A Proposed Taxonomy for Literature Review in Multi-Objective Vehicle Routing Problems

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Abstract. Vehicle routing problems deal with determining the routing of a fleet of vehicles under a set of constraints to serve geographically dispersed customers. The problems belong to a subset of combinatorial optimization problems and are widely studied due to their academic appeal and numerous applications. The classical version of this subject usually minimizes a single objective in total distance or total cost. However, given that many real-life problems are inherently multi-objective, a variant that considers multiple objectives is getting more attention nowadays. The latest review in this area was in 2008 and more than a decade has now elapsed with the absence of similar study. The objectives of this paper are to summarize the selected new research of multi-objective vehicle routing problems that span beyond 2008 and to propose a taxonomy that can be used to categorize the studies in this area. The proposed taxonomy includes eight criteria covering identification and characteristics of the papers. The findings from the review suggest tendencies toward certain scopes such as time windows formulation (VRPTW), the development of population-based algorithms especially the genetic algorithm and elitist non-dominated sorting genetic algorithm (NSGA-II), and the use of Solomon benchmark instances in the numerical experiment.

Keywords: multi-objective optimization; vehicle routing problems; taxonomy.

INTRODUCTION

Vehicle Routing Problem (VRP) is a routing problem from one central depot to several geographically dispersed customers satisfying a set of constraints. The common constraints require that each vehicle starts from and returns to the depot, each customer is visited exactly only once, and total demand in each trip does not exceed the vehicle capacity. Departure from any of these constraints is possible depending on the nature of the problem, for example if there are more than one depot, or if all vehicles do not have to be used to further save cost, or if each customer can be visited more than once (multi-trip or split-delivery VRP). Additional constraints may also be added such as time windows, backhauling requirements, demand stochasticity, or site dependency. These reflect the richness of problem characteristics in the field, which also lead to the birth of different variants of VRP. VRP is a complex problem (NP-hard), but it is widely applied, so many researchers continue to develop both heuristic and meta-heuristic methods to come up with the best solution.

Cost or distance minimization is the natural objective function in the mathematical programming formulation of VRP. However, not all measures can be expressed in cost or distance units. One example is route balance which leads to drivers' satisfaction. The need for secondary objective(s) calls for the multi-objective VRP (MO-VRP). The

methodology for this branch of VRP falls in the category of multi-objective optimization problem (MOOP) and is different from that of the other VRP variants. The divergence of MO-VRP from the main model produces different studies and thus different set of literature. The first comprehensive review of MO-VRP appeared in 2008 [1], but more than a decade has passed since that review. While the growth of VRP literature is exponential [2], the growth of MO-VRP is linear as suggested by the lack of articles found. This indicates a potential development considering many problems are inherently multi-objective if simplification is challenged. Therefore, this paper helps by not just providing review of the selected literature but also suggest a framework in the form of taxonomy that can be used to help classifying the research in MO-VRP.

The objectives of this paper are twofold. Firstly, it aims to summarize the selected new research of MO-VRP that span beyond 2008, hence, to fill some gap of additional studies of MO-VRP after the period 2008. Secondly, it aims to propose a taxonomy that can be used to categorize literature in this area for easier reference in studying MO-VRP.

The remainder of this paper is divided in several sections. The next section discussed the methodology used in searching the literature. The following section discussed the proposed taxonomy and explained the eight criteria used in the taxonomy. This is followed by a section that summarizes the selected papers and how they are mapped to the proposed taxonomy. The final section are the conclusion of the paper and discussion on further possible studies.

METHODOLOGY

The first part of the methodology is related to the search criteria in selecting the references. To differentiate our work from [1], we limit our search to journal articles published from year 2009 onwards. Two keywords were used as starting point: **vehicle routing problem** and **multi-objective**. From here we expanded our search with two additional keywords **bi-objective** and **bi-criterion**. This expansion is important because multi-objective problems often consist of only two objectives but some researchers maintain the term “multi-objective” to reflect their case. In recent years, the use of “bi-objective” or “bi-criterion” becomes more popular and it helps distinguish this class of problems from problems having three objectives or more. Therefore, the inclusion of the latter two keywords is a necessity to keep track on that problem class. On the other hand, the keyword multi-objective needs to remain as part of the search to cover the whole problem set.

