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The Development of Constraints in Role-based Access Control: A Systematic Review

Nazirah Abd Hamid [1], Rabiah Ahmad [2], and Siti Rahayu Selamat [3]
[1,2,3] Faculty of Information & Communication Technology, Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia
[3]Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin (UniSZA), Besut, Terengganu, Malaysia
[1]**owenira@gmail.com**

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ABSTRACT

Role-based access control (RBAC) model attracts many organizations to transform their traditional access control method to RBAC model mainly because of the security features in the RBAC. The RBAC model is generated to achieve security objectives and to do so, RBAC enforces various constraints to accomplish those objectives. Up to now, very limited studies provide systematic review of constraints in roles mining and in this study, we focus on the publications that published during 2011–2018. The main objective of this study is to recommend conceptual understanding through a systematic review by classifying the constraints and its proposed solutions. The analysis offered variety of areas that can be explored in leveraging constraints in the role mining development hence providing an improvement to roles-based access control growth.

I. INTRODUCTION

Access control model is very needed by an organization to administer their security policies and the resources. Role engineering or also known as role mining in RBAC can be described as a process to discover an appropriate set of roles that could perform as a control mechanism to access the organization's resources [1].

Nevertheless, to ensure that the generated roles are signifying the organizations security policies and user requirements persist a difficult challenge. Thus, there is a need to introduce the constraints that could govern the implementation of those policies and requirements especially in designing and developing role mining algorithms [1].

The development of constraints in RBAC are still quite limited so the key contribution of this paper is to present conceptual understanding through a systematic review by classifying the constraints and its proposed solution. The analysis offered variety of areas that can be explored in leveraging constraints in the role mining development.

This paper is adapted from the work presented by [2]. The remainder of this paper is organized as the following: section II provides the preliminaries study on the various constraints. Then in the section III shows the methodology of systematic literature review process. In section IV explains the data extraction and analysis process and, in the section, presents and classifies the constraints in role mining. Lastly, section VI and VII describe the discussion and conclusion of this study.

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II. PRELIMINARIES

In this section, we would examine the notions of constraints in role-based access control specifically in role mining.

The concept of constraints in RBAC models was introduced by the authors in [3] and they classified the constraints into several categories namely mutually exclusive roles, cardinality constraints and prerequisite roles. Moreover, the authors also characterized the constraints into several general classes: cardinality constraints and prerequisite constraints [4].

Furthermore, according to [5] constraints could be described as an important set of rules that governed the architectural structure of RBAC and the constraints were significant to be used as a control and protection mechanism in RBAC because of the nature of a RBAC model that heavily relied on the flow of the security such as who should has the permission to the objects or resources and so on.

The research study by the authors in [5] also have discovered that in the RBAC environment, cardinality constraints administrated the organization security policies. In the real scenario, in the beginning, the chief security officer is needed to list the minimum and maximum requirements of the security officers and users that would involve in the RBAC system.

III. SYSTEMATIC LITERATURE REVIEW

In order to do the survey and analysis on the current state-of-the-art of constraints in role-based access control, we have initiated a systematic literature review based on these research questions:

Question 1: What is the relationship between role-based access control and constraints?

Question 2: Which constraints that involved in existing role mining algorithms?

A. Exploration process

The exploration process has been commenced with the searching activity for the relevant research studies using search engines through digital libraries and databases as illustrated in **TABLE 1**. The keywords or search strings that have been applied were "constraints in role-based access control" and "constraints in role mining".

B. Inclusion and Exclusion Criteria

We have defined some inclusion and exclusion criteria to select the articles for the review process:

a) Inclusion criteria

Studies that have been published during 2011 to 2018 and related to the constraints in role-based access control and role mining. More articles have been discovered through examining the reference list of each one of these articles.

b) Exclusion criteria

The articles that unrelated to the research questions.

TABLE 1 provides the information on the number of research studies that have been ascertained during the exploration process of the digital libraries and databases.

TABLE 1: Number of Articles and Databases

Databases	Number of Articles		
	Based on keywords	Based on titles	Based on abstracts
ACM Digital Library	10	3	10
IEEE Xplore	7	3	11
Science Direct	4	2	4
Scopus	19	22	27
Google Scholar	19	19	26

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Total	**59**	**49**	**78**

IV. DATA EXTRACTION

For this data extraction section, there were 14 final articles that have been selected based on the inclusion and exclusion criteria as mentioned in section III. The final articles were focusing on "constraints in role-based access control" and "constraints in role mining" and each article has been summarized in **TABLE 2** in the term of the aim of the study and the methodology that involved, and the articles have been ordered by most recent year of publication.

