# MOPGP 2023

The 15th International Conference
on Multiple Objective Programming
and Goal Programming

## Book of Abstracts

October 02 - 04, 2023

Yaşar University, İzmir, Türkiye

YAŞAR UNIVERSITY
Department of Industrial Engineering

mopgp.org

in memory of
**Prof. Mehrdad Tamiz**

Professor Mehrdad Tamiz initiated the International Multiple Objective and Goal Programming (MOPGP) conference series in 1994 by chairing its inaugural conference in Portsmouth, UK and remained as Chair of the series until 2012. His desire for the conference series was to create a non-partisan space for open discussions on MOPGP topics and their application, an ethos that continues until the present day. Professor Tamiz gained his first academic position (tenure) at the University of Portsmouth, UK in 1991, following a PhD in Operational Research at Brunel University, UK. More recently, he held professorial positions at the University of Kuwait and Yasar University, Turkey. He published many articles in leading operational research journals and a textbook on the topic of goal programming. Mehrdad was known for his enthusiastic, generous and hospitable character, which resulted in the mentoring and training of many doctoral students and hosting of international visitors. He will be missed by his friends and colleagues in the MCDM community

# FOREWORD

Distinguished participants of the 15th International Multiobjective Optimization and Goal Programming Conference,

I would like to extend my sincere appreciation for your contribution and participation in the conference. We have the honor and pleasure of hosting this prestigious event which promises to be a stimulating and collaborative platform, fostering insightful discussions and innovative ideas at the Yaşar University, İzmir in 2023.

This year we dedicate the conference to the memory of Prof. Mehrdad Tamiz who initiated the conference series. Prof. Tamiz joined our department in 2021 but unfortunately lost his life unexpectedly last year. We will always remember him for his positive personality and contributions to the academic community. My condolences to all family, friends and colleagues, once again.

This year we have three plenary speakers and 33 talks from 12 different countries. I would like to thank all contributors for making this event possible. I hope that this conference series continues to be a platform for bringing academics and scientists together from all over the World.

I express my heartfelt gratitude to the organizing committee for their tireless efforts in curating a thought-provoking and comprehensive program. Their dedication and vision have shaped this conference into a beacon for academic and professional growth, fostering a collective spirit of progress and innovation.

To all participants, I encourage you to actively engage, network, and collaborate throughout this conference. Your contributions and insights are integral to the success of this event, and I am confident that the ideas generated here will resonate beyond these virtual walls, positively impacting our world.

Thank you for joining us on this exciting journey of discovery and exploration.

Warmest regards,

Prof. Ayhan Özgür Toy
Conference Chair

# 15th International Conference on Multiple Objective Programming and Goal Programming

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# INVITED SPEAKERS

## Serpil Sayın (Koç University):

She earned a B.S. degree in Industrial Engineering with a double major in Mathematics at Bogaziçi University in Istanbul in 1988. In 1992, she completed her Ph.D. studies in the department of Decision and Information Sciences at the University of Florida. She worked as an assistant professor in the Faculty of Business Administration at Bilkent University until July 1996. She then joined Koç University's College of Administrative Sciences and Economics where she currently serves as a professor within the Operations and Information Systems group. Her current research interests are in multiple objective optimization, data mining, decision support and healthcare.

## Representations of the Nondominated Set in Multiobjective Discrete Optimization

The solution to a multiobjective optimization problem consists of the nondominated set that portrays all relevant trade-off information. Obtaining the nondominated set in its entirety, however, is often computationally challenging. Although identifying a Decision Maker's most preferred solution without generating the entire nondominated set is a worthy goal, Decision Makers may not always be able to express their preferences without having a good understanding of the trade-off landscape.

In order to alleviate the computational and cognitive load that comes with obtaining the entire nondominated set, the representation idea suggests finding a representative subset of the nondominated set that conforms to some prespecified quality measure. We provide a brief overview of representation approaches for multiobjective optimization along with the associated quality metrics such as coverage error, epsilon indicator and hypervolume. We then focus on the multiobjective discrete optimization problem and describe a representation algorithm that delivers a solution set that conforms to a desired coverage error level. Observing the sensitivity of the computational effort to the number of objective functions of the problem, we report on an empirical investigation that uses projections to reduce the dimension of a given problem. We observe that a careful preprocessing of the problem data may have positive implications in terms of obtaining good representations. We conclude with implications for future research.

# INVITED SPEAKERS

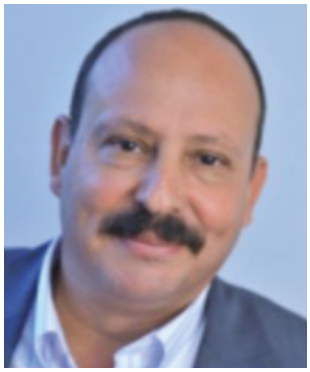
## Francisco Ruiz (University of Malaga):

He earned his B.S. degree in Mathematics at University of Malaga (Spain) in 1989. He completed his Ph.D. degree in Economy and Business Sciences at University of Malaga in 1994. He has worked as an Associate Professor at Applied Economics department of University of Malaga between 1999 and 2009. He has been working as a Full Professor at the same department of University of Malaga since 2009. His research areas are Multi-objective Optimization, Mathematical Programming, Multi-criteria Decision Analysis, Operation Research, and Applied Mathematics.

### SOME EXPERIENCES WITH GOAL PROGRAMMING: The Origins and Latest Contributions

This presentation begins with a brief review of the first MOPGP conference, held in 1994 in Portsmouth (United Kingdom) and organized by Professor Mehrdad Tamiz. It lists the names of the researchers I met there, and how they influenced my research career. As a result of this conference, I began working with professors Rodríguez-Uría and Romero, with whom I developed the Meta-Goal Programming methodology, which is described next. Finally, I present my two latest applications of Goal Programming. In the first one, Goal Programming is combined with statistical (econometric) analysis to determine the profile of the most profitable insurance companies. In the second one, the Meta-Goal Programming methodology is applied to the cardinal preference aggregation problem.

# INVITED SPEAKERS



## Fouad Ben Abdelaziz (NEOMA Business School):

He is currently Distinguished Professor at NEOMA BS, Rouen Campus, France. He received his PhD in Operations and Decision Systems from Laval University, Canada. He was a Senior Fulbright scholar at the Rutgers Center for Operations Research, Rutgers University, NJ, USA. He is a leading researcher in multi-objective stochastic optimization. Aside from his publications in outstanding journals like EJOR, ANOR and FSS, he has served as Guest Editor of special issues of reputed international journals. Dr. Ben Abdelaziz has worked/visited many universities around the world such as the University of Tunis, the American University of Beirut, the University of Dubai, and Pace University NY. He has been consulting for the chemical industry and was appointed as an assessor for the Dubai Business Award. His recent research interests are in Supply Chain Optimization and Applications. He was appointed as the director of the Doctoral School and the Director of the LARODEC Lab at the University of Tunis.

## Metaheuristics for Multiobjective Optimisation

In solving complex multi-objective optimizations, metaheuristic algorithms have emerged as an efficient strategy. These iterative computational procedures belong to an optimization algorithm category that possesses exceptional adaptability skills when it comes to handling diverse search spaces with intricate features along with several objectives and constraints simultaneously. We discuss different types of metaheuristics, such as genetic algorithms, particle swarm optimization, and simulated annealing, and explain how metaheuristics can be applied to multi-objective optimization problems.

We focus on the Many-Objective case where the number of objectives is large enough and cannot be handled easily with standard metaheuristics. We show that the main problem of such algorithms encounter is the balance between convergence and diversity.

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# Distributionally robust multiobjective optimization under partial knowledge and imprecise information

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**Keywords:** Robustness, Probability measure, Multiobjective optimization, Partial knowledge, Imprecise Information

## ABSTRACT

Stochastic optimization and multiobjective optimization saw a rapid, impressive and extremely fruitful development in the decades since then. Given a stochastic multiobjective problem, we explore different definitions of robustness associated with the notion of deterministic equivalent problem. The multiobjective approach can also be considered as a generalization of traditional mean-risk models.

In this paper we mainly analyze the notion of robustness in the case of partial knowledge and imprecise information. In many theoretical model the underlying probability distribution it is assumed to be known. But in practical applications of stochastic programming we often have partial knowledge on the statistical properties of the model parameters and the involved probability distributions are never known exactly (i.e. we are in the case of the so-called Knightian ambiguity about probability distributions). Specifically, the probability distribution quantifying the model parameter uncertainty is known ambiguously.

A common approach to deal with this ambiguity, from a statistical point of view, is to estimate the probability distribution using statistical tools. The decision-making process can then be performed with respect to the estimated distribution. Ambiguous stochastic optimization, instead, is a modeling approach that protects the decision-maker from the ambiguity in the underlying probability distribution. Ambiguity about probability distribution can be modelled using the concept of imprecise probability or more generally the notion of set-valued probability. Another way to model ambiguity is to assume the underlying probability distribution is unknown and belongs to an ambiguity set of probability distributions. This approach is well-known in robust optimization.

In this paper, we consider this last approach. More in details, we will focus on the worst-case (minmax) approach and introduce the notion of distributionally robust multiobjective optimization. We will give scalarization results and optimality conditions in the convex case. When robust solutions of a multiobjective optimization problem are considered, a loss of efficiency occurs with respect to the solution obtained in the nominal problem. We will provide results to estimate the efficient frontier of the nominal problem and the robust problem and the related efficiency loss through suitable nonlinear scalarizations and set distances, according to the shape of the uncertainty set. In particular, in this framework, we will study sensitivity analysis of the robust solutions with respect to changes of the uncertainty set. The Monge-Kantorovich distance between distributions will play a crucial role in estimating the loss of efficiency.

# Preferential perspectives on, and modifications to, revised multi-choice goal programming

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**Keywords:** Goal programming, Revised multi-choice goal programming, Multiple criteria decision making, Preference modelling, Sustainability

## ABSTRACT

This seminar examines the revised multi-choice goal programming (RMCGP) variant from the perspective of modelling the decision maker(s) underlying preferences. The contribution of the RMCGP to the goal programming paradigm and its range of applications are first detailed. Despite the healthy level of application of RMCGP, it has had little examination in the context of preferential modelling or in connection to the wider field of goal programming to date. This seminar therefore conducts a preferential and modelling analysis of the RMCGP from the perspective of the wider goal programming paradigm. Whilst unique contributions of the RMCGP are identified, points for enhancement are also revealed. This seminar therefore proposes modifications to the original RMCGP in order to deal with the following modelling and preferential enhancement issues:

(i) algebraic simplification

(ii) differential weighting of deviational variables

(iii) preferential compatibility with one-sided goals

(iv) normalisation and

(v) addition of a Chebyshev term to allow balanced solutions.

Enhancement (v) yields a further contribution, the development of a new, extended revised multi-choice goal programming (ERMCGP) variant. This is achieved by first implementing enhancements (i)-(iv), a modified version of the RMCGP is proposed which is more computationally efficient and preferentially straightforward. Its linkage to a weighted goal programming model with a penalty function is shown. Preferential enhancement (v) thus leads to the new goal programming variant, an extended revised multi-choice goal programming (ERMCGP) model. The modified RMCGP and the ERMCGP are demonstrated on an example from the literature and comparisons are drawn with the original RMCGP and extended goal programing. Implications for, and usage in a range of fields of application, including those drawn from the field of sustainability are discussed. Conclusions are drawn as to the future development of the RMCGP within the goal programming framework and its context within the wider fields of multiple criteria decision making and operational research modelling.

# A multiple criteria optimal control model for emission-mobility reductions and sustainable city planning

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**Keywords:** Multiple criteria optimization, Optimal control, Environmental control, Sustainability

## ABSTRACT

We propose a multiple criteria time-space model to decide the optimal allocation of economically attractive urban areas by transportation mode and land-use polices, and at the same time, minimizing the emission of pollutants and the impact of mobility trips among origin and destinations. The scope is to provide a multiple criteria optimal control model to balance the economic value of urban mobility and the its sustainability in terms of environmental emissions of the trips involved (see [1, 3]).