As the search was expanding, smaller subsets of the problems were encountered that are identified by keywords such as the following:

- location allocation routing/location routing
- production and pollution routing
- inter-terminal truck routing problem
- bus routing model
- dial-a-ride problem

To keep the focus on the larger set of the problems, articles with the above keywords are excluded. In addition, specific routing problems such as multi-depot VRP or orienteering problem are also excluded. It is worth to mention that in [1], the authors in fact included the traveling salesman problem (TSP) in their review. This addition enlarged the pool of articles in [1]. However, although both are routing problems, VRP and TSP have significant differences in model formulation and application. For this reason, multi-objective TSP was excluded from the search.

With regard to the publication outlets, our search was limited to the articles published mostly via Science Direct due to the availability of access, with the exception of one publication from one of the authors of this paper. Also, articles from conference proceedings (such as Procedia) are excluded since such typical articles are of lesser depth compared to articles from journal publications.

The above methodology led to the finding of 39 journal articles. Due to the page limitation, we cannot list them all so we selected only 11 articles to be reported in this paper.

PROPOSED TAXONOMY

The proposed taxonomy with the mapping of the 11 papers is shown in two parts in Table 1. It consists of eight categories, namely: (1) author(s), (2) year of publication, (3) journal title, (4) problem class, (5) proposed method, (6) benchmarked method, (7) benchmarked instances, and (8) the objectives. The first three criteria are self-explanatory. In criterion 3, Applied Soft Computing ranks first with three articles, followed by Journal of Cleaner Production with two articles. The rest of the criteria are explained below.

TABLE 1a. Mapping of the literature to the proposed taxonomy (Part 1)

No.	Authors	Year	Journal	Problem	Proposed method	Benchmarked method/tool
1	Ghoseiri & Ghannadpour [3]	2010	Appl. Soft Comput.	VRPTW	GP, GA	None
2	García-Nájera & Bullinaria [4]	2011	Comput. Oper. Res.	VRPTW	MOEA	NSGA-II
3	Melián-Batista [5]	2014	Appl. Soft Comput.	VRPTW	Scatter search	NSGA-II
4	Wibisono & Jittamai [6]	2016	Int. J. of Logistics Systems and Management	HVRPTW	NSGA-II mod.	None
5	Miranda et al. [7]	2018	Appl. Soft Comput.	(H)VRPTW	MO Memetic Alg. MO Iterated LS	García-Nájera & Bullinaria (2011)
6	Bula et al. [8]	2019	J. Clean. Prod.	HFVRP	e-constraint	None
7	Ghannadpour & Zarrabi [8]	2019	Swarm Evol. Comput.	HVRPTW	Hybrid GA	NSGA-II, CPLEX
8	Xu et al. [10]	2019	Comput. Ind. Eng.	GVRPSTW	NSGA-II mod.	NSGA-II
9	Zhang et al. [11]	2019	Information Sciences	MOVRPFlexTW	Hybrid ACO	None
10	Ganji et al. [12]	2020	J. Clean. Prod.	GHFVRPTW	NSGA-II, MO-PSO, MO-ACO	NSGA-II, MO-PSO, MO-ACO
11	Khoo & Mohammad [13]	2021	Expert Systems With Applications	VRPTW	Two-phase distributed HRRGA	Various literature

The problem class describes the variant of the VRP with majority of the articles include time windows in the formulation. Some authors explicitly state if the time windows are soft (i.e. they can be violated with penalty cost). In the absence of such confirmation, the time windows are assumed as hard time windows. Consideration of heterogeneous fleet is also common. This is indicated in our system by the letter(s) “H” or “HF” (heterogeneous fleet) in front of the variant abbreviation. It is possible that authors simply used “VRPTW” even if the fleet is heterogeneous. Therefore, to clarify, it is crucial to look into detailed mathematical formulation. Another positive development in the direction of green logistics is the green VRP discussed in two articles. Although the distinction is actually more on the scope rather than in the methodology, it is safe to consider its wider adoption in the future, hence a merit for its own abbreviation GVRP.

