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Roman and Inverse Roman Domination Number of Circulant Graphs

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Abstract: The research paper instigates the Roman domination number and the inverse Roman domination number of circulant graphs, which are an important class of graphs characterized by their cyclic symmetry and regular structure. The Roman domination number, denoted as $\gamma_R(G)$ is the minimum weight of a Roman dominating function on a Graph G. Conversely the inverse Roman domination number $\gamma_{IR}(G)$ is the maximum weight of a Inverse Roman dominating function. Through comprehensive analysis and new theoretical insights, the exact values of $\gamma_R(G) and \ \gamma_{IR}(G)$ can be determined. This paper concludes with a discussion on the implications of these results and potential avenues for future research.

Keywords*: Graphs, Circulant graphs, Cardinality, Roman Domination number, Inverse Roman domination number.*

1. Introduction:

A family of graphs known as circulant graphs have a special structural characteristic in which the adjacency matrix of the graph can be represented as a circulant matrix. A circulant matrix is a square matrix in which each row (or column) is a cyclic shift of the preceding row (or column).

Turner and Elspas wre the first to discuss the Circulant graph. The circulant was initially proposed by Wong and Coppersmith as a natural extension of the double loop network. Every circulant graph is both a cayley graph and a vertex transtive graph. Many studies and surverys of the qualities of Ciculant graph have been conducted by Bermond et al.

Over the last two devades, researchers have examined the Circulant Graphs. One of the fundamental characteristics of a circulant graph is its regular structure, where each vertex has the same number of neighbors. This regularity allows for efficient algorithms and analysis, as the properties of the graph can be derived from the structure of the circulant matrix.

2. Literature Survey

In 1975 Cockayne et al. presented the first dominance algorithm for trees, and David Johnson created the first demonstration that the domination issue for arbitrary graphs is NP complete around the same time.

Efficient algorithm for Inverse domination numbers t-layer cycles have been found by Jasintha Quardras et al.[9]. For a specific circulant graph, Indra Rajasingh et al. have discovered a minimum connected dominant set. Cynthia et al. have looked into S-(a,d) antimagic labeling of a class of circulant graph. For circulant graphs, Shobana et al. have discovered an effective 2-domination number. Indra Rajasingh et al. have investigated the embeddings of Circulant Networks. Cynthia et al. have investigated the local metric dimension of Circulant Graphs[10].

3. Circulant Graphs

3.1 Definition:

An undirected graph that is affected by a cyclic group of symmetries that maps any vertex to any other vertex is known as circulant graph. It is referred to as a cyclic graph at times.

To construct a circulant graph $Cn(S)$:

List the vertices as $v_0, v_1, \dots, v_{n-1}$. For each v_i, draw edges to the vertices $v_{(i+s)} \, mod \ n$ for each $s \in S$.

3.2 Definition:

A circulant graph $Cn(S)$ is a graph with n vertices, where the adjacency relationship is defined in a very regular manner. Specifically, Each vertex v_i $(where \ i \ ranges \ from \ 0 \ to \ n-1)$ is adjacent to the vertices $v_{i+s} mod \ n$ for each s in a given set S of integers. The set S is symmetric, meaning that if s is in S, then s must also be in S.

3.3 Definition:

A set D of vertices in a graph G is called a dominating set if each vertex in $V - D$ is adjacent to at least one vertex in D. A minimum dominating set is defined as a set, having the fewest number of vertices among all the

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dominating sets. The domination number of a graph G [4] is the number of vertices in that set; it is represented as $\gamma(G)$.

If every vertex in V-D is adjacent to atleast one vertex in D then a set D of vertices in a graph G is a dominating set, If D *has* minimum number of vertices among all the dominating set then it is referred to as a minimum dominating set. The number of vertices in that set is known as the domination number of a graph G [4], and it is denoted by $\gamma(G)$.