V. DATA ANALYSIS

From the data that has been extracted as in **TABLE 2**, there were two main findings that could be concluded as followed:

a) There were five different classes of cardinality constraints and
b) The algorithms from those articles, have been studied and sorted into the classes of abovementioned cardinality constraints

TABLE 2: Summary of Articles

No	Year	Title	Aim & Methodology	Type of Constraints
1	2018	Dynamic User-Oriented Role Based Access Control Model (DUO-RBAC)	This study discussed a dynamic user-oriented role-based access control model that could accommodate a way of new user-permission assignment (UPA)to be included into the existing one.	The number of role assignments for each user (R-U)
			The model involved three main processes including a preprocessing phase by eliminating users with the same permission, a candidate roles generation phase using a combination formula and lastly in role selection and assignment phase, dynamically choose candidate roles form the uncovered permission.	
2	2017	PRUCC-RM: Permission-Role-Usage Cardinality Constrained Role Mining	This study deliberated on two heuristics algorithms that could be used to execute the two type of constraints by implementing a pre-processing process in one algorithm where role was split and assigned based on the mentioned constraints and for the second algorithm, the conflicting roles were eliminated.	The number of permissions included in a role (P-R)
				The number of roles a user can own (R-U)
3	2016	Performance Evaluation of a Role Based Access Control Constraints in Role Mining Using Cardinality	This paper proposed a new concept of objective that intended to limit the most number of permissions that can be incorporated into the role by designing and developing a Matrix Based Role Assignment (MBRA) algorithm and role miner algorithm.	The number of permissions that can be incorporated in a role (P-R)
			The algorithms were designed by employing the visual method that could represent the UPA in a better manner and facilitated the way of doing analysis rapidly.	

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No	Year	Title	Aim & Methodology	Type of Constraints
4	2016	Role Mining Using Answer Set Programming	This article discussed an innovative way to leverage multiple constraints with numerous optimization objectives. Multiple constraints could cause conflicts if they were not being handled properly and the authors introduced role mining method using answer set programming (ASP) named constrained role miner (CRM).	Multiple constraints
			Fundamentally, ASP is a declarative problem-solving technique that enable a computer intelligently to propose a solution based on a problem such as in this research the conflicts that happen between constraints.	
5	2015	Meeting Cardinality Constraints in Role Mining	The discoursed two strategies in this article were to solve multiple constraints problems simultaneously and in this case, the multiple constraints were known as Multiple Cardinality Constraint Problem (MCP).	The number of roles to which an individual user can own (R-U)
			The two strategies specifically called as the postprocessing strategy and the concurrent processing strategy. The difference between those approaches was the way the user-assignment (UA) and permission-assignment (PA) matrices were obtained where the postprocessing was built without deliberating the constraints meanwhile in concurrent processing both constraints were simultaneously developed.	The number of roles that can include in a permission (R-P)
6	2015	Towards a General Framework for Optimal Role Mining: A Constraint Satisfaction Approach	The authors suggested a technique to convert the role mining problem (RMP) into a constraint satisfaction problem using satisfiability modulo theories (SMT) solvers that permitted RBAC model to be represented into multiple constraints. The transformation enabled to get an optimal RBAC model based on customized optimization metrics.	Multiple constraints
7	2015	Role Mining based on Cardinality Constraints	In this article, a role mining algorithm with the consideration of two constraints namely the number of roles to which an individual user can belong should be limited and the number of roles to which a permission can be assigned should also be restricted.	Multiple constraints

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No	Year	Title	Aim & Methodology	Type of Constraints
			The algorithm was developed by employing an improved graph optimization theory and it consisted of three major phases; generating the initial role set, selecting role pair for role update algorithm and updating the initial role state.	
8	2015	Towards User-oriented RBAC Model	This paper proposed role mining algorithms that complied with the constraint of the number of roles a user can own. The algorithm was designed and developed to solve four different problems specifically i) the user RMP and its approximate ii) the personalized RMP and approximate personalized RMP. The user RMP would allow all the users with the same maximum role assignment while the personalized RMP permitted different values for each user. The approximate versions could be defined as to place a threshold value that enabled a little bit deviation from the complete reconstruction.	The maximum number of roles each user can have (R-U)
			The heuristic algorithms consisted of i) candidate role generation phase and ii) role selection and assignment phase.	
9	2015	Role Mining Based on Permission Cardinality Constraint and User Cardinality Constraint	The constraints that involved in this study were permission cardinality constraint and user cardinality constraint and the authors developed a role mining algorithm to leverage those constraints while minimize the assignment cost. The algorithm comprised of three phases namely initial role set generation phase, role selection phase, and role state generation phase.	Multiple constraints
10	2014	Visual Approach to Role Mining with Permission Usage Cardinality Constraint	In this research, a graphic or visual approach was introduced to illustrate the UPA and eventually an analysis and optimal roles with constraint could be extracted rapidly. The authors built two heuristics algorithms particularly ADVISER and t-SMAR that could produce a UPA with the intended constraint.	The number of permissions that can be included in a role (P-R)

