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Designing Robust Optimization for a Scheduling Problem of Urban Rail Transit, Considering Uncertainty of Demand and Time in the Case of Tehran Metro

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Abstract
One of the most important issues in Tehran Metro is the planning of trains on the railway network. Over the past years, various approaches and computational tools have been proposed by various researchers to optimize the movement schedule of Tehran metro trains. However, the need to create and develop a robust approach to eliminate traffic disruptions in the Tehran metro network is still essential. To solve the traffic problems of Tehran metro railway systems, some suggestions have been made for establishing sound methods in the train schedule. In which the creation of stability based on the existing infrastructure of Tehran Metro such as the amount of demand and buffering time is considered and based on that, solutions are invented and presented. In such approaches, what is most important goes back to the components involved in setting schedules and controlling train traffic, which is dynamic and uncertain in nature and in dimensions such as train travel time, number of active trains ready for rail service. , The number of stations passed from the origin or remaining to the destination, etc ... has been considered. In this research, an attempt has been made to present a robust approach to optimize the schedule of Tehran metro trains.

Keywords:-Stability, optimization, schedule, Tehran Metro

Introduction
In recent years, with the increasing demand for the use of intercity rail transport services, the volume of traffic in the metro industry has increased in proportion. The result of the increasing demand for the use of trains in urban travel, reveals the need to optimize it to respond to demand in a timely and appropriate manner during service delivery intervals. In the term rail, stability means using a method in which the problem of train traffic is optimized for the worst possible case; Sustainability in metro train timetables is due to the existence of appropriate infrastructure, recent advances in computer science, process intelligence and management of technologies and human resources, etc., which can provide the basis for optimizing train timetables according to the existing infrastructure and Provide a favorable and optimal schedule to meet the demand and capacity of the metro network in the relevant time periods. The term robust optimization in the metro system refers to the resilience of scheduling tables in the face of all kinds of intentional and unintended disturbances in the rail network. Therefore, in many managerial decisions, it is necessary

to provide alternatives with a certain level of stability and resilience that, despite inaccurate, vague and incomplete data, provide a suitable framework for optimal decision-making based on feasibility studies. This data, which constitutes the main inputs of traffic control systems in the rail network to provide a robust schedule, must have the following characteristics:

Problem Statement

Due to the dynamic nature of traffic control issues, the data is based on the foresight of the metro network and evolves over time based on the improvement of the knowledge base, and as a result, updates the schedules regularly and continuously. To achieve this, dynamic scheduling ideas need to include alternatives that can cover a certain degree of uncertainty and resilience in the operation of trains in the metro network. In other words, solid alternatives in the timing table should detect dynamic changes in problems for both internal domains (such as incorrect definition of problems and common failures) and external causes (exogenous events due to ambiguous components in the metro network operating environment). And find timely and appropriate answers for them (Palisella, 2005). It should be noted that in a dynamic planning problem, the data related to predicting the future behavior of the system due to the nature of evolution in the context of time are not accurate and predetermined and according to the feedback obtained during the operation of subway lines. It is pursued with the aim of achieving a degree of stability in the provision of metro services. On the other hand, delays in the operation of trains on the rail network can significantly affect metro scheduling schedules. If scheduling tables can absorb the consequences of impact shocks well by setting up and reconfiguring, compensate for these delays with high reliability, and speed up trains to compensate for time lags in proportion to the increase in infrastructure proportionally. Data; They are able to improve the travel experience for passengers, as a result of the implementation of this method, the avoidable penalties of the railway network can be avoided and the profitability of the system can be significantly increased.

