches information (MML, resolution action, cost, and time)</td></tr>
</table>

Note

The proposed data synthesis technique is applied throughout the development of the prototyping system tool. This tool is used to conduct all the required calculations and comparisons that are needed during the decision making technique which helps to save the efforts, time, and provide accurate results. See the following diagram for mapping between the software tool and the proposed framework. (there are some example about the screens in each stage).





This part is established to verify the validity of the proposed data synthesis technique. Therefore, could you please answer the following questions by choosing your answer from the following choices.

1. Yes without modifications
2. Yes with modifications (please write your suggestions)
3. No (please write your suggestions)

#	Question	Tick your Answer			Suggestions
		Yes without Mod.	Yes with Mod.	No	
1	Does the proposed data synthesis technique correct?				
2	Does the proposed data synthesis technique achieve the decision making satisfaction by provide accurate results (comparing with other techniques)?				
3	Does the proposed data synthesis technique complete?				
4	Does the structure of the proposed data synthesis technique consistent and well-organized?				
5	Since the proposed synthesis technique is supported by software tool to do all steps systematically, does it easy to implement?				
6	Do the used equations in the proposed data synthesis technique are valid and sufficient?				
7	Does using the MLA mismatch resolution action's cost, time, effort, and risk to calculate the final mismatching level (FMML) give accurate result for selecting the fitness MLA software?				

Part Three

MLA Evaluation Criteria (CEC)

The MLA Evaluation Criteria (CEC) is constructed based on the review results of the state-of-theory and state-of-practice of the MLA evaluation and selection. The CEC proposes new criteria related to vendor and user organization. Five categories are established to classify the evaluation criteria, which are: quality, domain, architectural, operational environment, and vendor categories.

The CEC basically consists of four elements: i) categories, ii) characteristics, iii) sub-characteristics, and v) attributes. The categories describe the related characteristics of particular part of the MLA evaluation, while the characteristic can be decomposed into several sub-characteristics. An attribute is a measurable property of an entity. To make the CEC more accurate and applicable, several kinds of metrics are used to measure the attributes such as integer, ratio, time, and level.

The hierarchy structure of the ISO 9126 model was used to decompose and present the evaluation criteria in a full hierarchy structure (characteristics, sub-characteristics, and attributes). The CEC consists of four levels criteria. The first level contains the five evaluation criteria categories (quality,

Categories	Characteristics	Sub-characteristics	Attributes
Quality	Functionality	Suitability	Coverage, Excess, Service implementation coverage
		Correctness	Precision, Computational Accuracy
	Reliability	Recoverability	Serializable, Persistence, Error handling, Transactional
		Fault tolerant mechanism	Failure avoidance, Breakdown avoidance, Incorrect operation avoidance, Incorrect operation mitigation
	Efficiency	Resource behavior	Memory utilization, Disk utilization
		Time behavior	Response time, Throughput, Capacity
	Maintainability	Changeability	Customizability, Customizability Ratio, Change Control Capability
		Ease of migration	Migration ease level
		Stability	Stability level
	Usability	Learnability	Time to use, Time to configure, Time to admin, Time to expertise
		Understandability	The quality of help system, Computer documentation, Existing Training course, Demonstration coverage, Quality of user document
		Operability	Provide interfaces, Required interfaces, Effort for operating, Tailorability, Administrability
	Testability	Test document	Test suit document, Proofs of previous tests
		Start-up self-test	Self-test, Environment test
		Traceability	Performance trace, Error trace
Domain	Security	Data protection	Data encryption, Preventing data corruption
		Controllability	Execution control, Environment control, Function features control
		Auditability	User access recording
	Maturity	Volatility	Versions times
		Evolvability	Versions numbers
		Failure removal	Bugs fixed
	Popularity	Number of users	Installations/setup, Upgrades
		Locatability	Accessibility
		Internet discussions	Views of information page
Architectural	Reusability	Generality	Domain abstraction, History of reuse
		Hardware/software independency	Hardware dependency, Software dependency
	Portability	Installability	Installation Document, Installation complexity
		Deployability	Deployment document, Deployment complexity
		Adaptability	Mobility
		Replaceability	Replacement ease level
	Interoperability	Compatibility	Data compatibility, Version compatibility
	Safety in Use	Risk of software	The risk level
	Operation support	Diagnostic information	Monitoring system (*activity &performance*)
		Troubleshooting	Snapshot system's state, Detailed operational and functional reports, Logging and auditing information

Operational Environment	System Platform	Hardware platform	Processing unit performance, Memory system Data transfer system
		Software platform	Current operating system, Current middleware (e.g. CORBA standard), Communication applications
	Software Development Environment	Process	Development process *(tasks, roles, processes),* Supplementary process *(standards, guidelines)*
		Technology	Development tools *(Integration and configurations tools)*
		People (developers)	Developers' Skills/knowledge
	Culture	User culture	Expertise, Users' Knowledge/skills, Expectations
		Organizational culture	Behavior *(General operating norms, Interaction),* Symbols Language, Policies and roles
	Financial Issue	Acquisition costs	MLA price, Delivery (installation) cost, Training cost Infrastructure upgrading cost
		Further development costs	Adapting cost, MLA testing cost, Integrating cost

Vendor	Reputation	Certification	Employee certification, Development process certification, Software product certification
		Reference checks	List of clients
		Market coverage	The number of Customers
		Competence	Flexibility of development process, Using last technology
	Stability	Financial	Financial ratio
		Track record	Time in business, Time in development this software
		Employees	Number of employees
		Strategy	Long-term strategy
	Supportability	Delivery	On time delivery performance, Confirmation software functions
		Quality of training	Quality of training courses, Training tool/technology
		User support and communication	Help desk support, User queries/faults, Remote or online support
		Software support	Releasing functional software upgrade, Software upgrade path, Services warranty support