The next criterion is related to the previous one and still confirms the popularity of NSGA-II [14]. Some papers which proposed the modification of NSGA-II compared the results to those obtained from the standard application of NSGA-II, while some others that used different algorithm simply performed direct comparison to the NSGA-II. To conclude, in this criterion, NSGA-II was benchmarked in five of the 11 reviewed articles.

The next criterion is on the benchmark instances used in the numerical experiment. Solomon instances are clear favorite in the testing. Other remaining papers are usually a continuation of previous study hence benchmarked to the past literature, often from the same authors.

TABLE 1b. Mapping of the literature to the proposed taxonomy (Part 2)

No.	Authors	Instances	1st objective	2nd objective	3rd objective
1	Ghoseiri & Ghannadpour [3]	Solomon	distance	number of vehicles	-
2	García-Nájera & Bullinaria [4]	Solomon	distance	number of routes	delivery time
3	Melián-Batista [5]	Solomon	distance	balance of workload	-
4	Wibisono & Jittamai [6]	Random generated	routing cost	deviation of targeted workload	-
5	Miranda et al. [7]	Solomon	travel cost	service levels (max)	-
6	Bula et al. [8]	Golden et al. (1984) modified in Bula et al. (2016) to include the risk parameters	routing cost	routing risk	-
7	Ghannadpour & Zarrabi [9]	Random generated	total consumed energy	number of vehicles	customer satisfaction (max)
8	Xu et al. [10]	Various literature but mainly Xu et al. (2015)	fuel consumption	customer satisfaction (max)	-
9	Zhang et al. [11]	Solomon	routing cost	customer satisfaction (max)	-
10	Ganji et al. [12]	The three metaheuristics are compared	transportation cost	tardiness	customer dissatisfaction
11	Khoo & Mohammad [13]	Solomon	total distance	number of vehicles	-

The last criterion is on the objectives formulated. Here, eight of the eleven articles deal with two objectives or can be categorized as bi-objective, and the remaining three articles added the third objective. The first objective is obvious as in the classical single-objective optimization, which is to minimize total cost/time/distance. The term used in the literature varies from travel distance, total time, routing cost, or transportation cost, but the essence is the same. The second objective is usually related to the balancing of workload or routes of the vehicles, with some papers formulated a unique objective such as service levels, routing risk, and tardiness. The third objective (which is sometimes used as the second objective in other papers) is usually on the customer satisfaction (to be maximized). In most papers, objectives are to be minimized, except for service levels and customer satisfaction, although the latter can also be formulated for minimization as customer dissatisfaction, as in the case in one of the papers.

ANALYSIS OF THE SELECTED LITERATURE

In this section, the selected 11 journal articles are discussed. Each paper is briefly summarized and at the end of each summary, the characteristics of the paper are mapped to the taxonomy explained in the previous section. The papers are listed under their title and ordered based on the publication year.

Multi-objective vehicle routing problem with time windows using goal programming and genetic algorithm [3]

In this paper, goal programming and genetic algorithm (GA) were used to solve VRP. Both methods were used to minimize the number of vehicles and minimize the total distance without violating the existing capacity limit and the time windows. However, the relationship between the two objectives used in this study cannot be known for sure since the number of vehicles and the total distance can be positively correlated or conflicting. From the simulation results, it can be seen that the solution produced by both methods can be considered quite good because it is close to the existing best known solution value.

The GA method begins with several sets of chromosomes called the initial population, in which each set of chromosomes represents the solution to the problem. The sets of chromosomes are randomly generated, or they are the results of the heuristic method because the heuristic method has a local optimum solution to shorten the required simulation time. Then, the selection mechanism will be used to select the parent chromosome which is then combined with a crossover operator to generate a new potential population. Furthermore, the new chromosome will be mutated with the aim that the resulting solution is not trapped in the local optimum.

An improved multi-objective evolutionary algorithm for the vehicle routing problem with time windows [4]

The objective of Vehicle Routing Problem with Time Windows (VRPTW) is to produce solutions with minimum total costs in managing delivery routes at several customer points with time windows and vehicle capacity limitations. The objectives in this paper are to minimize the number of routes, the distance, and the delivery time.