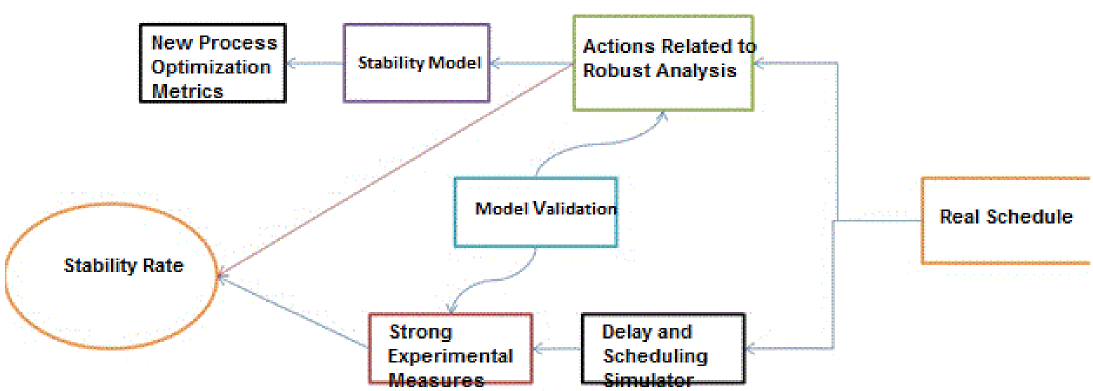

Figure 1) Graph of the stability of train schedule schedules in the metro network based on analytical and experimental methods

In the present study, robustness is examined for two cases:

1- Frameworks and policies that explain the role of sustainability in train scheduling

2- The effects and results of implementing sound methods in planning the movement of trains.

Therefore, after explaining some factors related to the stability of scheduling tables such as: measuring stability, random planning, analytical and experimental methods of reviewing tables and finally providing detailed definitions of stability in timing tables and related approaches in metro scheduling tables, to conclusion. And the proposal is addressed. It seems that the literature on the planning of subway train scheduling is still in its infancy according to previous studies to provide quality alternatives and therefore strong programs in combination with active and effective action on scheduling tables and the completion of its mechanisms. Although different approaches have been proposed so far, it has not been possible to establish a robust conceptual model for alternatives to train and train scheduling as well as other dimensions of the metro. In the meantime, several interpretations of stability have been presented, in some of which aspects such as providing alternatives to maintain a certain level of quality of service to passengers have been mentioned. In the studies of Leon and Storer (2006), stability is based on the ability to maintain the quality of output (product and service) during consecutive time periods or times required for product development, service, etc ... and also to add characteristics to achieve a strong goal based on Have defined operational data and the like (Leon and Storer, 2006). In another study, Hoysman and Butcher (2004) used genetic algorithms to provide robust programs to solve production scheduling problems in textile workshops. In this study, while designing and explaining a fitting function for synthesis algorithms, the researchers developed robust solutions with respect to possible manufacturing delays during the operation in terms of possible delays in real operating conditions based on the general theory of stable scheduling in order to perform roles and tasks. In another study by Davenport et al. (2004), general theories of train scheduling, including the definition of time, the occurrence of disturbances and possible failures in the movement of trains, were studied and offered to provide appropriate alternatives. And complementary solutions have been implemented instantaneously and according to the most appropriate methods (Davenport et al., 2003). In other studies that will be discussed in future sections; Creating a localized schedule according to the real conditions of the railway lines, based on the proposed alternatives in the form of minor changes in the schedule in order to achieve a certain degree of stability, and the flexibility of time tables to solve traffic problems of the rail network has been studied. , 2001; Pali Sella et al., 2008). In some researches, the stability of planning and achieving goals and in others, the stability of time tables have been mentioned in different comprehensible ways. Tomi (2008) expresses another definition of firmness in controlling the traffic of the metro network and in his research states that if the time tables are designed, they can identify and cover unexpected traffic problems well without the need for extensive changes and the necessary requirements of scheduling tables are necessary. Meet; Minimize the possibility of distortions. The researcher also explained several indicators to measure the degree of stability in each level, which is shown in Figure 2.