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No	Year	Title	Aim & Methodology	Type of Constraints
11	2013	Towards User-Oriented RBAC Model	A heuristic solution was proposed to enforce the intended constraint and the solution utilizing a dynamic role generation that used an iterative technique to uncover optimum roles. The author also mentioned that the algorithm was integrated with the end-user standpoint. In this study, two main role mining algorithms were designed i) user-oriented exact and user-oriented approximate and the difference was the threshold value of the reconstruction of the UPA where exact algorithm had to completely mimic the UPA whilst the approximate allowed some deviation.	The number of roles each user can have (R-U)
12	2012	Constrained Role Mining	The authors described two heuristic techniques to enforce the permission cardinality constraint, namely t-SMAR and t-SMAC to reconstruct a complete UPA and the they claimed that the algorithms could be expended to other types of cardinality constraints.	The number of permissions included in each role (P-R)
13	2012	Role Mining under Role-Usage Cardinality Constraint	Study by this article discovered two techniques to solve the role-user cardinality constraint problem in building the UPA. The first technique called as Role Priority based Approach (RPA) involved the process of ranking the roles based on the sizes and then enforced the constraint using the produced ranking. The Coverage of Permissions based Approach (CPA) as the second technique worked by choosing a role based on the largest uncovered number of permissions to impose the intended constraint.	The number of roles any user can have (R-U)
14	2011	Towards Role Mining with Restricted User-Role Assignment	Three algorithms were introduced by the authors to implement the number of users assigned to any role constraint and those algorithms could accommodate different requirements. The algorithms were designed by considering the problem of finding smallest biclique cover of the edges of a bipartite graph.	The number of users assigned to any role (U-R)

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A. Role-user cardinality constraint

The role-user cardinality constraint of role could be defined as the maximum number of roles that can be assigned to a user (R-U) or in the other words, the users could only perform a task based on the privileges that have been granted to them only as mentioned in [5][6].

The authors highlighted the need of a dynamic user-oriented role-based access control algorithm that could accommodate a way of new user-permission assignment (UPA) to be included into the existing one while the constraints were being maintained [7].

According to [8], a heuristic algorithm was designed and developed to solve four different problems specifically i) user RMP, ii) approximate user RMP, iii) personalized RMP and iv) approximate personalized RMP. The proposed algorithms were complied with the constraint of the number of roles a user can own and consisted of i) candidate role generation phase and ii) role selection and assignment phase.

A heuristic solution was proposed to enforce the intended constraint and the solution utilizing a dynamic role generation that used an iterative technique to uncover optimum roles. This paper [9] also mentioned that the algorithm was integrated with the end-user standpoint. Two role mining algorithms were designed, i) user-oriented exact and user-oriented approximate where exact algorithm had to completely mimic the UPA whilst the approximate allowed some deviation.

In this study, the authors discovered two techniques and the first technique called as Role Priority based Approach (RPA) involved the process of ranking the roles based on the sizes and then enforced the constraint using the produced ranking. The Coverage of Permissions based Approach (CPA) as the second technique worked by choosing a role based on the largest uncovered number of permissions to impose the intended constraint [10].

B. User cardinality constraint

The user cardinality constraint of user can be described as a constraint that restrict the number of users to which a role can have (U-R). For example, if a RBAC model allocates a huge number of users to a specific role, then the security officer would have difficulty to administrate the RBAC system.

So, to resolve the abovementioned constraint, three algorithms were introduced by the authors [11] to implement the number of users assigned to any role constraint and those algorithms could accommodate different requirements. The algorithms were designed by considering the problem of finding smallest biclique cover of the edges of a bipartite graph. Fundamentally, biclique problem could be expressed as a problem to discover a node that could stimulate a thorough subgraph [12].

C. Role-permission cardinality constraint

The role-permission cardinality constraint can be expressed as the maximum number of roles to which a permission can belong (R-P). One of the study [13] designed and developed two strategies known as the postprocessing strategy and the concurrent processing strategy. Moreover, the algorithm was developed by employing an improved graph optimization theory and it consisted of three major phases [14]. Both articles involved in the multiple constraints research.

D. Permission cardinality constraint

This permission cardinality constraint is applied to determine the maximum number of permissions that can be present in a role (P-R) and in [15] a new concept of objective was proposed by designing and developing algorithms that have employed the visual method that could represent the UPA in a better manner and facilitated the way of doing analysis rapidly.