Evolutionary Algorithm is an optimization method based on Darwin's theory of evolution which stated that the best individuals will survive and produce new individuals for the next generation population. In this study, the initial population was obtained from selected random results with the aim of opening a wider search space. The first step was choosing a customer at random, and then place it at the first location to be visited on the first route. Next, other customers were chosen randomly. If the capacity and time window limits can be met, this point would be placed as the second location that must be visited on the first route. However, if the constraints could not be met, the point would be the first location to be visited on the second route. The next process would continue repetitively until all customers enter the route. After the simulation was completed, it can be seen that the solution obtained from the multi-objective evolutionary algorithm (MOEA) when compared with the solution obtained from the single objective evolutionary algorithm would show that the MOEA is able to produce a solution with fewer routes, and similar or shorter distances from the single objective evolutionary algorithm.

A bi-objective vehicle routing problem with time windows: A real case in Tenerife [5]

The research in this paper was inspired by a real problem in Tenerife, Canary Islands, Spain. The company wanted to not only minimize the total distance but also balance the workload of the driver or the distance that had to be covered by every vehicle. There were several constraints in solving this problem, namely the total load of one route must not exceed the capacity of the existing vehicle, the vehicle must arrive within the existing time window, the vehicle must wait if it arrives faster, and each route must begin and end at the depot.

The method used to solve this problem was the scatter search meta-heuristic. Scatter search is a population-based meta-heuristic that uses a reference set with the highest quality and solution dispersion to combine solutions and construct something else. This method generates an initial reference set from the population solution, then several subsets will be selected from the initial reference set. Next, the results from each subset will be combined to obtain an initial solution to carry out the repair procedure. After that, the result of the repair will update the existing reference set, and the process will keep repeating until the specified number of iterations. In addition to the scatter search method, a mixed linear integer model with added constraints and auxiliary variables was also used to balance the resulting route distance. The results obtained indicated that the method used was able to produce a better solution in comparison to the previous solution implemented by the company.

Multi-objective evolutionary algorithm for a ship routing problem in maritime logistics collaboration [6]

The authors of this paper proposed a hybridization of NSGA-II with a split-based route construction in a multi-objective heterogeneous VRPTW (MO-HVRPTW) setting. Given its application on maritime routing, a specific name was proposed, namely a ship routing problem (SRP). This new variant was proposed considering that in maritime logistics, heterogeneity of vessels owned by a liner shipping company (in capacity and sailing speed) cannot be neglected as it translates to significant difference in costs. Furthermore, a liner schedule has to be strictly followed, thus, time windows are obvious part of the formulation. Based on these considerations, HVRPTW is considered synonymous with SRP. The two objectives studied were the total costs and the deviation of the targeted workload. The second objective is related to the idea in the paper regarding collaborative activities of two liner companies, i.e. to ensure the fairness of capacity (division of market), the deviation to the targeted workload should be minimized.

Algorithms for the multi-objective vehicle routing problem with hard time windows and stochastic travel time and service time [7]

Vehicle Routing Problem with Time Windows (VRPTW) generally assumes the time needed to get to each point and the service time at each point is fixed. However, in reality both are stochastic. Therefore, it is expected that the model that considers these two factors stochastically is able to provide more accurate results in decision making. In this paper, the time to go to each service point and the service time at each point were considered stochastically.

The objectives of this study were minimizing operational costs and maximizing service levels, which are generally conflicting. The method used in this study was multi-objective memetic algorithm and multi-objective iterated local search. Furthermore, the results of the two methods were compared using an evolutionary multi-objective optimizer. In addition, the Pareto-optimal alternatives method with different trade-offs was also used to assist decision makers in choosing. The result obtained was that the multi-objective memetic algorithm method was better than the other algorithms used.

Bi-objective vehicle routing problem for hazardous materials transportation [8]

In the case of shipping hazardous materials, stakeholders from the sending party expect efficiency in shipping costs, while the government and the society expect good shipping security. These two objectives were formulated in this paper. Two methods were used in the paper, namely the multi-objective neighborhood dominance-based algorithm and the e-constraint meta-heuristic algorithm. After obtaining the results, the two objectives were compared using the Pareto front to find a solution that had the minimum total routing cost and minimum total routing risk. The results obtained indicated that the dominance-based algorithm method was better than the e-constraint method.