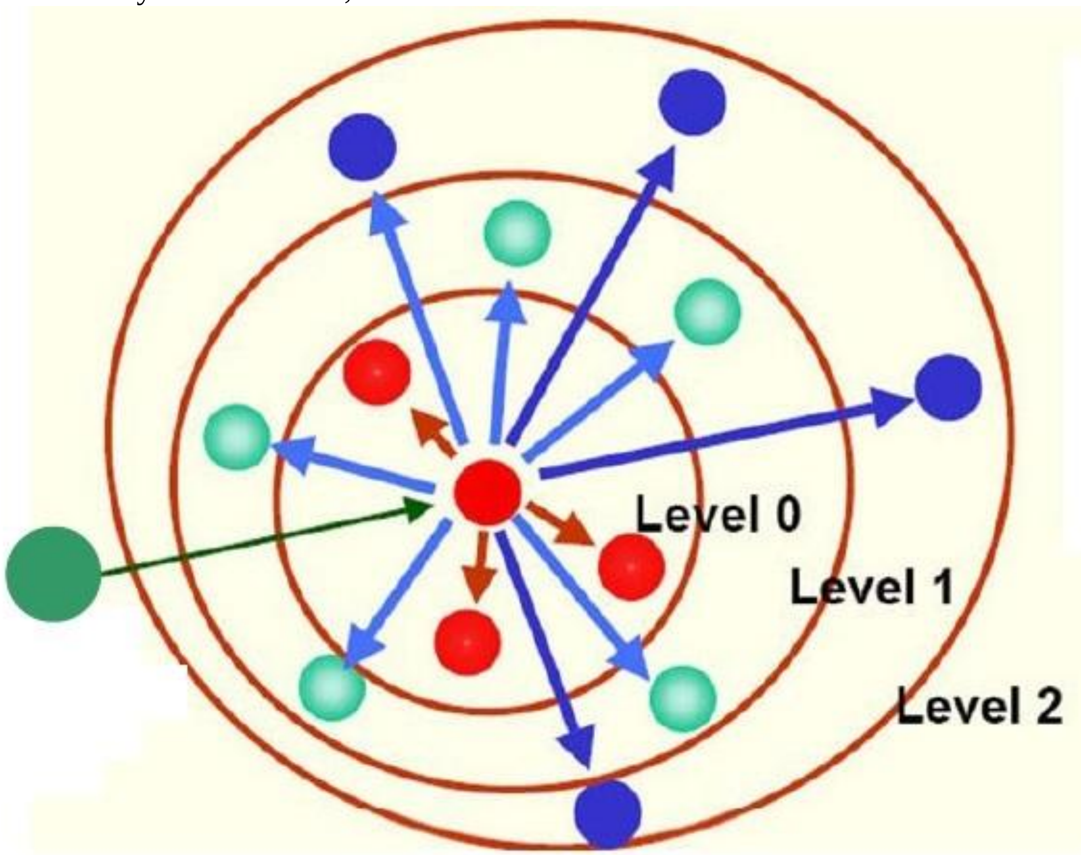

Figure 2) Stability levels in train and train scheduling tables taking into account the cost factor ((Tomi, 2008

In Figure 2, level zero indicates time and level one shows traffic instructions according to the conditions of monitoring and control of railway lines. Level 2 also shows the railway lines under the control of the command centers, the timing tables of which are designed for guidance and guidance. Level three shows the rail vehicles under the control of the Traffic Control Center, and finally level four depicts specific cases related to the failure and cancellation of passenger traffic on the rail network. In this study, it has been shown that in most cases, railway line disruptions occur at the level of zero, ie the length of operation intervals. Minor disturbances at higher levels often do not occur and therefore there is a possibility of rescheduling according to the actual condition of the lines, rail vehicles, number of dispatches, etc. Figure 3 shows the factors affecting the stability of the train schedule in consecutive times of operation.

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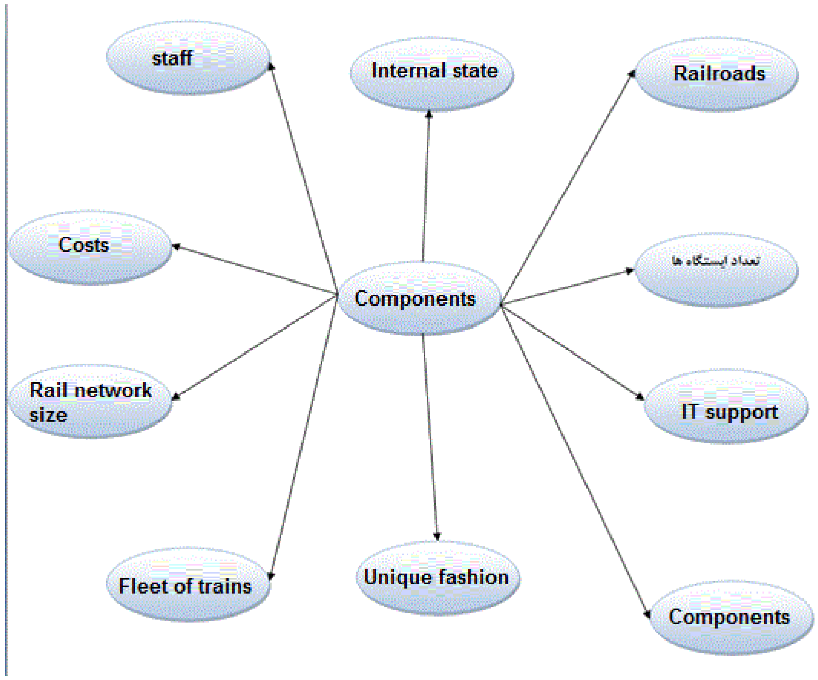