A geographical region of interest, R, is specified as the portion of territory which we are interested on. Over the region of interest, a set of geographical tiles called tessellation, T, made up of locations lj so that $\mathrm{T} = \{l_i : \mathrm{i} = 1 \ldots N\}$ so that the locations are non-overlapping, $l_i \cap l_j = \emptyset$, $\forall \mathrm{i} \neq \mathrm{j}$, and the union of all locations completely covers the region of interest, $\bigcup_{i=1}^{N} l_i = R$. In the case of interest, location tiles are the census areas defined by national authorities for administrative and demographic purposes. The underlying network is represented as a general Origin-Destination table which is a weighted adjacency matrix with nodes that are connected by directed links, and the links denote the trips (people moving) from location lj to location li per unit of time conditional to the feature variables characterizing the locations both as an origin and as a destination. More- over, each trip is characterized by the emission contribution due to the distance traveled between origin and destination with respect to the transportation mode used. In a latent-variable modeling rationale, each location is labeled as destination by latent variables $\mathrm{X_i} \in \Omega\mathrm{X}$, which represents the attractiveness of location where a trip ends and $\mathrm{Y_i} \in \Omega\mathrm{Y}$ represents the productiveness of travels where a trip starts. Those latent variables are interpreted as real-world urban features in terms of socio-demographic attributes and they can be identified as drivers of the travel demand and supply in the transportation system.

From a dynamical perspective, the dynamic constraints are modelled over a random graph process that is a stochastic process that describes a random graph evolving in time up to the final horizon T. The random graph process is a family of {G(t)} of random graphs where the parameter t is interpreted as time. The evolving mobility graph is fully described by means of a time-varying adjacency matrix A(t) which represents the origin-destination emission table. In particular, the sum along the columns represent the in-strength distribution of the nodes $R_\kappa$ (x, t) or equivalently, for a region x, the strength $\kappa$ is the number of visits (degree k) received up to time t multiplied by the weight of the correspondent trip-cost c between destination x and the origin y.

The model can be characterized by the temporal evolution of the strength distribution written as an integro-differential equation [2] describing the travel patterns and consequently the emission patterns throughout the urban region. A spatial cost term can be introduced in order to take into account that during the trip the emission has been diffused and dispersed in the path between an origin and a destination.

The cost functional includes different terms that measures- from one side- the financial efforts and the attractiveness of destinations and- from the other side- the effort to contain the environmental emissions due to trip-costs.

Finally, any trip between origin destination pairs (x, y), can be determined in an optimal way in order to minimize the environmental cost (i.e. pollutants) emitted during the trip in the areas crossed during the trips at the final daily horizon T.

In such perspective, green policies and sustainable investments can be introduced in urban planning policies in order to reduce the impact of transportation systems by balancing economic and financial investments and greener mobility strategies.

# Improving performance of a distance-based multi-criteria sorting method: DISWOTH II and DISWOTH III

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**Keywords:** Multiple criteria sorting, Nearest centroid classifier, Decision boundary, Mathematical programming, DISWOTH

## ABSTRACT

In this paper, a recently developed multi-criteria sorting method, DIstance based Sorting WithOut class THresholds (DISWOTH), is studied for performance improvements. DISWOTH is a distance-based multicriteria sorting method based on a NonLinear Programming (NLP) model. NLP models are computationally complex requiring high computational power to be solved in a reasonable time. Besides its computational complexity, as with all distance-based methods, the performance of DISWOTH is sensitive to distance function choice. There is no single distance function that results in the best performance for all data sets. It is also a nearest-centroid type of sorting method, and the centroid choice also affects the performance. DISWOTH suffers from the problem of parameter selection, namely the selection of distance function and centroid. To overcome these problems, the classification rule formulations, error formulations, and the decision boundary of the DISWOTH are analyzed.

This paper presents a solution to computational complexity and parameter selection problems by investigating the classification decision boundary characteristics of DISWOTH. To overcome the computational complexity problem, the distance function formulation is changed such that it keeps the decision boundary as is while linearizing the nonlinear formulations. As linear programming models are more efficient than NLP models, computational complexity significantly decreases. The parameter selection problem is handled by a distance and centroid selection algorithm based on a recent study on centroid-based methods. The algorithm selects a centroid and distance pair that results in relatively higher accuracy (lower misclassification/error). Two extensions of DISWOTH are developed. For both extensions, solutions for linearization and parameter selection are applied. The first extension, namely DISWOTH II, formulates the classification error with Pure Misclassification Minimization (PMM) formulation, which is a Mixed Integer Linear Programming (MILP) model. In the first extension, it is shown that employing the PMM model linearizes the distance formulation without changing its decision boundary characteristics. The second extension, namely DISWOTH III, combines minimizing the sum of deviations and pure misclassification formulations as a hybrid method. This extension is a two-step linear approximation of DISWOTH II, making it computationally more efficient than DISWOTH and DISWOTH II.

To examine the performance of the developed methods, experiments are conducted on 10 real life data sets. The data sets are partitioned into two, namely, reference and test sets. The models are solved for reference sets, and the optimal classification parameters are tested on test sets to obtain test classification accuracy. DISWOTH II and DISWOTH III are compared with DISWOTH and UTilities Additives DIScriminantes (UTADIS) from literature. CPU time and test classification accuracy are used as performance measures.

Computational experiments show that the developed methods significantly improve the performance of DISWOTH regarding CPU time and test classification accuracy. They decrease the CPU time of DISWOTH by 97% on average and increase test classification accuracy by 3.78% on average. The test classification accuracies of the developed methods are also significantly higher than UTADIS. Thus, these enhancements make DISWOTH more appealing to practitioners and increase its applicability.

# A multi-objective immediate due date assignment policy with family setups

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**Keywords:** Scheduling, Due date assignment, Family setup, Sequence-independent setup time

## ABSTRACT

Due date is the promised delivery time to customers. When a job is completed before the due date, a company may encounter earliness penalties such as inventory holding cost, tied-up capital (opportunity) cost and product deterioration cost. When a job is completed after the due date, a company may confront tardiness penalties such as monetary penalizations for late delivery, customer dissatisfaction, loss of customer goodwill, damaged reputation and potential loss of customers and market share in the long run.

Assigning loose due dates provides flexibility to assure delivery reliability for a company but also leads to loss of competitive power in highly competitive markets. This may cause customers to prefer a competitor company that promises earlier delivery. Assigning tight due dates is attractive for retaining customers but increases the potential tardiness risk of jobs. The trade-off between assigning tight and loose due dates reflects the trade-off between competitive power and delivery performance.

In this study, a dynamic environment is considered where jobs may arrive over time and job related data reveal at arrival times. Additionally, each job belongs to a family. A family is a set of jobs that can share a common setup. A sequence-independent setup time is required before switching to a different family.

Due dates can be assigned on a periodic basis at fixed scheduling periods. In this way, due dates can be assigned by a straightforward batching policy based on the jobs gathered within a scheduling period whose data are already revealed at arrival times. A batch is a group of jobs from the same family which can be processed consecutively by sharing a common setup. Batching increases operational efficiency through sharing a single setup for the jobs that belong to the same family. However, customers wait to get a due date in addition to flow time of jobs. Hence this method is not appropriate in highly competitive markets. Alternatively, due dates can be assigned immediately at the time of a new job arrival. In this approach, batching is not straightforward and can potentially lead to a high number of setups if the new arrival is assigned based on first-comefirst- served (FCFS) rule. By this way, a further due date can be assigned for that new job. Otherwise, the new job can be assigned a closer due date by inserting it into the existing Schedule through appending it to one of the batches allocated to its family. Yet, this will shift the current schedule and the completion times of incomplete jobs and possibly increase their tardiness.

In this study, immediate due date assignment is studied. While assigning a due date for the new arrival, that job should be introduced into an existing schedule. Accordingly, there are two conflicting objectives: i) minimizing tardiness of incomplete jobs with already assigned due dates, ii) minimizing the due date assigned for a newly arrived job. From companies' point of view, tardiness minimization is vital. From customers' point of view, a shorter due date is critical. Hence, an efficient due date assignment policy should capture this trade-off between two conflicting objectives.

A two-phase solution approach is suggested. In the first phase (batch allocation), a forward-looking family-based capacity allocation takes place in an offline and periodic manner. Family splitting is allowed hence one family can be assigned to more than one batch. The allocation is done according to the expected workload of families of new arrivals while taking incomplete jobs from previous periods into consideration. The outputs of this phase are family-batch allocations, the number and sequence of the formed batches, batch sizes, and assignment of rescheduled incomplete jobs. This phase serves as a pre-arrangement for the second phase. In the second phase (due date assignment), a due date is assigned for a new job arrival in an online fashion instantly, based on the configuration obtained from the first phase.

For each phase, a heuristic algorithm is developed. A simulation study is carried out to measure the performance of the proposed solution method against FCFS policy.

# Objective weights for multiple criteria: The Automatic Democratic Method

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**Keywords:** Multi-attribute decision making, Weighting, Ranking, Performance measurement, Composite indices, Data envelopment analysis

## ABSTRACT

We consider a situation where entities are being scored and ranked based on multiple attributes.

The entities may be products, services, organisations, candidates etc. Rankings of universities, countries, consumer products etc. often appear in the media, and so this is an attractive application area for the Multiple Criteria Decision-Making community to investigate.

A key issue is agreement on what the attribute weights should be. This weight elicitation is a 'cognitively demanding' problem. Currently, such weights are chosen by the publishers of the rankings, who typically have no expertise in the methods of MCDM.

In a competitive environment the problem can be perceived as one in which each entity wishes to maximize its score and hence we have a multi-objective programming problem.

We propose a scheme to produce objective weights which is data-driven and involves two steps.

Firstly, the maximum score for each entity in turn is obtained by allowing that entity to have its own weights, constrained to ensure that no scores exceed 100% for any entity. This is achieved using DEA (data envelopment analysis).

The second step is to find a single set of weights to be applied across all entities. This is achieved by regressing the optimal scores on the underlying attribute data. This regression has the effect of trying to make the final scores as close as possible to the optimal scores. The coefficients in this multiple regression provide the final weights.

The method is tested on data where the true scores and weights are known. We compare different forms of regression (distance metrics) as well as steps to ensure the final scores do not exceed the initial optimal scores, treated as upper bounds.

The functional form of the scoring formula is not restricted by our approach. Apart from a weighted sum, it could, for example, be a weighted product (multiplicative form), or a ratio of linear forms (which is often used when assessing efficiency, as a generalization of the productivity ratio).

The method enables the construction of an objective scoring formula which is generated directly from the data arising from all the assessed entities and is, in that sense, democratic. A valuable benefit of the proposed approach is the transparency of using a simple, and objectively constructed formula, for performance evaluation.

# Prioritizing payment methods with Integrated Fuzzy AHP- TOPSIS approach considering information security criteria in terms of cyber security strategy for e-Commerce sites

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**Keywords:** Multi-attribute decision making, Weighting, Ranking, Performance measurement, Composite indices, Data envelopment analysis

## ABSTRACT

The development of technology has led to changes in many areas, as well as changes in information security. With the increase in the use of digital media due to these developments, one of the areas affected by technology has been the environment where information is found and stored. For this reason, it is seen that the security of this digital environment, where information is kept, called CyberSpace, has become a very important issue for the functioning and protection of the existing order of states and institutions in today's world. Based on this need, it is important to carry out various security-enhancing studies on the security of information in the digital environment under the cyber security strategy. One of the areas where cyber security studies need to be done is e-commerce sites, which are frequently used by many people and where there is a lot of personal or corporate data flow, and many payment transactions can be made in this way. It is foreseen that the creation of a cyber security strategy to ensure information security will be beneficial for institutions. In this regard, it has been determined that examining and prioritizing payment methods for e-Commerce sites will be beneficial for ensuring information security, while increasing the quality standards of cyber security strategies of e-Commerce sites. In this context, this study first addresses the role of decision analytics in cyber security, examines information security criteria in detail, and includes the reviewed literature on Fuzzy Multi-Criteria Decision Making (FMCDM) methods. With the reviewed literature, it has been determined that the Integrated Fuzzy AHP TOPSIS Method, which is one of the Multi-Criteria Decision Making Methods, is suitable for this study. The methodology we propose is implemented in order to prioritize alternative payment methods according to information security criteria. The criteria used are confidentiality, integrity and accessibility criteria, which are known as the CIA Triad and have a critical role in information security. It was determined which of the alternative payment methods should be preferred within the scope of information security criteria within the scope of quality standards for e-commerce sites and decision analytics that ensure cyber security to be measurable. Thus, it is foreseen that this digital environment, where there are many important data flows such as the payment stage, will be more reliable and will benefit the satisfaction of customers who are e-commerce site users and the quality standards of institutions. In addition, in this study, the contributions of cyber security to sustainability in the environmental, social and economic fields are examined in line with the United Nations Sustainability Principles. In this way, the need for cyber security and strategies related to cyber security was explained with real life examples, and it was aimed to better assimilate the scope and importance of the subject.