Multi-objective heterogeneous vehicle routing problem and scheduling problem with energy minimizing [9]

Goods delivery from one point to several consumer points is very important because it is related to the transportation costs incurred. Therefore, setting the delivery route becomes a very important decision-making problem. Such decision-making problems are commonly studied in optimization problems, namely the Vehicle Routing Problem with Time Window (VRPTW). This research discussed the Multi-Objective Heterogeneous Vehicle Routing Problem (MOHVRP). The heterogeneous concept referred to in this paper was that each vehicle has a different capacity and cost. In addition, if the number of vehicles owned cannot meet all delivery schedule, the company can rent vehicles from another company to make deliveries.

In this paper, there were two scenarios of objectives to be achieved, firstly, the total energy and total vehicles were minimized while the total satisfaction rate from the customer was maximized. Secondly, the total distance, the total rented vehicle, and the total fuel were minimized while the total satisfaction was maximized. The number of vehicles owned and their capacity were known data while satisfaction rate was described by using fuzzy time windows method.

The method used to solve HVRPTW in this paper was a memetic algorithm. In the first scenario, the company was assumed to only use its own vehicles to make deliveries. Meanwhile, in the second scenario, the company could rent a vehicle to make deliveries if the vehicle's capacity did not meet the target. In general, the fuel consumption rate is considered the same for each vehicle, but in this paper the fuel consumption rate was considered in particular. After performing the simulation, the results obtained from the memetic algorithm method can be said to be fairly effective.

A model for capacitated green vehicle routing problem with the time varying vehicle speed and soft time windows [10]

The Green Vehicle Routing Problem (GVRP) was developed as a multi-objective mixed integer non-linear programming (MINLP) model that considers the calculation of fuel use. In this paper, a model was developed to solve the green vehicle routing problem with time varying vehicle speed and soft time windows. The developed model was an improvisation of the Non-dominated Sorting Genetic Algorithm (NSGA-II) method by adding an adaptive strategy and a greedy strategy.

GVRP has both economic and environmental objectives. From an economic point of view, it is expected that shipping costs will be as small as possible to obtain the highest possible customer satisfaction, while from the environmental point of view, the goal of GVRP is to produce as little carbon emissions as possible by considering the speed factor. The results of the experiments conducted show that the fuel consumption for delivery could be reduced without lowering the level of customer satisfaction. The developed method had better capability and efficiency than the undeveloped NSGA-II method.

A hybrid ant colony optimization algorithm for a multi-objective vehicle routing problem with flexible time windows [11]

Vehicle routing problem with soft time windows (VRPSTW) means that the vehicle can make deliveries faster or slower than the specified time as long as it is within the existing time tolerance limit. This flexibility makes logistics companies able to save on distribution costs incurred to meet customer satisfaction. Therefore, many researchers continue to develop methods for VRPSTW in order to produce the best solution. In this paper, a Multi Objective Vehicle Routing Problem with Flexible Time Windows (MOVRPFlexTW) method was developed with the aim of minimizing total distribution costs and maximizing customer satisfaction. This method is the development of the meta-heuristic Ant Colony Optimization (ACO) method combined with mutation operations.

The ACO method is a swarm based meta-heuristic approach for VRP settlement. The ACO method has been widely applied for the settlement of several types of VRP, such as VRP with simultaneous pickup and delivery, VRP mixed backhaul, etc. Thus, in this study the ACO method was developed for the completion of VRPSTW by adding mutation operations. The existing mutation operation helped the ACO method not to get trapped in the optimum local solution. The simulation results obtained indicated that the developed method was quite effective because the resulting solution can compete with the existing best known solutions.

A green multi-objective integrated scheduling of production and distribution with heterogeneous fleet vehicle routing and time windows [12]

Integrating problems related to due date, production time, delivery time, shipping route management, and environmental factors can reduce costs. There were several objectives in this paper, namely minimizing distribution costs, fixed and variable costs of fuel, carbon emissions produced, total delivery delays, and customer dissatisfaction. The methods used to integrate the above were three multi-objective metaheuristic algorithms: Multi-Objective Particle Swarm Optimization (MOPSO), Non-dominated Sorting Genetic Algorithm (NSGA), and Multi-Objective Ant Colony Optimization (MOACO). The results obtained were then compared with the results of each of the existing methods and showed that the NSGA method had better performance.