Figure No. 3) Components affecting the setting of sustainable schedules in the movement and movement of subway trains (Researchers, 1401)

Kerry and Carville (2003) in their study have described and developed the exploratory indicators of train schedule schedules, based on which it is possible to create relative stability in the early stages of design, planning and implementation of these tables (Kerry and Carville, 2003). . In another study (2007), the researchers presented a simulation model to test and measure the performance of train schedule according to the distribution function of the probability of secondary delays in the rail network (impact and non-cumulative effects) and in their study that the occurrence of perturbations The secondary type is mainly due to the initial delays and in their summary, by explaining the function of the model, they have examined its efficiency to solve the presented problems by evaluating the scheduling tables (Kerry and Carville, 2007). Ginsberg et al. (2000) have described the methods of eliminating and absorbing rail network delays through well-known models (called supermodels) and have concluded that the use of these supermodels can be a good basis for developing and measuring the stability of train timetables. And also provide appropriate alternatives according to the limitations of the model (Ginsberg et al., 2000). In their study, Hebrard et al. (2007) presented robust alternatives to traffic issues by considering limitations such as the user satisfaction and user satisfaction of the traffic control system and optimization methods. However, in general, due to the ambiguous and fuzzy nature of stability in planning and setting metro scheduling tables, the degree of stability has been evaluated through simulation and its implementation methods have been studied (Hebrard et al., 2007). In a 2009 study by Roman et al., Researchers developed the concepts of reliability in metro systems and subsystems by using simulation methods for heterogeneous lines and to test the effects of

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deviations and distortions on service instability. They deal with the number of stops and dispatches in Matson's schedule (Vroman et al., 2009).However, the background study and research on how and how secondary delays are related to the rate of primary delays in the metro network and the optimal use of rail network capacity to provide desirable and sustainable services in the study of Hogimestra and Tunisia (2000). In this study, researchers simulated the prototype by rail simulator to study the stability of train schedules in the Dutch metro network. The simulator used in this study to produce time tables is DONS, which according to the conditions and power of reproduction functions Schedule changes have guided alternatives to returning the rail network to normal (Hogimstra and Tunis, 2000). Similarly, in another study by Middleclope and Bowman (2004), researchers developed a simulation model called "SIMON" to analyze the stability of train schedule schedules and simulate a complete rail network. In this way, they have identified and refined the obstacles to the development of sound schedules (Middleclope and Bowman, 2004). Figure 4 shows the dimensions of the train scheduling problem.