3.4 Definition:

Cockayne [1], defined Roman dominating function of a graph $G = (V, E)$ as a function $f : V \rightarrow \{0, 1, 2\}$ where each vertex u, with $f(u) = 0$, is connected to at least one vertex v with $f(v) = 2$. The sum of $f(v)$ *for all* $v \in V$ is the weight of the function $f : V \rightarrow R$. The minimum weight among all RDFs in G is the Roman domination number (RDN) of G, it is denoted by $\gamma_R(G)$, In other words, a graph coloured with {0,1,2} at its vertex corresponds to a Roman dominant function, in a such that at least one vertex coloured "2" and every vertex

Coloured “0” share a side.

3.5 Definition:

A set $V - D$ is referred to as having an Inverse Roman dominating function[5] if it has the Roman dominating function $f^1 : V \rightarrow \{0, 1, 2\}$, where D denotes the vertices v that satisfy $f(v) > 0$. In the end, f^1 is recognized as an Inverse Roman Dominating function (IRDF) on a graph G with respect to f. The least weight among all the IRDF in G is represented by the inverse Roman domination function (IRDN), symbolized as $\gamma_{IR}(G)$, in G. We refer Harary [3].

3.6 Definition:

A Circulant Graph [8], denoted by $G(m; \pm\{1, 2 \ldots \boldsymbol{j}\}), 1 \leq \boldsymbol{j} \leq \lfloor m/2 \rfloor / m \geq 3$, is a graph with vertex set $V = \{0, 1, 2 \ldots m - 1\}$ and the edge set $\boldsymbol{E} = \{(\boldsymbol{i}, \boldsymbol{j}): |\boldsymbol{j} - \boldsymbol{i}| \equiv s(mod\ m), s \in \{1, 2 \ldots j\}\}$.

4. RDN of Circulant Graph:

Theorem 4. 1 : For Circulant Graph $G(m, \pm\{1, 2\})$, RDN is $\gamma_R(G) = 2 \lceil m/5 \rceil$.

Proof: Let $\{v_1, v_2, \ldots v_m\}$ represent the vertices of the undirected circulant graph $G(m, \pm 1, 2)$. It is evident that a vertex of G can dominate atmost four vertices since the set of four vertices $\{v_{i-2}, v_{i-1}, v_{i+1}, v_{i+2}\}$ adjacent to vertex v_i of G. Let $f(v_{i-2}) = f(v_{i-1}) = f(v_{i+1}) = f(v_{i+2}) = 2$. Elements in the dominating set are labled as 2. Hence its adjacent vertices will have label 0.

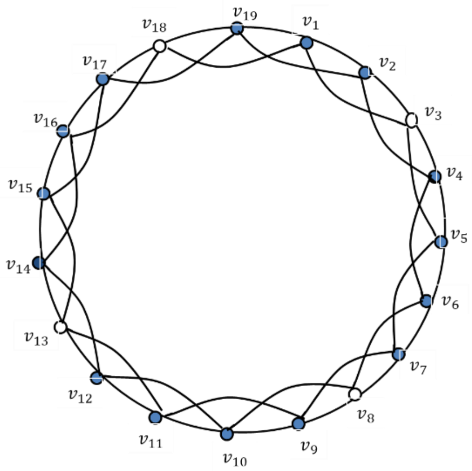
To find the RDN of $G(m, \pm\{1, 2\})$, where $m \equiv 0, 1, 2, 3, 4 (mod\ 5)$, Consider the following cases:

Case 1: $m \equiv 0(mod\ 5)$,

For $j = 0, 5, 10, \ldots, m - 5$, consider the set of vertices $\{u_{1+j}, u_{2+j}, u_{4+j}, u_{5+j}\}$ which are adjacent to the vertex v_{3+j}. Let $D = \{u_{3+j} / j = 0, 5, 10, \ldots, m - 5\}$, be a Roman dominating set. Cardinality of set D is $|D| = [n/5|$. Let $f(u_{3+j}) = 2$ where $j = 0, 5, 10, \ldots, m - 5$. Hence $\gamma_R(G) = 2 \lceil m/5 \rceil$.