# Interactive approach to multistage bipolar method

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**Keywords:** Multistage decision process, Multistage alternative, Reference sets, Multistage bipolar method, Interactive approach, Dynamic programming

## ABSTRACT

The Bipolar method, proposed by Konarzewska-Gubała is an MCDA method; here we will call it the classic Bipolar method. The individual phases of this method use elements of the Electre methodology as well as algorithms of confrontation. This method has been described in many earlier papers and applied in practice. A detailed description of the classic Bipolar method, published in Trzaskalik et al. (2019), compares it with other multicriteria methods.

A fundamental feature of the Bipolar approach is that the decision alternatives are not compared directly with each other, but by means of two sets of reference points: objects with desired characteristics, called “good” objects, and objects with undesired characteristics, called “bad” objects.

Multistage Bipolar Method (Trzaskalik 2021, 2022) is an extension of the classic Bipolar approach —which is a single-stage procedure—to control multistage discrete decision processes. This requires that new notions should be defined, directly related to the extension being constructed, such as stage alternative, multistage alternative, stage reference sets, vectors of indicators and pointer function.

We consider T-stage decision process. Two kinds of alternatives: stage alternatives at for t = 1, ..., T and multistage alternatives a = (a1, ..., aT) are distinguished. At each stage of the process, two reference sets are defined: the first, containing “good”, desirable reference objects, named Gt, and the second one, containing “bad”, non-acceptable reference objects, named Bt. They make up a reference system. At each stage, the reference set of good objects and the reference set of bad objects are disjoint.

The numerical procedure in the Bipolar Multistage Method consists of three phases. In the first phase a comparison of stage alternatives with stage reference objects is performed. In the second phase the position of stage alternatives with respect to the bipolar stage reference system is defined. We calculate the values the degree of stage success achievement as well as the values of the degree of stage failure avoidance.

In the third phase relationships in the set of multistage alternatives are considered. For each multistage alternative values of the multistage success achievement degree as well as the values of the multistage failure avoidance degree are defined.

Using these values, the multistage alternatives can be sorted into six classes in such a way, that each multistage alternative from the class of the lower index is preferred over any multistage alternative from class of the higher index. Within the classes the ordering of the multistage alternatives is defined.

The final solution is defined as the multistage alternative which belongs to the non-empty class with the lowest index m and is the best within this class.

Till now the method has been considered as a single-run method. The aim of the present contribution is to introduce interactive approach to the method. We propose introducing dialog procedures with a DM in each phase of the method.

An essential part of the contribution is a numerical example which illustrates the notions relationships and interactive procedures introduced.

# Goal programming technique for fair single source capacitated facility location problem

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**Keywords:** Facility location problem, Single source capacitated facility location problem, Goal programming, Multi-objective optimiza-tion, Multi-criteria decision making

## ABSTRACT

Facility Location Problem (FLP) is of paramount importance in Operations Research (OR) literature since it plays a vital role in developing the service quality of facilities to potential customers. This problem concerns companies as well as governments and they should take this problem into account to solve problems to the optimality or near optimality with the hope of improving their objectives. These objectives range from maximizing profits/minimizing costs to maximizing customer satisfaction. Along with the drastic increase in the number of companies in recent years, decisions related to facility locations have been rendered more sensitive to make while considering all problem-specific constraints. In private sector, the aim of companies is to maximize profits and share of the market (i.e., food, automotive, energy, construction industry) to be able more competitive. Nonetheless, the objective of governments is to decide on the best possible locations of facilities under budget constraints. The primal purpose of the facility location problem is to maximize the welfare of the government in lieu of maximizing profit. In the conventional FLP, the chief aim is to minimize the total cost arising from opening facilities and assigning customers to the opened facilities which are fixed and variable costs, respectively. However, there are various types of FLP where capacity constraints of the facilities, supply of goods/services to customers by only one facility, and fairness of distribution of costs among customers are widely considered.

Due to the abundance of stakeholders related to this problem, it is no surprise that FLPs in the literature are modeled as both single and multiple-objective optimization problems. To handle different single-objective FLPs, there exist a lot of well-known solution methods, categorized as exact and heuristic depending on the size of the problem. For example, B&B and Benders' Decomposition methods can be given as good examples of exact solution techniques to solve the small-sized instances to the optimality. On the other hand, Lagrangian heuristics, Greedy heuristics, and Local Search heuristics are often employed to tackle with large instances in a reasonable amount of computational time. In addition to problem-specific heuristic algorithms, such meta-heuristics as Simulated Annealing, Genetic Algorithm, Tabu Search, Greedy Randomized Adaptive Search Procedure are also used to provide a reasonable solution to large instances. In order to solve a multi-objective FCP, an effective solution technique such as Goal Programming (GP) is also a promising one where the objective is to minimize the total deviation from the pre-determined aspiration level of each goal.

In this study, a bi-objective Single Source Capacitated Facility Location Problem with Fairness objective (F-SSCFLP) is dealt with to provide a compromise solution for these conflicting objectives. The first part of the objective functions is related to the total costs which exist in the conventional FLP. On the other hand, the second part of the objective function represents the fairness of these variable costs among customers. To measure this fairness among customers, the conditional β-mean concept is employed. The properties of the F-SSCFLP model are discussed and the corresponding mathematical formulations are provided. Due to the bi-objectivity of the problem, an exact solution method, namely Goal Programming (GP) is considered. GP is a genre of Multiple Objective Programming by which various Multi-Criteria Decision Making (MCDM) problems are solved efficiently. To determine the aspiration levels of each objective function in the bi-objective model, two single-objective models are solved separately, and the obtained solutions are considered as the aspiration level of the relevant objective. Then, deviations from these target values are minimized by using an achievement function as an objective. Therefore, the best compromise solution is attained under resource-related constraints with different weights of the goals. Small, medium, and large-scale problem instances from the OR literature are used to solve the F-SSCFLP with the suggested solution methodology. Then efficiency of GP to solve the F-SSCFLP is discussed by comparing the results with the ones existing in the literature.

# Multi-objective reinforcement learning application for supply chain management of a textile company

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**Keywords:** Supply chain management, Markov decision process, Goal programming, Multi-objective optimization, Reinforcement learning

## ABSTRACT

Reinforcement learning is a type of machine learning approach that focuses on training the agents of a system to make near-optimal decisions by interacting with the environment. It is an efficient tool that has been getting more and more popular in various Operational Research (OR) applications. It is inspired by the idea that intelligent systems can learn through trial and error (i.e., a process similar to human reasoning). In RL, the agent learns through a process of exploration and exploitation. It takes actions in the environment and receives feedback in the form of rewards or penalties. In exploration phase, new features of the environment, the world, are explored by selecting sub-optimal actions. On the other hand, in the exploitation phase, it utilizes what is already learnt while searching for actions that improve the performance. The aim of RL is to learn the best possible action in each state of a dynamic system in order to improve the policy. In the OR literature, RL can be applied to both single-objective and multi-objective optimization problems. Although it is rather practical to apply RL to single-objective optimization problems, most real-life problems are multi-objective where the objectives happen to be conflicting. In such scenarios, Multi-Objective Reinforcement Learning (MORL) which is an extension of reinforcement learning dealing with problems involving multiple conflicting objectives is rather handy. In MORL, the agents aim to find a policy to achieve good compromise solutions for different objectives. In many situations, we encounter such multi-objective problems to which MORL can be applied. Supply Chain Management (SCM) involves such models with multiple objectives due to its complex nature. Especially, the manufacturing process of textile goods gives rise to different performance measurements and corresponding target levels at each stage of the supply chain that consists of procurement, operations management, logistics, and marketing channels. The performance measures, namely criteria, have various impacts on the overall objective function of the problem. Consequently, SCM of textile products is a difficult process and is a reasonable example for multi-objective decision-making. Due to this aforementioned complexity, the application of MRL techniques to find compromise solutions is challenging. Under the scope of this study, we contacted a garment manufacturing company situated in İzmir/TURKEY to apply our methodology. We aimed to construct a multi-objective objective optimization model for the manufacturing process of this company that considers performance criteria for all stages of the supply chain from raw materials to finished goods. Then, we converted the formulation of this optimization problem to a Markov Decision Process (MDP) and applied the MORL approach to solve this model in an efficient way. Moreover, the efficiency of the proposed approach will be compared to some of the well-known methods to solve multi-objective problems such as Multi-Objective Particle Swarm Optimization (MOPSP), Pareto Local Search Algorithm (PLS), and NSGA II. The superiority of using MORL approach to other popular methods while solving such multi-criteria optimization problems is its flexibility. MORL can be utilized to solve the same problem with different datasets via online platforms, continuously updating the solution as the environment changes in time.

# Multi-criteria decision-making on transportation of a metropolitan city: İzmir case study

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**Keywords:** Transportation problem, Goal programming, Multi-objective optimization, Multi-criteria decision making

## ABSTRACT

Nowadays, transportation is a significant issue that is considered worldwide. Due to increased sensitivity to green environments, more and more people have started to prefer public transportation. Especially the governments in metropolitan cities offer various public transportation modes and routes for the residents to encourage them to use public transportation opportunities. Depending on the route, and the type of the vehicle, the capacity, speed, comfort level, and fare may change among alternatives. Every day, thousands of people travel from an origin to a destination within the city at different times of the day. The travel usually requires walking to and from the nearest station and transfer between vehicles and transportation modes. Passengers may have different and alternative criteria depending on their objectives and preferences. Some people prefer the cheapest alternative, whereas others prefer the fastest. Walking distance, number of transfers, comfort level, ability to carry baggage, and group traveling can be considered factors that passengers consider while choosing the transportation mode, line, and timing.

In addition to these factors, there may be some constraints, such as the capacities of vehicles, the budget of customers, the minimum level of comfort level, the maximum level of carbon footprint, or the maximum number of transfers that can be made free of charge. When some of these constraints and choices are considered, this real-life system can be represented as a transportation model with multiple objectives. This study considers the city of İzmir for such a multi-criteria decision-making problem. İzmir is a metropolitan city in Turkey with the third highest population, with 4.4 million people. The total area of İzmir is 11,973 square kilometers. First, we will pick a particular location for originating a trip and another location for the destination within this area. Then, we will develop a mathematical model representing the transportation network for that origin and destination pair.

As discussed above, we will identify various objectives and constraints for a passenger and represent those objectives as functions with these constraints. Possible objective functions are minimizing travel distance and total cost maximizing comfort level and passenger satisfaction with relevant constraints. After determining the objective functions and corresponding constraints, we will construct the multi-objective mathematical model for the system we consider. After the construction phase of the model, we will implement some solution methodologies appropriate to our model. We will solve the corresponding model using IBM CPLEX Solver for minor or medium-scale problems. We will explore some rule-based heuristic or metaheuristic methods as well in order to solve large-scale problems in a reasonable time and efficient way. Finally, we will generalize the model to incorporate arbitrary origin-destination pairs and the presence of intermediate stop-over locations based on user preferences. The results for the medium-scale problems will be reported separately for both heuristic and exact methods, and comparisons will be made. Moreover, results for all scales of problems will be reported and discussed. Future works and possible real-life applications will be mentioned.