The parallelization of a two-phase distributed hybrid ruin-and-recreate genetic algorithm for solving multi-objective vehicle routing problem with time windows [13]

Single-objective vehicle routing problem with time windows (VRPTW) optimizes only one objective function, while multi-objective vehicle routing problem with time windows (MOVRPTW) optimizes two or more conflicting objective functions. In the case of multi-objectives there can be more than one feasible solution, or it can be called non-dominating solutions. Non-dominating solutions means feasible solutions that do not dominate each other. The goal of MOVRPTW is to produce non-dominating solutions.

In this paper, a method was developed to solve the MOVRPTW problem by combining the principles of Hybrid Genetic Algorithm (HGA) and Hybrid Ruin-and-Recreate (HRR). In the classical Genetic Algorithm (GA), each genetic operator generates a solution and passes to the next operator sequentially. While in the HRRGA method, there are two phases. The first phase is the HRRGA phase, and the second phase is the HRR phase. In the HRRGA phase, the HGA will generate a customer list and then the customer list will enter the HRR phase to generate solutions. In the HRR phase, the principle used is ruin-and-recreate with different combination strategies. The objective of the developed model is to minimize the total distance and minimize the number of vehicles used for delivery. The results obtained indicate that the HRRGA method is superior to the classical hybrid genetic algorithm method.

CONCLUSION

This paper proposed a taxonomy for classifying studies on multi-objective vehicle routing problems. A number of journal articles were selected to be reviewed, summarized, and mapped to the proposed taxonomy. The number of papers reported here is limited because the main purpose of this paper is to show the applicability of the proposed taxonomy. From the review, it can be concluded that the majority of the VRP formulation includes time windows. Studies involving two objectives, leading to the search of the Pareto front, are more common than those with three or more objectives. As to the choice of algorithm, population-based algorithms, particularly those developed from the GA, stand out. Furthermore, NSGA-II seems to be a popular choice whether as the basis of a modified algorithm or as a benchmark algorithm. Finally, most researchers chose Solomon instances for the numerical experiment.

Given the general picture described above, it can be concluded that the taxonomy helps filtering various aspects of research in MO-VRP and is able to identify the trend in terms of choices in scope, tested/developed algorithm, and benchmark instances. These findings are promising and further expansion of the literature study can be suggested with the aim to fill the gap of literature review on MO-VRP beyond 2008.

ACKNOWLEDGMENTS

The authors wish to thank Ministry of Education and Culture and Ministry of Research and Technology of the Republic of Indonesia for funding this research under the scheme Penelitian Dasar Unggulan Perguruan Tinggi (PDUPT) contract no. 004/SP-Lit/AMD/LPPM-01/Dikbudristek/Multi/FT/VII/2021.

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Proceedings of the 8th International Conference on Engineering, Technology, and Industrial Applications 2021 (8th ICETIA 2021)

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Surakarta, Indonesia • 15–16 December 2021

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Hafidh Munawir; Muhammad Kuntoro Cahyono Putro; Hari Prasetyo

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Ergonomic risk assessment using ERIN and LUBA methods in rooftile product at Indonesia

Indah Pratiwi; Fitri Noer; Mila Faila Sufa; Afiqoh Akmalia Fahmi; Rizka Amelia Gestinengtias

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Implementation of key performance indicators (KPIs) in garment cutting section using balance scorecard (BSC)

Arinda Soraya Putri; Mohamad Joehan Fadhkurridha; Rizka Amelia Gestinengtias

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Experimental investigation of ash deposit behavior during coal cofiring with palm oil waste

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Soap product innovation from waste cooking oil by using coffee grounds adsorbent to increase eco efficiency

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The design and analysis of energy management for the optimal charging of electric vehicles based on estimated power flow and load conditions at electric vehicle stations using fuzzy logic controllers

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Herry Oktadinata; Sri Bimo Pratomo; Supono Adi Dwiwanto; Husen Taufiq; Hidayathul Akhmal

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Herry Oktadinata; Sri Bimo Pratomo; Supono Adi Dwiwanto

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Pramuko Ilmu Purboputro; Revan Fajar; Kholqillah Ardhian Ilman; Agus Yulianto; Dessy Ade Pratiwi; Ummi Kultsum; Nur Annisa Istiqamah; Desi Gustiani