Case 2: $m \equiv 1(mod\ 5), m \geq 6$

For $j = 0, 5, 10, \ldots, n - 6$, consider the set of vertices $\{u_{1+j}, u_{2+j}, u_{4+j}, u_{5+j}\}$ which are adjacent to the vertex v_{3+j}. Vertex u_m is dominated by u_{3+j} for any j. So we select u_{3+j} *where* $j \in \{0, 5, \ldots m - 6\}$ to be member of D. Since u_n is not adjacent to u_{3+j} for all j, we select the vertex u_m for the Roman dominating set. So we obtain a Roman dominating set $D = \{u_{3+j} / j = 0, 5, 10, \ldots, m - 6\}\ U\ \{u_m\}$. Thus $|D| = \lceil m/5 \rceil$. Let $f(u_{3+j}) = 2$, where $j = 0, 5, 10, \ldots, m - 5$ and let $f(u_m) = 2$. Hence $\gamma_R(G) = 2 \lceil m/5 \rceil$.



Roman domination number of $G(19,2)$

Case 3: $m \equiv 2(mod\ 5), m \geq 7$

$For\ j = 0,5,10,\ldots,m-7$ consider the set of vertices $\{u_{1+j}, u_{2+j}, u_{4+j}, u_{5+j}\}$which are adjacent to the vertex u_{3+j}. Then for the set of remaining vertices $\{u_{m-1}, u_m\}$, choose the vertex v_{n-1} to be a member of Roman dominating set, $D = \{u_{3+j}/j = 0,5,10,\ldots,m-7\}\ U\ \{u_{m-1}\}$.
Thus $|D| = [n/5|$. Let $f(u_{3+j}) = 2\ where\ j = 0,5,10,\ldots,m-5$ and $f(u_{m-1}) = 2$. Hence $\gamma_R(G) = 2\lceil m/5 \rceil$.

Case 4: $m \equiv 3(mod\ 5), m \geq 8$

$For\ j = 0,5,10,\ldots,m-8$ consider the set of vertices $\{u_{1+j}, u_{2+j}, u_{4+j}, u_{5+j}\}$ which are adjacent to the vertex v_{3+j}. The remaining set of three vertices $\{u_{n-2}, u_{m-1}, u_m\}$ are dominated by the vertex u_{m-1}. Consider a Roman dominating set $D = \{u_{3+j}/j = 0,5,10,\ldots,n-8\}\ U\ \{u_{m-1}\}$. Thus $|D| = [n/5|$. Let $f(u_{3+j}) = 2$ where $j = 0,5,10,\ldots,n-5$ and $f(u_{m-1}) = 2$.

Hence $\gamma_R(G) = 2\lceil m/5 \rceil$.

Case 5: $m \equiv 4(mod\ 5), m \geq 9$

The vertexu v_{3+j} is adjacent to the set of vertices $\{u_{1+j}, u_{2+j}, u_{4+j}, u\}$ $for\ j = 0,5,10,\ldots,m-9$ and the remaining set of four vertices $\{u_{m-3}, u_{m-2}, u_{m-1}, u_m\}$ is dominated bythe vertex u_{m-1}. So taking a Roman dominating set $D = \{v_{3+j}/j = 0,5,10,\ldots,m-9\}\ U\ \{u_{m-1}\}$, the cardinality of the set D is $|D| = \lceil m/5 \rceil$. Let $f(u_{3+j}) = 2\ where\ j = 0,5,10,\ldots,m-5$ and $f(u_{m-1}) = 2$. Hence $\gamma_R(G) = 2\lceil m/5 \rceil$.

5. Inverse Roman Domination Number of Circulant Graph

Theorem 5.1: The IRDN of Circulant Graph $G(m, \pm\{1,2\})$ is $\gamma_{IR}(G) = 2\lceil m/5 \rceil$ |.