# Gradient descent approach for multi-objective picture-fuzzy stochastic portfolio selection

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**Keywords:** Fuzzy stochastic, Multi-objective, Picture fuzzy, Gradient-based, Portfolio selection

## ABSTRACT

The focus of this study is on a cutting-edge probability maximization model designed specifically for stochastic linear programming with picture-fuzzy flexible goals and constraints. In this unique formulation, all parameters associated with linear constraints are treated as stochastic variables, contributing to the complexity of the problem. The significance of this problem within the realm of optimization cannot be overstated, as it represents a challenging endeavor due to the nonconvex nature of the objective function. To tackle this formidable challenge head-on, the study leverages the powerful concepts of picture-fuzzy theory and flexible optimization. Through the careful application of these methodologies, the fuzzy portfolio problem undergoes a transformative process, culminating in its conversion to a crisp form. Notably, this transformation reveals a key insight: the resultant crisp problem is proven to be a pseudoconvex programming problem, regardless of the choice of monotonic membership functions. This remarkable property of the equivalent problem serves as the foundation for developing an efficient solution methodology. Drawing upon the rich arsenal of available convex programming algorithms, specifically those based on gradient methods, the study formulates an optimal approach for resolving the main problem. By harnessing the strengths of these established algorithms, the study overcomes the challenges inherent in the nonconvex objective function, leading to an efficient and effective solution. To provide concrete evidence of the model's practicality and performance, the study undertakes a comprehensive application in the realm of portfolio selection. Specifically, the popular Sharpe ratio is selected as the goal, while the portfolio's mean and variance are incorporated as constraints. By employing the probability maximization model developed within this study, the researchers showcase its capabilities in addressing real-world decision-making scenarios and generating optimal portfolios. Moreover, to ensure a thorough evaluation and validation of the proposed model, the study meticulously gathers and presents a comprehensive computational experiment dataset. This dataset serves as a valuable resource for researchers and practitioners, facilitating a comprehensive assessment of the model's performance under various conditions and scenarios. Through rigorous analysis and evaluation of this dataset, the study effectively demonstrates the robustness and reliability of the proposed approach. In conclusion, this study introduces a groundbreaking probability maximization model for stochastic linear programming, featuring the integration of picture-fuzzy flexible goals and constraints. Leveraging the principles of picture-fuzzy theory and flexible optimization, the study successfully transforms the fuzzy portfolio problem into a crisp form, which is established as a pseudoconvex programming problem regardless of the chosen monotonic membership functions. Through the application of the proposed model in portfolio selection, with the Sharpe ratio as the goal and the portfolio's mean and variance as constraints, the study demonstrates its practicality and effectiveness in addressing real-world decision-making scenarios. The provision of a comprehensive computational experiment dataset further reinforces the robustness and reliability of the proposed approach. As a result, this study opens up new avenues for addressing complex optimization problems, empowering decision-makers across various domains with powerful tools and insights.

# An Innovative Approach for Solving Multi-Level Programming Problems Using Fuzzy Linguistic Preferences

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**Keywords:** Multi-level programming problems, Fuzzy logic, Fuzzy linguistic preferences, Membership functions

## ABSTRACT

Multi-Level Programming Problems (MLPPs) are considered as a complex subset within the domain of mathematical optimization due to their inherent hierarchical decision-making structure with multiple, often conflicting, objective functions. Traditionally, each level of the hierarchy corresponds to a separate decision-making entity, thereby significantly increasing the complexity of MLPPs, making them NP-hard problems. This paper introduces a novel alternative solution approach using the principles of fuzzy logic to simplify and enhance the effectiveness of solving MLPPs. In the proposed method, fuzzy linguistic preferences are employed to define the priority among decision variables and objective functions at different hierarchical levels. This innovative application of fuzzy logic adds a degree of flexibility and adaptability to the decision-making process, enabling more nuanced consideration of the preferences and needs of each level's decision-maker. The proposed methodology involves developing membership functions for both the decision variables and objective functions, using fuzzy linguistic preferences as the foundational framework. We propose three distinctive types of membership functions- linear, exponential, and parabolic.

The key strength of our methodology lies in its ability to model the inherent complexity and uncertainties within MLPPs, thereby leading to more realistic and robust solutions. It provides a more manageable, intuitive way to navigate the intricate decision-making landscape of MLPPs, extending its applicability across diverse practical scenarios like supply chain management, advertising allocation, and vendor selection, to name a few. This proposed solution methodology will be tested on real-world examples to demonstrate its robustness, efficiency, and wider application potential. This approach offers a promising direction for tackling the challenges associated with multi-level programming problems, contributing significantly to the further development and application of optimization models in real-world situations.

# A general review on FN-DBSCAN clustering algorithm based on fuzzy density concept

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**Keywords:** FN-DBSCAN, Clustering, Fuzzy logic, Data mining

## ABSTRACT

Data mining, object detection, and pattern recognition all make use of clustering, a fundamental and important data processing approach. Clustering's major purpose is to partition the dataset into multiple clusters in which the points from the same cluster are more similar than the points from different clusters. Clustering is an unsupervised learning technique that must be capable of processing data in the absence of prior knowledge. There are many clustering algorithms and they are divided into five main groups (partitioning based, hierarchical based, density based, grid based, and model based) according to the methods they use.

The primary idea behind density-based clustering is to create groups based on dense and non-dense regions. DBSCAN (Density-Based Spatial Clustering of Applications with Noise) is one of the most popular density based clustering algorithms [1]. It determines that two clusters with different point locations are the same. Nasibov and Ulutagay proposes FN-DBSCAN (Fuzzy Neighborhood Density-Based Spatial Clustering of Applications with Noise) algorithm by including fuzziness to DBSCAN algorithm [2]. According to FN-DBSCAN, two clusters with different point locations are perceived as different thanks to the fuzzy neighborhood cardinality [3]. If a cluster's points are closer to the core point, the cluster is tighter than other clusters with distant points. In this way, FN-DBCAN gives more robust results than DBSCAN.

This paper presents a review of the studies using the FN-DBSCAN algorithm. These studies are divided into two sub-groups. While some studies examine the performance of the FN-DBSCAN algorithm, other studies suggest new versions that will tolerate the shortcomings of this algorithm. The studies of [4-11] are among the studies in the first sub-group. They examine the performance of FN-DBSCAN on datasets that have not been tried before using this algorithm. In all studies except the studies of [8] and [11], FN-DBSCAN is the algorithm that gives more successful results than other clustering algorithms used. While the algorithm they develop in study [8] gives more successful results, no comparison is made using any other clustering algorithm other than FN-DBSCAN in study [11]. FN-DBSCAN is an algorithm that has disadvantages as well as advantages like other algorithms.

The disadvantages of FN-DBSCAN are that it gives results in a longer time compared to DBSCAN, it depends on two input parameters (ε 1 and ε2), and changes in these parameters affect the results, although not as much as in the DBSCAN algorithm. When the variants of FN-DBSCAN are examined as the second sub-group, the researchers mostly deal with the time complexity problem of FN-DBSCAN, which is more robust and higher performing than DBSCAN. SFN-DBSCAN [12], AFN-DBSCAN [13], landmark-FNDBSCAN [14], FNGMDBSCAN-UR [15], and a specific FN-DBSCAN algorithm [16] are the proposed solutions to the time problem of FN-DBSCAN. The common feature of them is to divide the data set into subsets. AFN-DBSCAN [17], AF-DBSCAN [18], FN-DBSCAN-GM [19], and FN-DBSCAN with genetic algorithm [20] are the suggested solutions to the challenge of dependency on input variables. These studies have generally added a technique for accurate parameter estimation prior to FN-DBSCAN. IWO-based FN-DBSCAN [21] is a more robust version of FN-DBSCAN.

The aim of this study is to provide an insight into the conceptual framework for future research from a structured literature review. In the future, it is aimed to compare the variants with each other. In order to compare them with other density based clustering algorithms, it is planned to perform tests on frequently used data sets from the UCI Machine Learning Repository.

# Multicriteria decision making in water quality evaluation using fuzzy TOPSIS methodology

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**Keywords:** Drinking water, Water treatment plants, MCDM, TOPSIS, Fuzzy arithmetic.

## ABSTRACT

Access to clean and safe water is of paramount importance for safeguarding human health and well-being. The quality of water plays a pivotal role in ensuring its suitability for various domestic purposes, including consumption. Inadequate water quality can have grave implications for human health, contributing to the spread of waterborne diseases such as cholera, typhoid fever, and dysentery. Furthermore, water quality holds significant ecological value as it directly impacts the well-being of ecosystems and the wildlife dependent on water sources. Consequently, it is imperative to consistently monitor and evaluate the quality of water sources.

Multi-criteria decision making (MCDM) represents an approach to decision-making that enables the evaluation and selection of optimal alternatives from a pool of options based on multiple criteria. This methodology proves particularly valuable in decision-making processes characterized by the involvement of diverse factors or criteria, each carrying distinct levels of importance. MCDM methods empower decision-makers to make informed choices by thoroughly considering all relevant factors and criteria. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) stands as an MCDM method employed to assess alternatives based on multiple criteria. TOPSIS involves a comparative analysis wherein each alternative is contrasted against an ideal solution and a negative ideal solution. The ideal solution represents the most desirable outcome for each criterion, while the negative ideal solution denotes the least desirable. Subsequently, TOPSIS calculates the distances between each alternative and the ideal and negative ideal solutions, ultimately generating a final ranking based on these distances.

In the conducted study in Iraq, Fuzzy-TOPSIS was employed to evaluate the water quality and performance of water treatment plants (WTPs). There are various benefits of using fuzzy logic in data analysis when using Multi-Criteria Decision Making (MCDM) techniques. First, fuzzy logic allows for the representation of imprecise or uncertain facts. Second, it makes it possible to incorporate subjective assessments and linguistic factors, resulting in a decision-making process that is more intuitive and human-like. Thirdly, fuzzy logic makes it easier to handle a variety of factors with variable degrees of significance, enabling a thorough examination of complicated decision-making scenarios. Fuzzy logic improves the accuracy and robustness of data analysis in MCDM by taking into account the fuzzy character of data, resulting in more well-informed and successful decision-making results. The investigation concentrated on determining the influence of fourteen parameters that directly impact the quality of drinking water. The participation of thirty-two domain experts in the study facilitated the assessment of WTPs using the Likert scale (ranging from 1 to 7). RII calculations were subsequently employed to derive the weights necessary for the implementation of the TOPSIS method. To enhance the efficacy of the TOPSIS method, the researchers chose to incorporate fuzzy TOPSIS. This extension of the traditional TOPSIS approach utilizes fuzzy sets to account for data uncertainty and imprecision. Within the study, two fuzzy scales, namely (1, 2, 3) and (0, 0.1, 0.2), were applied to the survey and RII results, effectively generating a secondary layer of weights for the MCDM/TOPSIS method. The execution of the TOPSIS method was facilitated through the utilization of Octave software, thereby establishing three key variables: the decision matrix derived from WQ testing results of the WTPs, the final weights generated by employing the two fuzzy scale methodologies, and the identification of beneficial and non-beneficial values utilizing the water quality parameters scale.

The results of the Fuzzy TOPSIS analysis revealed that the final rankings of the WTPs, as obtained over a period of six months using both fuzzy scales, exhibited remarkable consistency. The study shed light on the necessity for water treatment plants in Fallujah City to enhance their performance to ensure compliance with essential drinking water standards. Moreover, the investigation identified the pivotal parameters influencing water quality in the city, underscoring the need for improved monitoring and regulation of the water treatment process. To summarize, the study conducted in Iraq underscores the significance of regular assessment and monitoring of water quality sources. It demonstrates that MCDM techniques such as TOPSIS can be effectively employed to evaluate and compare water treatment plants based on multiple criteria. The integration of fuzzy TOPSIS within the evaluation process enhances the accuracy of the assessment by considering data uncertainties and imprecisions. The study's findings underscore the ongoing necessity for endeavors aimed at improving water treatment processes and regulations to ensure the delivery of safe drinking water.

# Selection of warehouse location in the framework of sustainable supply chains for geographical indication products: The case of Izmir Kemalpaşa Cherry

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**Keywords:** Geographical indication products, Sustainable supply chain, Warehouse location selection, Izmir Kemalpaşa Cherry, Multi-criteria decision-making methods, AHP, COPRAS

## ABSTRACT

Rising rural poverty, access to safe food and environmental degradation are more important issues in agriculture. Therefore, there is a new consumer group that is increasingly moving away from industrial agriculture. The interest of this consumer group in high quality and local products produced with local production techniques is rising day by day. Geographical Indication products constitute one such group of demand products. Geographical Indications are a sign used for products with a specific geographical origin and with qualities or reputation derived from this origin. A successful Geographical Indication can prevent the displacement of production; create jobs, support local development; and contribute to a safe, diversified, and healthy diet by protecting traditional food products, the environment, and biodiversity. To increase the contribution of Geographical Indications to sustainability, the supply chain must be supported. In general, although the number of products with Geographical Indications has increased, the added value of these products has not increased at this rate. The added value to be achieved is insufficient based on local producers and exporting enterprises.