This part is established to verify the CEC in term of its comprehensive, understandability, accuracy, and coherence. Therefore, could you please answer the following questions by selecting your answer from the following choices:

1. Yes without modifications
2. Yes with modifications (please write your suggestions)
3. No (please write your suggestions)

#	Question	Tick your Answer			Suggestions
		Yes without Mod.	Yes with Mod.	No	
1	Does the CEC (*categories, characteristics, sub-characteristics and attributes*) enough to evaluate MLA software?				
2	Does the CEC (*categories, characteristics, sub-characteristics and attributes*) clear and easy to understand?				
3	Does the CEC (*categories, characteristics, sub-characteristics and attributes*) adequate to achieve precise evaluation?				
4	Does the structure of CEC (*categories, characteristics, sub-characteristics and attributes*) consistent and compatibles with the standard model's structure and components?				

General Comments

THANK YOU

APPENDIX D

Equations of the FAHP and TOPSIS Methods used to rank and select MLA

FAHP Method (equations)

Step 1: The value of fuzzy synthetic extent with respect to the i^{th} object is determined as

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \oplus \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (1)$$

To derive $\sum_{j=1}^{m} M_{gi}^{j}$, the fuzzy addition operation of m extent analysis values for the certain matrix is performed such as;

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) (2)$$

And to acquire $[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}]$, by performing the fuzzy $M_{gi}^{j}(j = 1, 2, \dots,)$ addition operation of such that; $[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}]^{-1} = (\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j)(3)$

and $[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}]^{-1}$ can be calculated by the inverse of Eq. (3), as follows

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right) (4)$$

Step 2: as $M_1 = (l_1, m_1, u_1)$, and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 \geq M_1$ is defined as;

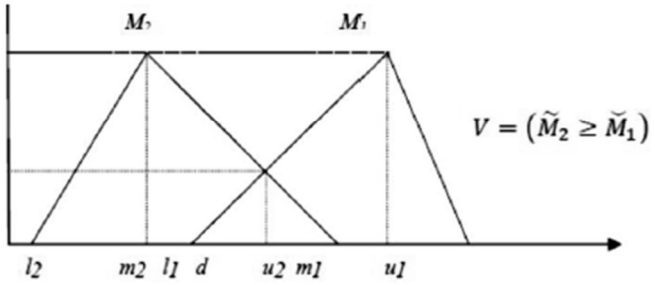
$$V = (M_2 \geq M_1) = \sup_{y \geq x}[\min(\mu_{M_1}(x), \mu_{M_2}(y))] (5)$$

And can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_2 \cap M_1) = \mu_{M_2}(d) = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{(l_1 - u_2)}{(m_2 - u_2) - (m_1 - l_1)} & Otherwise \end{cases} \quad (6)$$

Where d, as shown in Figure 3, is the ordinate of the highest intersection point D between $\mu_{M1}$and μ_{M2}.

To compare $M_1 = (l_1, m_1, u_1)$, and $M_2 = (l_2, m_2, u_2,)$we need both the values of $V(M_1 \geq M_2)$and $V(M_1 \geq M_2)$



Step 3: The degree possibility for a convex fuzzy number to be greater than *k* convex fuzzy Mi (i= 1,2,...,k)

numbers can be defined by $V(M \geq M_1, M_2, \ldots, M_k) = v[M \geq M_1)$and $M \geq M_2$and $M \geq M_k)$

$= \min v\ M \geq M_1, i=1, 2, \ldots, k$ (7)

$d'(Ai)=\min V (S_i \geq S_k)$ for$k=1,2,\ldots,n ; k \neq i$ Then the weight vector is given by

$W' = (d'(A_1), d'(A'_2, \ldots, d'(A_n))^T$ (8)

Where *Ai* (*i*=1,2,…,n) are n elements.

TOPSIS Method (equations)

According to Hwang and Yoon (1981) the following shows how the method is calculated.

Step 1: Evaluate the normalized decision matrix with value r_{ij} :

$$r_{ij} = x_{ij} \sqrt{\sum_{i-1}^{m} x_{ij}^2} \; i = 1, 2, \ldots, m \; and \; j = 1, 2, \ldots, n. \qquad (10)$$

Where, w_j is the assigned weight of each j^{th} criterion and $\sum_j^n wj = 1$

Step 2: Evaluate the weighted normalized decision matrix with value vij :

$v_{ij} = r_{ij} \times w_j$, i =1, 2,….m and j = 1, 2, …n (11)

Step 3: Get the ideal (A^*) and negative ideal (A^-) solutions

$$A^* = \left\{\left(\max_i v_{ij} \mid j \in C_b\right), \left(\min_i v_{ij} \mid j \in C_c\right)\right\} = \{v_j^* \mid j = 1, 2, \ldots, m\} \quad (12)$$

$$A^- = \left\{\left(\min_i v_{ij} \mid j \in C_b\right), \left(\max_i v_{ij} \mid j \in C_c\right)\right\} = \{v_j^- \mid j = 1, 2, \ldots, m\} \quad (13)$$

Step 4: Evaluate the separation measures using the m-dimensional Euclidean distance of each alternative from positive ideal solution and negative ideal solution:

$$S_i^* = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^*)^2, j = 1,2, \ldots, m} \quad (14)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2, j = 1,2, \ldots, m} \quad (15)$$

Step 5: Evaluate the relative closeness to ideal solution of the alternative A_i with respect to A^* is defined below:

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, i = 1,2, \ldots, m \qquad (16)$$

Step 6: Finally, rank in order of its preferences.