Proof : Let $\{u_1, u_2, \ldots, u_m\}$ be the vertices of the undirected circulant graph G. Domination number of G is given by $\gamma(G) = \lceil m/5 \rceil$. Let the Roman dominating set of G be D (as in Theorem 4.1). To determine the Inverse roman dominating set of G, consider the following cases of m

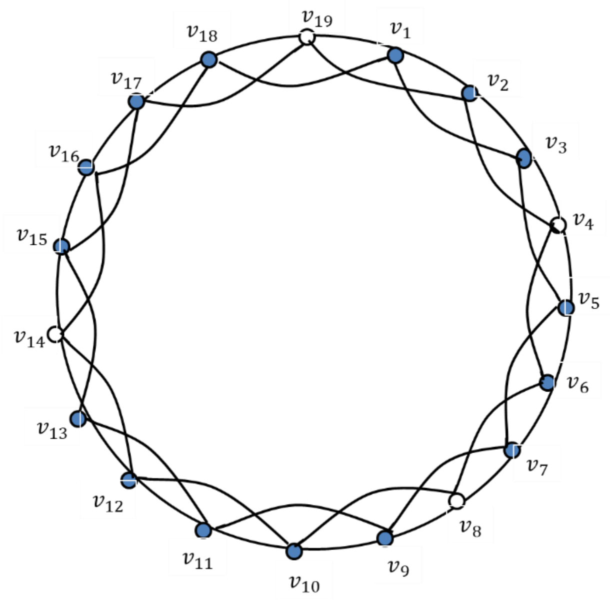
Case 1: $m \equiv 0(mod\ 5), m \geq 5$

Consider the vertex v_{4+j}. It is adjacent to the set of vertices $\{u_{2+j}, u_{3+j}, u_{5+j}, u_{6+j}\}$ for $j = 0,5,10,\ldots,m-5$. Hence we obtain an Inverse Roman dominating set $D^1 = \{u_{4+j}/j = 0,5,10,\ldots,m-5\}$. Therefore $|D^1| = [m/5|$. Let $f^1(u_{3+j}) = 2$ where $j = 0,5,10,\ldots,m-5$. Hence $\gamma_{IR}(G) = 2[m/5|$.

Case 2: $m \equiv 1(mod\ 5), m \geq 6$

The vertex v_{4+j} is adjacent to the set of vertices $\{u_{2+j}, u_{3+j}, u_{5+j}, u_{6+j}\}$ for $j = 0,5,10,\ldots,n-6$. Hence u_{4+j} $(j \in \{0,5,\ldots m-6\})$ will be a member of D^1. Since v_1 is not adjacent to any u_{4+j} for all j, we choose the vertex u_1 for the Inverse roman dominating set. Consider the Inverse roman dominating set

$D^1 = \{u_{4+j}/j = 0,5,10,\ldots,n-6\}U\ \{u_1\}$.
Thus $|D^1| = \lceil m/5 \rceil$. Let $f^1(u_{3+j}) = 2$ where $j = 0,5,10,\ldots,m-5$ and $f^1(u_m) = 2$. Hence $\gamma_{IR}(G) = 2\lceil m/5 \rceil$.



Inverse Roman domination number of G(19,2)

Case 3: $m \equiv 2(mod\ 5), m \geq 7$

Consider the vertex u_{4+j} which is adjacent to the set of vertices $\{u_{2+j}, u_{3+j}, u_{5+j}, u_{6+j}\}$ $for\ j = 0, 5, 10, \ldots, m - 7$. Then for the set of remaining vertices $\{v_n, v_1\}$, we choose the vertex v_{n-1} to be a member of Inverse roman dominating set, $D^1 = \{u_{3+j}/j = 0, 5, 10, \ldots, m - 7\} U \{u_{m-1}\}$. Thus $|D^1| = \lceil m/5 \rceil$. Let $f^1(u_{3+j}) = 2$ where $j = 0, 5, 10, \ldots, m - 5$ and $f^1(u_{m-1}) = 2$. Hence $\gamma_R(G) = 2[\lceil m/5 \rceil$.

Case 4: $m \equiv 3(mod\ 5), m \geq 8$

$For\ j = 0, 5, 10, \ldots, n - 8$, consider the set of vertices $\{u_{2+j}, u_{3+j}, u_{5+j}, u_{6+j}\}$ which are adjacent to the vertex v_{4+j}. The remaining set of three vertices $\{u_{m-1}, u_m, u_1\}$ is dominated by the vertex u. Hence we obtain an Inverse dominating set $D^1 = \{u/j = 0, 5, 10, \ldots, n - 8\}\ U\ \{u_m\}$.