In this context, it can generally be said that there is no effective sustainable supply chain management for Geographical Indication products, and there are deficiencies in this regard. To determine the supply chain network structure, all stakeholders and their roles should be structured correctly. At this point, it is very important for sustainable chains that warehouses, which are an important link in the supply chain, are built at the right points and managed correctly. Warehouses also play an important role in ensuring that products are received from the supplier, kept in appropriate storage conditions, and delivered to the customer at the right time, according to demand. Different alternatives and many qualitative and quantitative factors are evaluated in warehouse location selection, because different structures in the supply chain should be determined in an integrated manner.

Based on these points, this study aims to make a warehouse location selection decision that will support the sustainable supply chain structure in the case of Izmir Kemalpaşa Cherry as a geographical indication product. In this study, we aimed to determine the most appropriate alternative in line with the evaluations to be made based on quantitative and qualitative criteria among the decision units to be determined based on the district alternatives of İzmir or Manisa Province. In line with the opinions collected from the experts, the necessary analyses will be carried out using the analytic hierarchy process (AHP) and complex proportional assessment (COPRAS) from multi-criteria decision-making methods. It aims to weigh the criteria options with AHP and then evaluate the weighted criteria using the COPRAS method.

As a result, it is thought that a basic point will be established in terms of warehouse location selection in order to increase the export capacity of Geographical Indication Product, Izmir Kemalpaşa Cherry, to reduce losses arising from storage conditions, and to provide added value for both producer and exporter associations. In the future, we plan to extend the study by using different multi-criteria decision-making methods and publish it as an article.

# Multi-objective optimization for automated guided vehicle (AGV) assisted order picking problem

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**Keywords:** AGV-assisted order picking, Multi-objective, Warehouse management, Order assignment, AGV routing

## ABSTRACT

Efficient warehouse management and effective order picking play critical roles in the success of modern supply chains. Warehouse management encompasses a range of activities, including inventory control, warehouse layout optimization, space utilization, and order fulfillment. Effectively managing these processes is critical to ensuring the smooth flow of goods in and out of the warehouse, minimizing costs, and meeting customer requirements. Order picking, a key component of warehouse management, involves selecting and retrieving items to fulfill customer orders. However, several challenges can arise during the order picking process, leading to inefficiencies and increased costs. These challenges include suboptimal picking strategies, poor layout design, lack of real-time visibility, and inadequate employee training. In this study, the Automated Guided Vehicle (AGV)-assisted order-picking problem is considered. AGV-assisted order picking is when an AGV moves alongside a human picker and returns to a collection point after reaching capacity or completing assigned orders. There are two stages for this problem. First, the assignment of orders to AGVs should be done. Second, each AGV's routing must be determined to minimize the total traveled distance. Minimizing travel distance can help decrease the energy consumption of AGVs. Additionally, there is an investment cost associated with purchasing new AGVs. Completing all orders within their due times with minimum total energy consumed may require a higher number of AGVs to be purchased. The challenge is to find solutions that balance these two conflicting objectives. Therefore, AGV-assisted order-picking problems can be solved as multi-objective problems with these two objectives. In this study, we developed a mathematical model to solve the multi-objective AGV-assisted order-picking problem. In addition to this model, we propose a clustering algorithm to efficiently solve the problem by reducing its time complexity. In the first mathematical model, the objective is to minimize the maximum distance using the Miller Tucker Zemlin (MTZ) subtour elimination constraint. For this model, we initially minimize the number of AGVs used and determine the optimal value. Subsequently, we use this optimal number of AGVs and minimize the maximum distance traveled by AGVs, adding the number of AGVs as a constraint in the second stage. However, due to the NP-Hardness of the model, performance becomes an issue for large instances. Therefore, we propose a new algorithm to overcome this problem. In the clustering algorithm, we attempt to assign orders to AGVs intelligently. While assigning orders to AGVs, we consider the distance between the selected centers of orders assigned to AGVs and the depot, as well as the total distance between these centers and assigned orders. We then apply the Nearest Neighbor Algorithm (NNH) to each AGV to find the maximum distance traveled. We add a new constraint to the assignment model and solve it again. This constraint helps to separate sets of orders that have the highest traveling distance. The first mathematical model and the proposed algorithm are used to solve nine different generated datasets of different sizes using identical AGVs. Order weights, AGV capacities, and distances between orders are considered. It was observed that the proposed algorithm is solvable in a faster manner. However, the mathematical model provides better results in terms of the traveled distances. In future work, instead of the NNH algorithm, other routing algorithms can be used to solve this problem, such as savings and 2-opt.

# Goal programming: A review and comparison of Turkey with Middle Eastern countries

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**Keywords:** Goal programming, Review, MCDM, Multi-criteria decision making, Middle eastern countries, comparison

## ABSTRACT

Goal programming was introduced by Charnes, Cooper, and Ferguson's (1955) study for the determination of executive compensation, since then it has been used as one of the multi-criteria decision-making (MCDM) techniques. In today's world, MCDM is an important decision support tool and an indicator of scientific development, to whom in the position of multidimensional thinking and planning. The nature of multi-criteria decision making includes to consider and evaluate very different situations and criteria within the same mathematical model, and studies on this subject are quite abundant in the literature.

In this study, the literature obtained from Web of Science and Scopus is reviewed in terms of Goal programming and between the Middle East countries and Turkey, where such decision-making approaches are most needed; Comparisons has been made under the assumption that "the country that will enter the arena of developed countries will come out of the Middle East".

Search with the term "goal programming" results 5587 documents in Scopus and 4185 documents in Web of Science (WoS) worldwide and merging of these two databases, a corpus of 6679 studies was obtained. The first study which was indexed by the considered databases dated back to 1968 in the world and 1973 in middle east. Since than the number of studies grown up rapidly in the world and a little bit slower in 70's and 80's in middle east. However, the realizations of the last 5 years reveal that almost 1/3 of the goal programming studies originate from the Middle East. Therefore, in this study within the resulting corpus, goal programming studies in both the world and the Middle East were discussed and a comparison was made to reveal the place of Turkey with middle eastern countries is made after a brief statistical evaluation of goal programming. Consequently, it was seen that Iran is the leading country with 495 studies indexed by Scopus and 447 studies indexed by WoS and total 576 indexed studies. Turkey is in the second rank the follower just behind İran with 282 studies indexed by Scopus, 292 studies indexed by WoS and total of 363 studies.

Furthermore, internationally most influential authors, papers, institutions, and international collaborations is summarized under the context of comparison. The most influential study of goal programming is a review by Boysen et al., cited 561 times which was published in 2007 and made a classification about assembly line balancing problems. It is followed by a paper by Charnes & Cooper who are the pioneers of many methods like Data Envelopment Analysis etc. Correspondingly, the most influential study in the Middle East is also a review, the study of Farahani et al., which received 370 citations, on multi-criteria facility location problems published in 2010. It is followed by a study which combines goal programming and analytic network process for Product planning in quality function deployment by Karsak et al., which is published in 2003.

Furthermore, international collaborations, network of authors, institutions, publishers, key words, research areas and under some other topics goal programming is summarized under the context of comparison.

# A reinforcement learning based approach for the multi-objective traveling salesman problem: Q-learning

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**Keywords:** Multi objective traveling salesman problem, Reinforcement learning, Q-learning

## ABSTRACT

This study investigates the feasibility and effectiveness of a Reinforcement Learning (RL) based approach, specifically Q-Learning, for solving the Multi-Objective Traveling Salesman Problem (MOTSP). In the Traveling Salesman Problem (TSP), the salesman tries to find the shortest tour to visit a set of cities exactly once and return to the starting point. The multi-objective version of this problem searches for efficient tours visiting all cities, where each tour has a nondominated objective vector. The single and multi-objective versions of TSP are frequently encountered in the logistics and transportation industry.

RL is an artificial intelligence approach where agents try to achieve the best result in performing a certain task. Specifically, agents receive a positive or a negative reward after performing a certain task, and this reward helps them learn how to shape their future actions. In the domain of MOTSP, the RL agent learns to find efficient routes by considering multiple objectives simultaneously. The agent performs a series of tasks, receives rewards and penalties, and learns to select the best actions using this feedback. The reward function is designed to consider multiple objectives and the algorithm terminates with a set of efficient solutions. For example, for the single-objective case minimizing the total distance, the agent receives a positive reward when it finds a shorter route and a negative reward (penalty) when it finds a longer route. For the multi-objective case minimizing both distance and cost, the efficient routes receive rewards, whereas inefficient routes receive penalties. The magnitude of the penalties assigned to the inefficient routes increases as the number of solutions dominating those inefficient routes increases. These rewards and penalties help the agent learn how to improve future actions.

In our approach, we address the MOTSP minimizing the two objectives: cost and distance. We employ Q-learning, which is a type of RL algorithm. This algorithm operates on a Markov Decision Process (MDP) and learns a Q value for each state-action pair. Q values represent "expected future rewards," a concept taken from game theory and control theory. An agent uses these Q values to decide which action to take in a particular situation. The algorithm relies on the agent randomly selecting actions during the learning process and observing the resulting reward and the new situation. It then uses these observations to update the Q values. We represent the states as the cities the vehicle is at, and actions as the city to go to next. Rewards and penalties are related to the distances between the cities and the transportation costs. The higher the cost of transportation and the distance between the cities, the larger the penalty costs will be.

The aim of the study is to examine the effectiveness of an RL-based approach in solving the MOTSP and to develop new and effective approaches for small-scaled problems. It is intended to demonstrate that these findings can offer new and powerful solutions that could significantly contribute to planning and optimization processes in the logistics and transportation industry and have the potential to advance research in this field.

# Constraint programming model for hybrid flow shop scheduling with batch delivery problem

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**Keywords:** Supply chain management, Hybrid flowshop scheduling, Batch delivery, Total tardiness cost minimization

## ABSTRACT

Rapid changes in the production environments and increasing competition motivates researchers and manufacturers to improve supply chain management and find new production methods. As it is difficult to develop models close to real life, it may also be difficult to implement them in our live production systems.

The supply chain does not end with the end of production. Every process, from the procurement of the raw material to the delivery of the product to the customer, should be under the control of the manufacturer and planned. Delays in production and delivery can reduce competitiveness and increase costs, so they should be minimized. Every stage should be under the responsibility and follow-up of the manufacturer until the product reaches the customer on time. The manufacturer is responsible for any delays that result in penalties and customer dissatisfaction.

Standard models may be insufficient when we want to improve more than one purpose. Therefore, integrated and multi-purpose models should be used for better results. Our problem consists of two parts. The first part is the production stage which is focused on minimizing production times. Hybrid flow type productions are familiar and very realistic production environments that consist of a series of stages with identical machines in each stage. This complex combinatorial problem is encountered in many real-world applications. Although the number of machines in each stage may differ, there must be more than one parallel machine in at least one stage. Every product must be produced by going through the same stages. Each job must be processed on only one of the parallel machines at any given stage. Jobs cannot be divided after it starts production until it is finished. Machines can only process one job in a given time period. Moreover, when a job is finished, there is a delivery time for transmitting the finished job from the factory. Manufacturers often deliver jobs in batches (batch delivery) to minimize the delivery cost. The delivery time of a job depends on the completion time and shipping time. It is assumed that there are unlimited vehicles in the problem. Each vehicle can go to one customer in one turn. Multiple tours were not considered. Vehicles' travel time to each customer differs, and the amount of products that vehicles can receive is limited. Under these conditions, the second part of the problem intends to serve customers with minimum delay with the minimum number of vehicles.

This study integrates batch delivery with the hybrid flowshop scheduling problem. The aim is to optimize production and delivery time to deliver jobs on time or with minimum delay, thus minimizing overall costs in the supply chain. In order to solve the mentioned problem, this study proposes a constraint programming model. While mixed integer linear programming models may give faster results in small size problem, constraint programming models gives faster results in large size problem. The proposed model can help managers to make efficient scheduling and delivery planning for their systems using hybrid flowshop scheduling and batch delivery methods.