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Ummi Kultsum; Bambang Waluyo Febriantoko; Ibrahim Aji Eko Imam Santoso; Masyrukan; Patna Partono; Dessy Ade Pratiwi; Desi Gustiani; Nur Annisa Istiqamah

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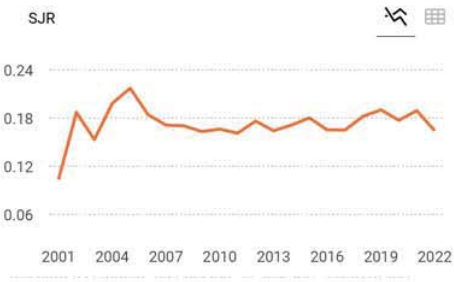

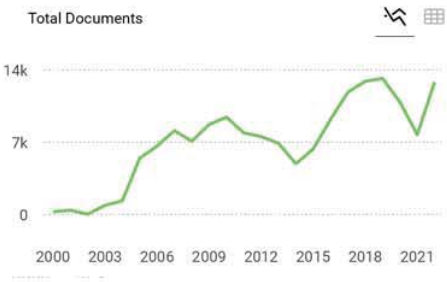

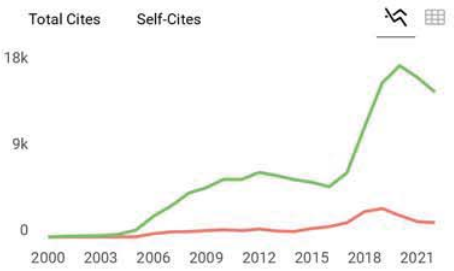

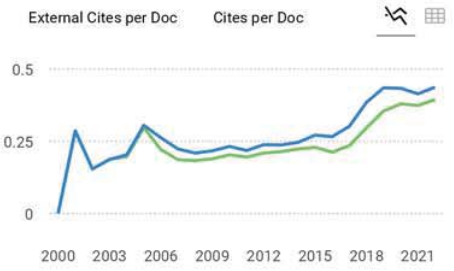

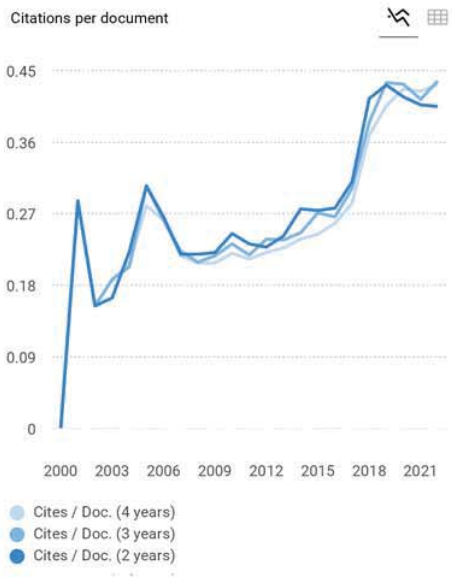

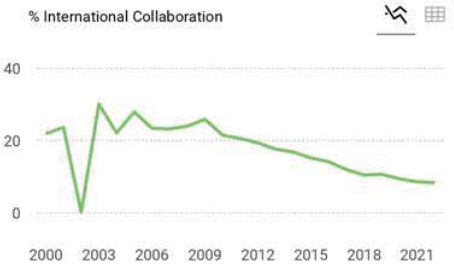

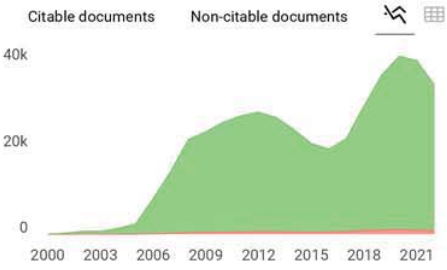

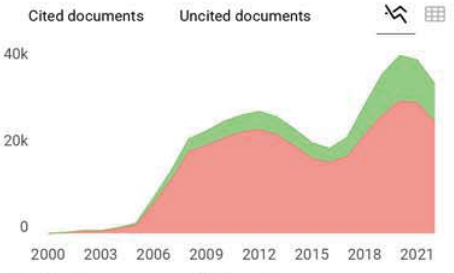

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