Let $f^1(u_{3+j}) = 2$ where $j = 0, 5, 10, \ldots, n - 5$ and $f^1(u_{m-1}) = 2$

Thus $|D^1| = \lceil m/5 \rceil$. Hence $\gamma_{IR}(G) = 2\lceil m/5 \rceil$.

Case 5: $m \equiv 4(mod\ 5), n \geq 9$

F$or\ j = 0, 5, 10, \ldots, m - 9$, consider the set of vertices $\{u_{2+j}, u_{3+j}, u_{5+j}, u_{6+j}\}$ which are adjacent to the vertex v_{4+j}. The remaining set of four vertices $\{u_{m-2}, u_{m-1}, u_m, u_1\}$ is dominated by the vertex u_m. Hence we obtain an Inverse roman dominating set $D^1 = \{u_{4+j}/j = 0, 5, 10, \ldots, n - 9\}\ U\ \{u_m\}$.

Let $f^1(u) = 2$ where $j = 0, 5, 10, \ldots, m - 5$ and $f^1(u_m) = 2$

Thus $|D^1| = \lceil m/5 \rceil$. Hence $\gamma_{IR}(G) = 2\lceil m/5 \rceil$.

The Roman domination number and Inverse Roman domination number of $G(m, \pm\{1, 2\})$ are having equal cardinality $2\lceil m/5 \rceil$.

6. Conclusion

Circulant graphs have found numerous applications in various fields, including parallel computing, coding theory, and the study of infinite graphs. These graphs possess several interesting properties that make them attractive for both theoretical and practical purposes. Circulant graphs also have connections to number theory and algebraic structures, adding to their significance in diverse mathematical contexts. The symmetry and regularity of circulant graphs make them an intriguing subject for further study, as they offer insights into the fundamental properties of graph theory and its applications. Additionally, the unique properties of circulant graphs contribute to their relevance in the development of efficient network designs and communication protocols. Exploring the interplay between circulant graphs and various mathematical disciplines can lead to a deeper understanding of their inherent structures and their wide-ranging implications in different areas of mathematics and computer science. Circulant graph have been used in the design of computer and telecommunication networks due to their optimal fault-tolerance and routing capabilities. It is also used in VLSI designs and distributed computation.

REFERNCES:

[1] Henning, M. A., & Hedetniemi, S. T. (2003) Defending the Roman Empire – A new strategy, Discrete mathematics, 266, 239–251.

[2] Cockayne, E.J., Dreyer Jr., P.A., Hedetniemi, S.M., Hedetniemi, S.T., McRae, A.A. The algorithmic complexity of Roman domination.

[3] F. Harary, Graph theory (Addison Wiley, Reading Mass, 1975)

[4] Haynes, W., Hedetniemi, S. T., Slater, P. J. Basics of Domination in Graphs, Marcel Dekker, the New York (1997).

[5] Kamal Kumar, M., & Murali, R. (2014) Inverse Roman domination in some classes of graphs, International Journal of Computer Application, 4(4), 219–238.

[6] Kamal Kumar, M., & Sudershan Reddy, L. (2013) Inverse Roman domination in graphs, Discrete

Mathematics, Algorithm and application, 5(3), 1–4.

[7] E. J. Cockayne and S. T. Hedetniemi, Theory of Domination in Graphs, Networks, (1977), 247-261.

[8] C. Berge, Theory of graphs and its applications, Methuen, London, (1962).

[9] Jasintha Quardras, Jude Anne Cynthia and J. Christina, An algorithm for the Inverse domination number of t-layered cycles, Proceeding of the National Conference on Recent Trends In Mathematical Computing (2013)

[10] V Jude Annie Cynthia, A Kavitha, Inverse Domination number of Circulant Graph , In International J. of Math. Sci. & Engg. Appls. (IJMSEA) (Vol. 11, Issue III, (2017)pp. 203–209)

[11] R. Ramesh, M. Kannan and M. Seenivasan, "Achievement Estimations of Priority Queue System in Fuzzy Environment", Advances in Mathematical Modelling and Scientific Computing, Trends in Mathematics, Springer Link (Book Chapter),2024, pp. 637-658.