# Exact and heuristic algorithms for multi-objective multi-man assembly line rebalancing problem

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**Keywords:** Assembly line balancing, Multi-manned lines, Mixed integer linear programming, Genetic algorithm based heuristic

## ABSTRACT

Assembly lines dedicated to the production of large products often allow multiple workers to perform tasks on the product at the same time. Assembling large and complex products requires enormous production resources, such as workers, equipment, and residential areas. The multi-manned assembly line balancing problem refers to the challenge of optimizing the allocation of tasks among multiple workers in an assembly line system. In these problems, the goal is to distribute the workload evenly across the workers and workstations while minimizing cycle time or the number of workstations and maintaining high productivity. The complexity arises from the interdependency between tasks, the varying skill levels of workers, and the need to synchronize their activities. The general objective is to achieve a balanced assembly line that maximizes efficiency and throughput. Solving the multi-manned assembly line balancing problem plays a crucial role in enhancing production efficiency and reducing costs in industries ranging from automotive manufacturing to electronics assembly.

This study considers a real-life problem, so the assembly line of a tractor assembly company is discussed. In the investigated problem, an existing assembly line examined, which includes multi workers in the line, and the line was rebalanced by trying to convert it back to its most efficient state. The problem tries to optimize two different and conflicting objectives, so it is classified as a multi-objective multi-man assembly line balancing problem. The main objective of the problem is to minimize the cycle time, and the secondary objective is to minimize the number of workers while balancing the line. In the problem, some tasks need special equipment dedicated to some stations; thus, these tasks have to be done at the designated station. All operating times are known, deterministic and cannot vary according to the operators. Task division is not allowed, so when a task is started to be performed, it must be finished at the same workstation. The precedence relations of the tasks are known. Different than the literature, the problem also includes another constraint. An operator is not dedicated to a single workstation, so a single operation. Operators are allowed to work at the adjacent workstations besides the assigned station. Therefore, the described situation adds extra difficulty to the problem.

In order to solve the considered multi-man assembly line balancing problem, a new mixed integer linear programming (MILP) model was proposed. Small test instances were obtained from the literature and modified, respecting the additional features of the considered problem. Small instances were solved by the MILP model on the black box solver to optimality. Large instances were obtained from the real case observed in the tractor company. Since the problem is NP-hard, the MILP model cannot obtain optimal results for the large-size instances within the given time limit. Moreover, the MILP model cannot find any feasible solution to some instances of the real scenario. Therefore, a customized heuristic procedure based on a Genetic Algorithm (GA) was implemented to solve the problem and compare the results with the results of the MILP model. Finally, all obtained solutions were compared to each other and a sensitivity analysis were conducted.

# The electric vehicle routing problem with simultaneous pick-up and delivery

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**Keywords:** Electric vehicle routing problem, Simultaneous pick-up and delivery, Mixed-integer linear programming model

## ABSTRACT

Nowadays, one of the important concepts that is frequently emphasized in the field of transportation is green logistics. While companies are trying to provide competitive advantage, they are also trying to ensure their sustainability in environmental and economic fields. Especially in recent years, the increasing CO2 emission has a negative effect on the environment. In this direction, the negative environmental effects of conventional fossil fuel vehicles have led to a decrease in interest in these conventional vehicles. In line with the concept of green logistics; to reduce these negative environmental effects of conventional vehicles, electric vehicles have started to be used in transportation field. In the future, it is expected that instead of fossil fuel vehicles, the use of environmentally friendly electric vehicles that produce less noise than conventional vehicles will become more widespread.

In this direction, many studies have been carried out on the electric vehicle routing problem in the literature, considering various constraints specific to electric vehicles. In the electric vehicle routing problem, the presence of electric vehicles with limitations such as limited battery life and certain charging features, causes differences from conventional vehicles in vehicle routing decisions. Especially, constraints such as the small number of battery charging stations and the limited ranges allowed by the battery levels complicate the routing decisions of electric vehicles.

In this study, there are electric vehicles that start their route from a single depot. The electric vehicles have certain load and charging capacity restrictions. The electric vehicles have to travel to customers in their routes and complete their routes by returning to the depot. Electric vehicles can visit any charging station to recharge their batteries on their route. Each charging station can be visited by more than one electric vehicle. It is assumed that the locations of charging stations and customers are known in advance. In addition to delivering products from the depot to customers, electric vehicles are also required to simultaneously collect products from customers. It is assumed that the products distributed and collected are compatible and can be loaded into the same electric vehicle. Electric vehicles must comply with load capacity restrictions along the route. In line with these assumptions, electric vehicle routing problem with simultaneous pick-up and delivery is studied in this study. The minimization of distribution costs is considered in the objective function of the studied problem. The minimization of tardiness costs is also included in the objective function to increase customer satisfaction. In this study, a mixed-integer linear programming model, in which the routes of electric vehicles are optimized, is proposed for the problem. The performance of the proposed mathematical model has been evaluated on small-sized instances. Computational results show that the mathematical model provides good quality solutions for the small-sized instances.

# The distributed permutation flowshop scheduling problem with batch delivery

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**Keywords:** Distributed permutation flowshop scheduling, Batch delivery, Mixed -integer linear programming.

## ABSTRACT

This study considers a complex scheduling and distribution problem, which integrates a distributed permutation flowshop scheduling problem and a batch delivery process. The existence of distributed factories and the integration of batch delivery and scheduling processes increase the complexity of the problem and makes the problem more challenging. Hence, the solution for this problem requires careful planning, strategic assignment and scheduling during the distributed permutation flowshop scheduling and batch delivery processes, incorporating a set of jobs, machines, factories and vehicles.

In the scheduling phase, jobs are distributed to the factories, where each factory has a flowshop system. Each job can only be assigned to a single factory. It is assumed that all machines and jobs are ready at time zero. All operations related to the same job are performed sequentially on serial machines in the flowshop. Each machine at each factory can only process one job at a time. All jobs follow the same route through the machines. In the scheduling phase, the aim is to determine the job processing sequence for the jobs assigned to each factory.

After the scheduling phase, batch delivery plans are created for the completed jobs. In the batch delivery phase, jobs are assigned to specific batches, and jobs belonging to the same batch can be delivered to a customer at once. The aim at this stage is to optimize the batch delivery process and meet customer demands as effectively as possible. Consequently, the aim of the integrated problem is to determine the assignment of jobs to factories, job processing sequence for each factory and assignment of the jobs to batches for the delivery, according to certain objective function. The objective function of the problem is determined as to minimize both total tardiness and batch delivery costs.

In the literature, various mixed-integer linear programming models and algorithms have been proposed for the distributed permutation flowshop scheduling problem. This study integrates the distributed permutation flowshop scheduling and batch delivery processes. Consequently, in this study, a mixed-integer linear programming model is presented for this integrated problem for effective permutation flowshop scheduling and batch delivery planning in distributed factories. The performance of the mixed-integer linear programming model is evaluated on small-sized instances. The computational results show that the mixed-integer linear programming model is effective for providing good-quality solutions for the distributed permutation flowshop scheduling problem with batch delivery.

# Bi-criteria optimization of makespan and total flow time in no-wait flowshops

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**Keywords:** Bi-criteria optimization, No-wait flowshops, Makespan, Total flow time

## ABSTRACT

No-wait flowshop scheduling problems (NWFSPs), as a modified version of permutation flowshop scheduling problems (PFSPs), have recently taken broader attention from the practical and academic world due to their wide application range in various industries. A set of jobs with no relation are aimed to be treated on a set of machines in PFSPs. The modification of NWFSPs is that no intermediate queues between consecutive machines are allowed in NWFSPs. Once the jobs begin to be processed, they must be completed until the last machine, which alludes to the job's no-wait limitation. In this study, the NWFSP is treated as a bi-criteria combinatorial optimization problem where the makespan and the total flow time are optimized simultaneously. We exhaustively studied the bi-criteria NWFSP to examine the trade -off between two objective criteria. Given an instance problem, the sequence of jobs procures a makespan value and a total flow time value. Bi-objective NWFSP's primary purpose is to procure Pareto solutions and approximate non-dominant solutions for simultaneously optimizing these objectives. The stated bicriteria scheduling problem turned out to be NP-hard in the literature of scheduling problems in a strong sense. Thus, we provide a deterministic mixed integer linear programming model for bi-criteria NWFSPs. Moreover, three metaheuristic algorithms are developed: Bi-Criteria Iterated Greedy Algorithm with QLearning for Block Insertion (BC-IGQL-BI), Bi-Criteria Iterated Greedy Algorithm with Q-Learning for Destruction and Construction (BC-IGQL-DC), and a collection of Bi-Criteria Genetic Local Search Algorithms (BC-GLS). By employing the Q-learning algorithm, we aim to enhance the effectiveness of the adaptive operator selection mechanism by dynamically selecting the suitable perturbation operators and aim to improve the overall performance of the Iterated Greedy Algorithm in finding Pareto optimal solutions. The complete computational experiment of the proposed algorithms is performed on the small VRF instance sets (Vallada et al. (2015)), in which the benchmark set consists of 24 collections of small-size problems. Each collection has ten instances. Small instances vary in the number of jobs to 10, 20, 30, 40, 50, and 60; and in machines 5, 10, 15, and 20. Therefore, we carry out 240 problem instances of Vallada et al. (2015) through this study. The outcome of the experimental study indicates that the BC-IGQL-BI and the BC-IGQL-DC algorithms outperform the mixed-integer linear programming model and the variants of the BC-GLS algorithm. However, BC-IGQL-BI and the BC-IGQL-DC algorithms are competitive with each other in terms of various performance metrics, such as cardinality, proportion of the Pareto-optimal solutions discovered, inverted generational distance, distribution spacing, coverage of two sets, and hypervolume. For future work, different mathematical model constructions or constraint programming model constructions can be generated for this problem environment since there is enough room to enhance the performance of the proposed mixed-integer linear programming model. Moreover, the integration of Qlearning algorithm is a new research field that can be applicable to other meta-heuristic algorithms. Last but not least, the outcomes of this study encourage us to discover many more bi-criteria NWFSPs to reveal the trade-off between other conflicting objectives, such as makespan & the number of early jobs, total flow time & the number of tardy jobs, and mean completion time & on-time jobs are considered to overcome various industries' problems.

# Multi-objective optimization approaches for the sustainable production scheduling problems: A review and discussion

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**Keywords:** Sustainable scheduling, Energy efficiency, Low carbon, Multi-objective optimization, Sustainable production management

## ABSTRACT

Sustainability in the production environment has become a critical research focus in response to the challenges posed by global environmental issues. Production management offers the opportunity to redesign production plans with sustainability considerations without incurring initial investment costs or additional expenses. This study aims to address how to enhance sustainability accounting for the complex dynamics inherent in production environments from the production management perspective. This study provides insights that can inform sustainable practices and decision-making in production environments. Production scheduling includes all activities related to coordinating and assigning activities to personnel or machines and issuing work orders at each workplace. The primary objective of production scheduling is to address various challenges, such as minimizing the total completion time of orders, flow time, earliness or tardiness while making efficient use of available production resources.

The problems in which multiple objectives are simultaneously optimized are able to represent real-life production situations better. This study examines the relevant literature to identify the objectives addressed in these multi-objective sustainable production scheduling problems and highlights potential research directions regarding key sustainability indicators. Sustainability encompasses three main pillars: social, economic, and environmental. Scheduling problems should be considered multi-objective optimization problems while considering sustainability and traditional goals. Sustainable scheduling problems include optimizing conflicting goals such as production completion time, energy consumption, carbon emissions, and social and environmental sustainability indicators. The multi-objective optimization approach enables decision-makers to explore trade-offs between these objectives and generate a set of Pareto-optimal solutions. Therefore, decision-makers can select the most suitable solutions based on their requirements and constraints. Multi criterion approach captures the complexity of real-world production systems and provides a comprehensive evaluation of different trade-offs between the objectives. Incorporating sustainability goals into the multi-objective optimization allows for developing scheduling strategies that align with broader objectives, contributing to sustainable manufacturing practices.

There are multiple approaches to tackling multi-objective optimisation in the context of production scheduling problems. One common approach is to optimise a weighted combination of objectives hierarchically. In the hierarchical approach, the optimal value of the primary objective is first determined, and then the secondary objective is optimised with the fixed primary objective value. Besides, the decision-makers can provide preferences interactively during the solution process, expressing their preferred solution stepwise. The interactive approach aims to find a satisfying compromise between the objectives, often using goal-programming techniques. In some cases, the objective is to minimise the sum of the objectives, and the e-constrained method can be employed to solve multi-objective problems.