In this research, a graphic or visual approach was used to illustrate the UPA and eventually an analysis and optimal roles with constraint could be extracted rapidly. The two heuristics algorithms were produced particularly ADVISER and t-SMAR that could construct a UPA with the intended constraint [16].

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The two heuristic techniques could be applied to enforce the permission cardinality constraint, namely, t-SMAR and t-SMAC to reconstruct a complete UPA and the authors claimed that the algorithms could be expended to other types of cardinality constraints [17].

E. Multiple constraints

This study deliberated on two heuristics algorithms that could be used to execute the two type of constraints specifically constraints on the number of permissions included in a role (P-R) and the number of roles a user can own (R-U) by implementing an algorithm with a pre-processing process and another algorithm without the pre-processing stage [1].

The authors investigated two strategies to solve multiple constraints problems simultaneously known as Multiple Cardinality Constraint Problem (MCP). The multiple constraints that involved were known as dual of each other specifically a role-user cardinality constraint (R-U) and its dual namely role-permission cardinality constraint (R-P). The two strategies were called as the postprocessing strategy and the concurrent processing strategy. The difference between those approaches was the way the user-assignment (UA) and permission-assignment (PA) matrices were obtained, where the postprocessing was built without deliberating the constraints meanwhile, in concurrent processing both constraints were simultaneously developed. [13]

In this article [14], a role mining algorithm with the consideration of two constraints namely the number of roles to an individual user can belong (R-U) and the number of roles can be assigned in a permission (R-P). The algorithm was developed by employing an improved graph optimization theory [18] and it consisted of three major phases.

The constraints that involved in this study were permission cardinality constraint (P-R) and user cardinality constraint (U-R) and the authors [19] developed a role mining algorithm to leverage those constraints while minimize the assignment cost. The algorithm comprised of three phases namely initial role set generation phase, role selection phase, and role state generation phase.

According to the authors in [20], they discovered an innovative way to leverage the conflicts between multiple constraints with numerous optimization objectives using answer set programming (ASP) named constrained role miner (CRM) that enable a computer intelligently to propose a solution based on a problem.

The authors [21] suggested a technique to convert the role mining problem (RMP) into a constraint satisfaction problem using satisfiability modulo theories (SMT) solvers [22] that permitted RBAC model to be represented into multiple constraints. The transformation enabled to get an optimal RBAC model based on customized optimization metrics.

VI. DISCUSSION

From the exploration process that has been described in the section III, there were 78 publications have been published from 2011-2018 and after the inclusion and exclusion criteria, 14 related studies have been selected for further analysis.

In the data analysis sections as in section V, there are two main findings that needed to be deliberated. Firstly, there are five different classes of cardinality constraints that can be discovered as the following:

a) Role-user cardinality constraint (R-U) - the number of roles a user can own.
b) User cardinality constraint (U-R) - the number of users to which a role can have.
c) Role-permission cardinality constraint (R-P) - the number of roles that can include in a permission.
d) Permission cardinality constraint (P-R) - the number of permissions that can be incorporated in a role.

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e) Multiple constraints – involve the enforcement of two constraits as above.

Secondly, over the years, the research on constraints in the RBAC have attracted many researchers but the resources are quite inadequate. Based on the reviews, there are some discussion that could be summarized:

a) Most of the researchers have concentrated on findings the solutions for a single constraint and the most discussed constraint is the role-user cardinality constraint.
b) The researchers have designed and developed heuristics algorithms because they have showed that the role mining problem of constraints are NP-hard.
c) For the multiple constraints' techniques, most of them have developed two separate strategies to enforce the constraints.

Furthermore, all the selected articles have been using some or all the nine real-world datasets as portrayed in **TABLE 3**. The datasets have been introduced by [23] and the elements in **TABLE 3** can be denoted as |U| as user and |P| as permission.

TABLE 3: Elements in the Datasets

Dataset	|U|	|P|
americas_large	3485	10127
americas_small	3477	1587
apj	2044	1164
emea	35	3046
healthcare	46	46
domino	79	231
customer	10021	277
firewall1	365	709
firewall2	325	590

VII. CONCLUSION

The development of constraints in RBAC are still quite limited and the main contribution of this paper is to present a systematic review and the analysis offered variety of areas that can be explored in the research of constraints in the role mining development.

There are some potential paths that can be explored by the researchers in the future. The first path is to propose a dynamic solution to find more interesting roles that can resultant more accurate results and for the second direction in the multiple constraints, the researchers could explore some techniques to enforce the constraints to be executed simultaneously.

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