[12] R. Ramesh and M. Seenivasan, "Analysis of Attainment Estimates of Loss System Queue", Advances in Mathematical Modelling and Scientific Computing, Trends in Mathematics, Springer Link (Book Chapter),2024, pp. 519 – 531.

[13] K. Sakthivel, N. Paramaguru, R. Ramesh and P. Syamala., " Accomplishment Expedients of Batch Arrival Queuing Model by Fuzzy Ordering Approach ", Advances in Mathematical Modelling and Scientific Computing, Trends in Mathematics, Springer Link (Book Chapter),2024, pp. 487 – 496.

[14] A. Hari Ganesh, N. Jaimurthi, R. Ramesh and M. Seenivasan, "On testing of Fuzzy Hypothesis for mean and variance using centroid-based new distance functions under symmetric fuzzy environment", Contemporary Mathematics, Vol. 5. Issue 1, December 26, 2023, pp. 60-92, https://doi.org/10.37256/cm.5120243317.

[15] M. Seenivasan, S. Chandiraleka, H. Manikandan and R. Ramesh, "Single Server Queueing Model with Multiple Working Vacation, Feedback and Catastrophe", 4th International Conference on Material Science and Applications, AIP Conference Proceedings 2822, November 14, 2023,pp.020245-1 – 020245-9,ISBN NO: 978-0-7354-4724-0.

[16] M. Seenivasan, F. Patricia and R. Ramesh, "Analysis of Single Server Queue with single working vacation subject to Catastrophe", 4th International Conference on Material Science and Applications, AIP Conference Proceedings 2822, November 14, 2023,Pp.020246-1to 020246-6,ISBN NO: 978-0-7354-4724-0.

[17] R. Ramesh and M. Seenivasan, "Cost Appraises of a Phosphorescent Bulk Arrival Queueing system by Wingspans Fuzzy Ranking Approach", Stochastic Processes and Their Applications in Artificial UIntelligence chapter 5, Pp. 50-64 ACIR Book Series: ISSN NO: 2327-0411 (Scopus).

[18] P. Syamala, R. Ramesh, M. Seenivasan and R. Singaravel, "3D Based CT Scan Retrial Queuing Models by Fuzzy

[19] Ordering Approach", 2023 Second International Conference on Electrical, Electronics, Information and

[20] Communication Technologies (ICEEICT), Trichirappalli, India, 2023, Pp. 01-05,(Scopus).

[21] P. Gnaanachandra, A.M. Kumar, M. Seenivasan and R. Ramesh, "On Generalization of Fuzzy Topological Groups and Modelling Robotic Crash*",IEEE Xplore, 2023 Second International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT), Trichirappalli, India 2023, Pp.1-8, DOI: 10.1109/ICEEICT56924.2023.10157226 (Scopus).

[22] R. Ramesh and M. Seenivasan, "Discouraged Arrivals Queuing System in Inter valued type-2 Fuzzy Environment, Recent trends on Type-2 Fuzzy Logic systems: Theory, methodology and Application", Studies in Fuzziness and Soft Computating, Pp. 235-247, 2023, Volume 425, (Springer): ISSN: 1434 – 9922.

[23] R. Ramesh and M. Seenivasan, Performance Analysis of Single Server Low Priority Queue Based on Electronic Transmitter, Lecture Notes in Electrical Engineering, Springer Book Series, (ICAECT 2021), Vol.881,Pp.347-359,June 26th, 2022, ISBN: 978-981-19-1110-1&ISBN 978-981-19-1111-8.

[24] R. Ramesh and M. Seenivasan, "Achievement expedients of fuzzy queuing models with an unreliable electrical transformer", IEEE Xplore (ICEEICT 2022) Vol. 22, February 2022(Scopus), ISBN:978-1-6654-3647-2.