Dispatching rules can be an alternative in solution methodologies for sustainable scheduling problems. Dispatching rules, particular rule-based heuristics developed for solving scheduling problems, have traditionally focused on time-related factors such as processing or delivery time. However, sustainability-based dispatching rules have received limited attention in the literature. The dispatching rules should consider not only time-related aspects but also sustainability objectives. The emergence of the circular economy approach has created an opportunity to develop dispatching rules that explicitly incorporate sustainability criteria. Developing new rules hold great promise for addressing the sustainability challenges in scheduling problems.

# Multi-objective-based immunization and portfolio selection strategies for corporate green bonds

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**Keywords:** Corporate green bond, Portfolio immunization, Goal programming, Performance measures

## ABSTRACT

Corporate green bonds, whose proceeds finance environmental and climate-friendly projects, have become very popular in financial markets over the last decade. In this paper, we propose a novel immunization approach for green bond portfolio management when an environmental dimension of these financial securities is considered. In particular, we develop a multi-objective-based immunization problem to optimize their performance and thus compare them with their matched "brown" bonds. To achieve this aim, we adopt a mathematical programming technique that allows us to handle multiple competing criteria based on Goal Programming type models and thus leads to a more flexible immunization approach. Moreover, using proper ex-post results from the optimal immunization problem, the market risk is addressed by maximizing portfolio wealth using either reward-risk or drawdown-based performance measures. This modeling approach gives investors and portfolio managers more flexibility to incorporate their preferences and express their aspiration levels. Empirical analyses of the European fixed-income market during the 2013–2023 period are conducted. The results confirm the proposed methodologies and show that they can assist climate-friendly investors in determining their optimal immunized portfolios under uncertain aspiration levels.

Furthermore, to assess the performance of our green portfolio, we compare it to a matching brown portfolio constructed using conventional bonds. We adopt the matching methodology used by Flammer (2021) and Zerbib (2019), wherein we create a pool of brown bonds that closely match the initial pool of green bonds in terms of characteristics, except for their green attributes. Subsequently, we apply the two-step optimization strategy to this pool of conventional bonds while excluding the objective related to the environmental score. For robustness checks, we also construct the matching pool of brown bonds using Propensity Score Matching techniques as suggested by Gianfrate and Peri (2019). This additional analysis ensures the reliability and validity of our results in comparing the performance of green and conventional bond portfolios.

To empirically test our strategy, we concentrate on EUR-denominated corporate bonds over the 2013–2023 period. This choice is based on the fact that corporates account for over half of green bond issuances, and 46% of green bonds are denominated in EUR, ensuring that the initial pool is well diversified. By focusing on EUR-denominated corporate bonds, we aim to capture a representative sample of the green bond market and assess the effectiveness of our multi-objective-based immunization approach for this particular segment. The 2013–2023 period provides a substantial timeframe for analysis, allowing us to observe performance trends and evaluate the strategy's robustness over various market conditions. By conducting our empirical analysis on this dataset, we can draw valuable insights into the performance of our green bond portfolio compared to its conventional counterpart, and also gauge the effectiveness of incorporating environmental scores based on ESG ratings into the immunization process. The results will contribute to a better understanding of how our proposed approach can cater to investors' preferences for both financial performance and environmental sustainability in bond portfolio management.

# On solving a quadratic multiobjective problem as a linear complementarity based weighted problem

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**Keywords:** Multi-objective polynomial optimization problem (MPOP), Quadratic multi-objective Problem,
Linear complementarity problem (LCP), LCP related weighted problem, Zero-efficient point, Pivotal algorithms, Interior point algorithms

## ABSTRACT

The multi-objective optimization problem is a class of optimization problems, where several objectives (two or more) are to be minimized over a common feasible set. MOPs have broad applications in economics, finance, and machine learning. The weighted-sum method is one of the most popular scalarizing approaches that reformulates a multi-objective optimization problem (MOP) into a single objective problem by using a convex combination of the objective functions. With this method, each objective function is associated with a weight of non-negative coefficient and then the weighted sum of the objectives is minimized. The weighted sum method is effective for solving some special cases of multi-objective optimization problems (MOP). In various applications, some complex systems are modelled as a MOP with special structure. The linear complementarity problem (LCP), (a special class of MOP) consists of finding a vector in a finite-dimensional real vector space that satisfies a certain system of inequalities. LCP arises in some mathematical programming problems, game theory, control theory, economics, and some engineering applications. The linear complementarity problem can be formulated as a multi-objective optimization problem subject to linear constraints. The problem of finding a solution to LCP is equivalent to the problem of finding a member of a particular subset of efficient points of a certain class of MOP. It is well-known that a subclass of linear complementarity problem (LCP) can be solved by solving a suitable LCP-related weighted problem associated with it (Math. Program. 60, 349–359 (1993), JOTA 86, 389-405, (1995), Math. Program., Ser. A 100: 339-–344 (2004), EJOR 254, 1 715-738 (2016)). Using this approach, the nonempty and closed feasible set of the LCP is mapped into the nonnegative orthant of the objective space. Some sufficient conditions for the existence of efficient solutions of this multiple-objective programming problem are also known in the existing literature.

In this talk, we revisit the problem of finding efficient solutions to a multi-objective optimization problem using an LCP-related weighted problem. This flexibility in the choice of weights is one advantage that the multiple-objective model has over other optimization-based approaches to LCP. In JOTA 86, 389-405, (1995), it is mentioned that ``the effects of applying this technique to other LCP approaches are unknown and may form an area for future research". We observe that the class Q0 matrices (class of matrices for which feasibility implies solvability of LCP) play a significant role in the application of this approach. We present some new sufficient conditions involving the Q0 matrix class. Recently several researchers have studied multi-objective optimization given by polynomials (J Glob Optim 80, 117–138 (2021)). There are some open questions for studying these topics. We consider a special subclass of Multi-objective polynomial optimization problem (MPOP) with linear constraints and construct an equivalent quadratic multi-objective problem from the MPOP. Subsequently, we reduce this to an equivalent LCP-related weighted problem. We also discuss the MPOP that arises from the generalized class of LCP such as the extended linear complementarity problem (ELCP) (Math. Prog., 71, 289–325 (1995)) and explore the problem of solving a special class of ELCP by constructing a suitable LCP-related weighted problem. We also discuss the problem of finding a zero-efficient point for the MPOP using Lemke's algorithm, obtain some new results, and present the applications of other pivoting algorithms/interior point algorithms for solving this special class of multi-objective polynomial optimization problem. Further, we present an application of the MPOP approach developed here in structured stochastic games for the computation of value vectors and optimal stationary strategies.

# Maximizing the procurement of items with multiple priorities within a fixed budget

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**Keywords:** Knapsack problem, Fixed budget procurement, Optimization problem

## ABSTRACT

In the process of public procurement planning for a specific time period, it often becomes challenging to accommodate all necessary items due to various constraints. Among these constraints, a fixed budget necessitates critical decision-making regarding the items and quantities that can be procured while adhering to the financial boundaries. The primary objective of the procurement plan is to maximize the utilization of allocated financial resources efficiently. However, dealing with a large number of items can add complexity to the decision-making process.

This procurement planning problem can be likened to the classic Knapsack problem, where the goal is to select a subset of items with specific quantities, while respecting the fixed budget, to obtain the highest total value of items. In this context, the value of an item corresponds to its priority in the procurement process. However, real-life situations often involve items whose value varies depending on the context in which they are procured. For instance, a certain item might be required in different quantities, each serving a distinct priority—such as essential quantities for system function, improving functionality, and maintaining reserves—all carrying different degrees of importance.

A relevant example of this scenario is evident in the procurement planning of military uniforms. The task is to determine the total quantity of each uniform type to be procured for a specific period, typically a year. Military uniforms serve specialized purposes exclusively for the army, and contracts are established with manufacturers at fixed prices for the designated duration. To illustrate the variability in item priorities, consider the case of a soldier in the infantry who relies heavily on combat uniforms for daily duties, occasionally using service uniforms and ceremonial uniforms several times a year. The combat uniform takes precedence as the highest priority. In contrast, an education officer in a military school utilizes service uniforms for daily duties, ceremonial uniforms on occasion, and combat uniforms several times annually. Here, the service uniform holds the highest priority, followed by the combat uniform with a lower priority compared to the service uniform.

By addressing this multifaceted problem of procuring items with varying priorities within a fixed budget, our research aims to propose effective solutions and methodologies. These approaches are intended to enhance procurement planning efficiency and contribute valuable insights to the field.

The mathematical model describing the situation can be viewed as a variant of the Knapsack problem, where maximization function consists of quantities for each item and the corresponding priorities, as decision variables. The function is constrained by the budget, and the decision variables must be positive integers whose values do not exceed the number of actually required items.

To assess the viability of constructed formulation, we conducted tests on a simplified example involving a smaller military unit. Employing Excel and its add-in Solver, we obtained one solution. However, this example raises several open questions.

Like many optimization problems, this procurement problem can yield multiple optimal or sub-optimal solutions. For instance, when two items possess the same priority but differ in cost, there exist scenarios where either one higher-priced item or two lower-priced items could be purchased. Excel, typically designed to find a single optimal solution, might only offer one result, depending on the input values' arrangement in the Excel table. While Excel proves suitable for tackling smaller problems, the complexity of larger instances necessitates the development of appropriate procedures and algorithms, as well as the preparation of specialized software tools (solvers) dedicated to handling optimization problems.

Another crucial aspect to consider is the definition of priorities, as they significantly influence the resulting solution. Consequently, modeling priorities requires meticulous examination to comprehend how different approaches impact the solution.

Therefore, for successful implementation, we must explore employing structured decision-making methods and devising a robust decision-making procedure, particularly concerning prioritization. Suitable algorithms and custom-built tools must be developed to address the complexities of the problem at hand.

# Simulation-based multi-objective traffic signal timing optimization framework for urban signalized intersection

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**Keywords:** Multi-objective optimization, Genetic algorithm, Traffic signal timing, Signalized intersection, SUMO

## ABSTRACT

Signalized intersection control is essential to manage traffic flow and ensure safety for all road users, including pedestrians. Traditional signal timing algorithms often focus on vehicular traffic flow while ignoring the unique requirement and safety considerations of pedestrians. In this research, a comprehensive Multi-Objective Simulation-based Optimization Framework (MOSOF) is presented. The MOSOF integrates the simulation of urban mobility (SUMO's) platform to optimize signal timings in a four-way signalized intersection, taking into account the needs of both motorists and pedestrians. The goal of the proposed framework is to improve traffic efficiency and safety at the same time by optimizing signal timings for all user groups. The concept of MOSOF intends to optimize multiple objectives simultaneously, such as minimizing vehicle loss time and waiting time in a queue, decreasing pedestrian waiting time at the intersection, and improving traffic flow efficiency. The framework attempts to develop a balanced solution that satisfies the requirements of all road users by taking into account the interactions between various types of mobility.

The integration of SUMO into the optimization algorithm enables the framework to perform a detailed evaluation of possible traffic signal timing under realistic traffic conditions. The specific characteristics of traffic data, such as traffic volume, arrival patterns, signal phase duration, and the behaviours of all road users are incorporated into the SUMO's microsimulation traffic model. The capabilities of the microsimulation enable the framework to capture intricate traffic dynamics, including vehicle interactions, crosswalks, and drivers' behaviours. The microsimulation model was then linked with an optimization algorithm to analyze all possible solutions. This integration enhances the accuracy and reliability of the optimization process, making the MOSOF better equipped to handle complex urban traffic scenarios.

To optimize traffic signal timing, the framework employed Multi-Objective Evolutionary Algorithm (MOEA), particularly Genetic Algorithm (GA) within the SUMO framework. The algorithm explores the solution space to identify a set of Pareto-optimal solutions, representing trade-offs between conflicting objectives. Decision-makers can then select the most suitable signal timing plan from the Pareto front, considering the diverse needs of all road users.

The primary objective of the MOSOF is to enhance pedestrian safety at signalized intersections while still keeping vehicular objectives good enough. The framework utilizes advanced pedestrian safety models to analyze pedestrian crossing patterns and identify potential conflict zones with vehicular traffic. By optimizing crosswalk timing and coordinating them with vehicular traffic, the MOSOF reduces conflicts and improves pedestrians' safety.