[25] R. Ramesh and M. Seenivasan, "Performance Calibrations of A single server Glycolic Acid Based Beauty Parlor by Fuzzy Retrial Queuing Models", Materials Today: Proceedings, Vol.51, Pp.2422–2426, December2022, (Science Direct), (Scopus) https://doi.org/10.1016/j.matpr.2021.11.603: ISSN: 2214-785

[26] Bhaskaran, S. S. (2024). Discovery of contextual factors using clustering. Multimedia Tools and Applications, 1-30.

[27] Bhaskaran, S. S. (2021). Investigation of student performance with contextual factors using association rules in higher educational institutions (HEIs). In Data Engineering and Intelligent Computing: Proceedings of ICICC 2020 (pp. 431-442). Springer Singapore.

[28] Bhaskaran, S. S., Al Aali, M., & Lu, K. Contextual Data Mining for Higher Educational Institutions.

[29] Bhaskaran, S. S. (2017). An Investigation into the Knowledge Discovery and Data Mining (KDDM) process to generate course taking pattern characterised by contextual factors of students in Higher Education Institution (HEI) (Doctoral dissertation, Brunel University London).

[30] Bhaskaran, S. S. (2021). Investigation of factors affecting adoption of FinTech in financial institutions. In Innovative strategies for implementing FinTech in banking (pp. 222-241). IGI Global.

[31] Sailesh, S. B. (2022). Adapting IT governance policies and technology to cope with COVID-19 at Ahlia University. In COVID-19 Challenges to University Information Technology Governance (pp. 359-372). Cham: Springer International Publishing.

[32] Intelligent context driven data mining to analyse student performance in higher educational institutions (HEIs)

Bhaskaran, S.S

[33] International Journal of Recent Technology and Engineering, 2019, 8(2), pp. 856–861

[34] Khalaf, F., & Baskaran, S. S. (2023, March). Predicting Acute Respiratory Failure Using Fuzzy Classifier. In 2023 International Conference on IT Innovation and Knowledge Discovery (ITIKD) (pp. 1-4). IEEE.

[35] Hasan, Z., & Baskaran, S. S. (2023, March). Propose a Recommender System to Dynamically Align Higher Education Curriculums With 4IR Market Needs. In 2023 International Conference on IT Innovation and Knowledge Discovery (ITIKD) (pp. 1-7). IEEE.

[36] Bhaskaran, S. S., & Al Aali, M. (2021). Investigation on the Influence of English Expertise on Non-native English-Speaking Students’ Scholastic Performance Using Data Mining. In Smart Computing Techniques and Applications: Proceedings of the Fourth International Conference on Smart Computing and Informatics, Volume 2 (pp. 9-14). Springer Singapore.

[37] Bhaskaran, S. S., & Aali, M. A. (2021). Data mining model for better admissions in higher educational institutions (heis)—a case study of bahrain. In Advanced Machine Learning Technologies and Applications: Proceedings of AMLTA 2020 (pp. 141-150). Springer Singapore.

[38] Sailesh, S. B., Lu, K. J., & Al Aali, M. (2016, August). Profiling students on their course-taking patterns in higher educational institutions (HEIs). In 2016 international conference on information science (icis) (pp. 160-167). IEEE.

[39] Sailesh, S. B., Lu, K. J., & Al Aali, M. (2016, August). Context driven data mining to classify students of higher educational institutions. In 2016 International Conference on Inventive Computation Technologies (ICICT) (Vol. 2, pp. 1-7). IEEE.

[40] Bhaskaran, S. S., Lu, K., & Aali, M. A. (2017). Student performance and time-to-degree analysis by the study of course-taking patterns using J48 decision tree algorithm. International Journal of Modelling in Operations Management, 6(3), 194-213.

[41] Bhaskaran, S. S. (2018). Facilitate decision making in higher educational institutions by linking course-taking pattern and student performance characterised by contextual knowledge. International Journal of Society Systems Science, 10(3), 182-200.