In this study, the typical four-way multiphase signalized intersection is studied. The usual phase sequence at the four-phase intersection is an east-west straight line, east-west left turn, south-north straight line, and south-north left turn. For the right turning of vehicles, a designated lane was allocated through which turning motorists must have to give preference to pedestrians to cross at the time of turning. To evaluate the effectiveness of the MOSOF, extensive simulations are conducted according to peak-hour traffic scenarios and conditions. The simulations consider various factors, including traffic volume, pedestrian demand, and traffic patterns, along with varying signal control parameters. The results demonstrate substantial improvements in traffic efficiency, reduced delays, enhanced pedestrian safety, and minimized conflicts at signalized intersections compared to conventional signal timing approaches.

The results obtained are compared with Webster's Solution and it is found that the proposed framework outperforms Webster's solution by up to 35% in traffic efficiency, and reducing delays for all road users. The algorithm also enhanced safety, and minimize conflicts compared to conventional signal control approaches.

The research findings have significant implications for urban transportation planning and signal control systems. By implementing the MOSOF integrated with SUMO, decision-makers can create sustainable and user-friendly transportation systems that prioritize safety and efficiency. The framework's adaptability and effectiveness make it a valuable tool for transportation planners and decision-makers seeking to create efficient, safe, sustainable, and user-friendly urban transportation networks. The proposed framework is capable of accommodating the needs of all user groups and ensuring their safe coexistence at signalized intersections.

# Inland container repositioning with depot pricing policies

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**Keywords:** Empty container transportation, Inland repositioning, Empty container repositioning, Mathematical modelling

## ABSTRACT

The logistics and transportation industry is critical to the global economy, facilitating the movement of goods across enormous distances from manufacturers to consumers. The use of shipping containers and standardized units that ensure efficiency in cargo handling and transportation is central to this industry. Optimizing operations, particularly inland containers, and reducing costs associated with these containers, is a complex problem. These operations require efficient repositioning and management of empty containers. Ineffective management of empty containers has a negative economic impact on stakeholders along with container logistics chains. In addition to that, it also poses environmental and sustainability challenges due to increased fuel consumption. This study delves into the multifaceted domain of the repositioning of inland or domestic containers with a specific focus on minimizing the cost associated with their operations which has a pivotal impact on efficient management.

Inland repositioning is critical in logistics and international trade, involving the relocation or transportation of empty shipping containers from their initial location, typically a port or depot, to another location within a country or region where they are needed. The efficient management of this process is essential to ensure that the containers are readily available at various locations, effectively meeting supply and demand requirements. Efficient inland repositioning maintains a smooth flow of goods, minimizes logistics costs, and optimizes international trade by matching containers with importers' and exporters' demands.

In order to investigate the dynamics of inland container repositioning, this study offers a thorough and in-depth exploration of various facets related to this process. The primary objective of this paper is to analyze the impact of different depot pricing policies on repositioning decisions, and costs. For that, a multiple-objective function that minimizes the overall cost of containers sent to customers has been developed. This cost encompasses both transportation and storage expenses incurred until the containers are released from depots. The storage cost calculation involves the contract types of depots, including the duration and location of container storage. The total transportation cost from depots to customer locations is then added to calculate the overall cost. To achieve this objective, a mixed-integer linear programming model is proposed, considering depot pricing policies and distances between container depots and customer locations. Computational results demonstrate the effectiveness of the model in identifying viable alternatives for minimizing repositioning costs.

In conclusion, the reduction of inland repositioning costs for empty containers holds significant importance for the global shipping industry. This study sheds light on the intricacies involving the repositioning of inland containers and emphasizes the pivotal role of depot pricing policies in shaping strategies and outcomes. The proposed methodology offers valuable insights for shipping companies, logistics providers, and policymakers who are aiming to improve container repositioning operations and enhance supply chain efficiency. By addressing challenges through this mathematical model, significant cost reductions can be achieved.

# Multiobjective optimization models for integrating circular economy principles in slurry management

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**Keywords:** Circular economy, Slurry management, Optimization modeling

## ABSTRACT

Circular economy policies are based on the principle of reuse, reduce and recycle to extend the life cycle of products as long as possible. Within this framework, waste is no more regarded as an issue but rather is transformed into a new resource. A circular economy is a production and consumption model aimed at attaining a society that generates no waste or, in other words, a zero-waste society, leading to minimized environmental impact and reduced energy consumption.

This paper addresses several issues faced by a system responsible for managing slurry. Effective management of slurry is crucial for achieving social, economic, and environmental sustainability in regions that are regarded as vulnerable due to high nitrate contamination from agricultural or livestock activities.

There are two types of users within the management system: pig farm owners, who are responsible for managing the pig slurry and are billed for it, and other farmers who pay to use this slurry as organic fertilizer. The combination of both users within the management system provides a circular economy solution to the management of pig farm waste. Hence, a key issue is determining the appropriate price for delivering the service to the users of the system to enhance the value of the slurry and ensure the sustainability of the management system.

The process being modeled involves the collection of resources from pig farms and its immediate utilization as organic fertilizer on either the same farmer's field or a different farmer's field. Alternatively, if the weather is unsuitable, the slurry is stored in ponds. To distribute the new fertilizer, it is essential to determine the appropriate dose based on agricultural and environmental considerations, as well as the quality of the slurry, and to select the optimal timing based on the crop type.

The slurry management system has to make both short-term operational decisions, as well as medium-term planning decisions. The main focus of this work is on planning decision-making. The proposed models aim to establish a fixed annual service fee charged to users, taking into account that the management system is not profit-oriented but rather primarily aimed at promoting the use of slurry as fertilizer.

The first step is to outline the problem faced by the slurry management system, including the characterization of user types based on their attributes and the interactions between the system and its users. Next, the planning horizon and the parameters of the problem (such as vehicle capacity, fertilization periods for each crop on every farm, etc.) are identified. In the second step, two optimization models are formulated based on different assumptions. When assuming that the management system can fully control the pricing, a multi-objective optimization model with a single decision level is proposed. On the other hand, when considering farmers' reaction to the set prices, a multi-objective model with two decision levels and multiple decision makers is formulated. Finally, the proposed models are evaluated in a case study. Several scenarios are presented that consider potential pricing constraints depending on the type of user or different approaches to address the multiobjective problems formulated.

# Multi-objective optimization for homecare delivery during health emergencies

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**Keywords:** Goal programming, Health care delivery, Home care, Multi-objective optimization, Heuristic algorithms

## ABSTRACT

The demand for home health services has been increasing globally due to factors such as an aging population, increased prevalence of chronic diseases and increasing waiting times at hospitals. In addition, the COVID-19 pandemic proved the instrumental role of home care services in the broader health services industry. In this research, we focus on operational planning decisions related to home healthcare services and aim to optimize service providers' (HSPs) daily routes and prioritized patient visit schedules dynamically, as new emergency requests arise within the day. We suggest the HSPs cooperate with each other through central decision making. We formulate this dynamic problem with multiple objectives in a lexicographic goal programming (LGP) framework. A mixed integer linear programming (MILP) model and a greedy randomized adaptive search procedure (GRASP), followed by a variable neighborhood search (VNS) procedure for local improvement are developed together with a hybrid approach that utilizes both the MILP model and the proposed heuristic. The three approaches are compared for a case to consider serving COVID-19 patients. To show the effectiveness of centralized planning with HSP cooperation and compare the proposed solution approaches, several performance metrics are analyzed through extensive computational and simulation experiments. In addition to a novel approach for solving the formulated LGP, how HSP cooperation improves overall system performance in a dynamic setting is demonstrated.

This study contributes to the existing literature by addressing a unique combination of key problem features of a realistic setting, and, by proposing a cooperative approach while ensuring care continuity and incorporating time-dependent travel times for the first time in the literature. Moreover, we ensure a service quality requirement by imposing a deadline for serving emergent patients and optimizing several objectives simultaneously. In healthcare systems the emergence of new and urgent requests is common, especially in a health emergency, such as a pandemic. Hence, the schedule needs to be updated with new arrivals but at the same time should not be altered drastically and the already scheduled patients should not be postponed as much as possible. We address this re-optimization problem with several objectives and aim to generate solutions that excel in these objectives according to their importance rankings in the healthcare context, i.e., giving more importance to patient-oriented objectives. In terms of solution methodology, we present a fast and effective heuristic (GRASP + VNS metaheuristic) designed in accordance with lexicographic goal programming (LGP). In our computational study, we show the effectiveness of our solution approach and quantify the benefits of HSPs' cooperation through a case study.

Our main contribution is the centralized optimization of multiple HSPs' schedules and routes in a dynamic setting that accounts for urgent visit requests with the cooperation of HSPs, while also ensuring care continuity and incorporating time-dependent travel times. Multiple objectives are optimized to minimize delays, postponements, overtime, and schedule disruptions. To the best of our knowledge, the resulting problem is addressed for the first time in the literature and captures many aspects arising in practice. We show the benefits of such an approach, via a computational study, as opposed to generating the schedule of each HSP separately, which is the common approach in the literature. We also present a simulation study conducted on instances with different sizes and varying parameter values that leads to several important insights for operational planner.

# Long-haul direct flights or sustainable connecting flights? A multi-objective approach to network design under CORSIA

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**Keywords:** Hub network problem, Pro_t maximizing networks, Coopetition, Duopoly, CORSIA, Carbon Neutral Growth (CNG)

## ABSTRACT

The aviation industry, like many other sectors, has found itself grappling with the pressing issues of climate change and the escalating challenges posed by global warming. Notably, the industry has become subject to increasingly stringent regulations aimed at curbing carbon emissions. This environmental imperative has gained momentum as the detrimental effects of human activities on the planet have become more evident. However, the aviation sector has encountered additional complexities that have compounded its struggles – factors such as volatile fluctuations in fuel prices and unexpected disruptions like the global COVID-19 pandemic. These elements have rendered airlines particularly susceptible to unpredictable revenue streams and mounting operational expenditures, undermining their stability.

The focal point of this investigation lies at the intersection of these concerns. Specifically, this study endeavors to explore the ramifications of fostering a cooperative and competitive symbiotic network, referred to as a "coopetitive network," within the aviation industry with a pronounced environmental orientation. To this end, the study selects two airlines, facilitating their entry into each other's markets situated on disparate continents. The central objective is to dissect the repercussions of the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) on this resultant transcontinental network.

To scrutinize this intricate nexus, a novel approach is employed. By formulating a cooperative alliance – a duopoly coopetitive framework – between the chosen airlines, the study endeavors to maximize profits while contending with a multiplicity of objectives. A significant facet of this endeavor is the strategic identification of optimal hub locations, a puzzle that is emblematic of the aviation industry's intricate web of interconnections. This quandary is tackled using an augmented e-constraint algorithm, a computational technique aimed at optimizing complex multi-objective challenges.

The study's methodological rigor is further enhanced by the articulation of diverse hypothetical scenarios. These scenarios illuminate the spectrum of potential outcomes based on varying circumstances, thereby enriching the understanding of the dynamics at play. One pivotal facet of inquiry pertains to the configuration of the intercontinental hub network, which is markedly affected by the proposed coopetitive alliance. Additionally, the study scrutinizes the evolution of carbon emissions patterns engendered by the cooperative efforts of the two airlines.

Central to the study's findings is the imperative of mitigating carbon footprints within the aviation realm. Collaboratively addressing environmental concerns prompts a collective endeavor to eliminate extended international routes, a step that holds the promise of curbing carbon emissions in the vast expanse of the global skies. Importantly, fuel efficiency emerges as a critical determinant in the distribution of market share amongst competing entities under the purview of CORSIA.

The study's results are instrumental in characterizing the diverse responses exhibited by airlines that vary in their environmental conscientiousness. Distinct behavior patterns emerge between airlines that prioritize fuel efficiency and those that are less attuned to environmental considerations. The study thus underscores the transformative impact that regulatory frameworks such as CORSIA can wield, transcending economic and operational considerations to engender a profound shift towards sustainability.

In conclusion, the aviation industry's confrontation with the intertwined challenges of climate change and operational uncertainties necessitates innovative paradigms. The convergence of cooperative and competitive dynamics within a greener framework has the potential to reshape the industry's landscape. By delving into the implications of a coopetitive network, this study provides a robust foundation for understanding the intricate interplay between environmental imperatives, regulatory interventions, and market dynamics within the aviation sector.

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