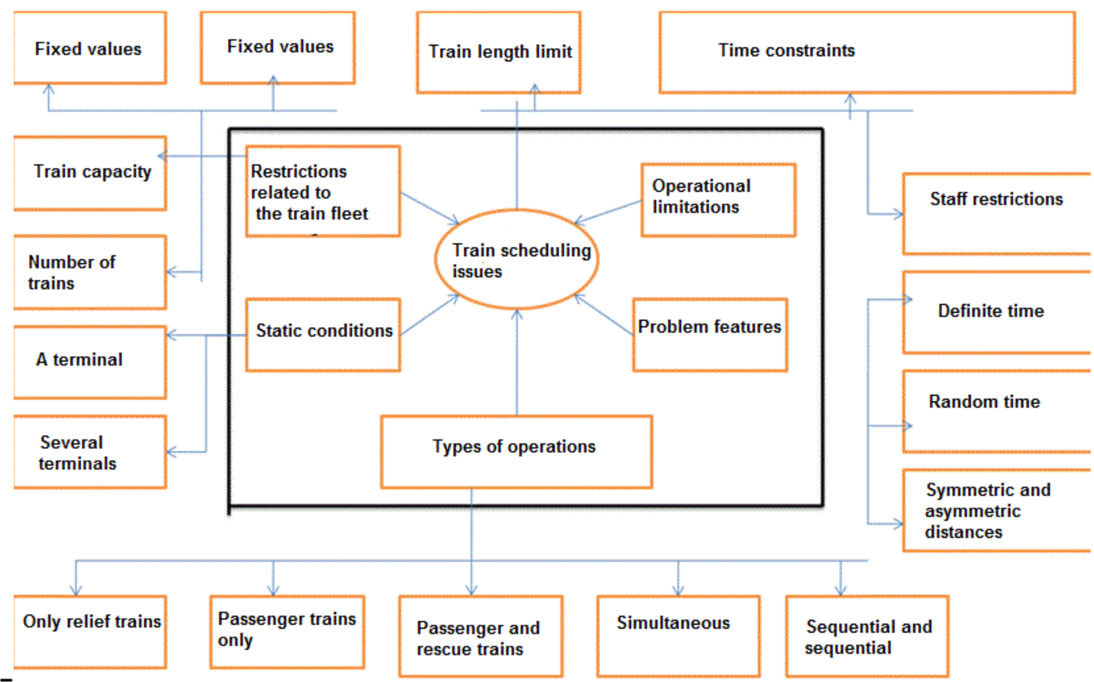

Figure 4) Dimensions of the train scheduling problem

some limitations need to be considered as problems with train schedules (Bodin et al., 2000):

.1The maximum period of time that a train may provide service before returning to terminals or terminals on the rail route.

.2The need to determine a sufficient period of time for emergency maintenance and repairs before and during the provision of services on the rail route according to the scheduled schedules

.3Terminals that can accommodate the train in the event of a sudden failure or after the provision of daily services for daily post-service visits without any noticeable deviation in the schedule.

.4Considering the fact that a number of trains are not always in good service condition and the timetable faces serious problems.

Now, considering that solving planning problems in the metro network is among the strategic and long-term decisions that lead to planning and planning the process of operation of trains, so the use of research methods in operations plays an effective role in Plays the train scheduling process. In recent years, however, serious attention has been paid to solving planning problems through considerations related to stability and improving the quality of traffic control through it. Stability generally refers to the capacity of systems to absorb the consequences of delays or to be resistant to distortion. The stability of the metro rail network is often directly related to capacity. In some special cases, such as disturbances in the railway network, such as delays or fatal errors, paying attention to stability can lead to the inclusion and consideration of actions and goals in train movement planning issues and by providing appropriate tools to improve the level of reliability and continuity. Rail network operations lead to distortion conditions. Now, considering the quantitative growth trend of Tehran's metropolitan population and the need of citizens for sustainable inner-city rail (metro) services, the main question of this research is what are the effective factors and components of stability in the schedules of trains? And what model can be designed for stability in Tehran metro?The train schedule is a strategic, vital and important document for planning and organizing train traffic in the metro network. This table, although it may be set up with high quality, is applicable only in railway network operating environments when the railway capacities and infrastructure in the metro are efficient. Therefore, the problem of scheduling trains in the metro with different operating speeds on different lines is made possible through a practical, multi-purpose and high-efficiency schedule that ensures stability for specific conditions.The stability of train timetables is a key indicator of the success of the metro network. A criterion according to which the efficiency of train schedules can be determined during the operation. Operators in the metro system to deal with unexpected and unforeseen disruptions that do not normally occur normally in the daily process of train travel on the rail network and include special conditions, resulting in delays in the movement of trains or from Shows the effects of impacts on the rail network. They have always been concerned. Absorb in itself. Therefore, the importance of identifying the main components of table design that can be directly related to stability as a main necessity helps metro network operators to determine and measure the stability by determining traffic parameters and analyzing and refining them using simulation tools. To determine its characteristics with sufficient validity according to the degree of operational stability and analysis of historical data on disturbances obtained through traffic operators, and to achieve practical methods for the formulation of traffic events and the elimination of distortions in the process of scheduling schedules. Get help.Due to the role and importance of train scheduling in the operation of metro systems, much research has been done on the planning of trains and the movement of trains in the rail network. In these studies, there have been many problems to achieve the goals of research, which are generally divided into two categories;

First: The study of documentation related to train schedule scheduling issues in the nominal sense and with its steady load, which is generally used to optimize a scheduling objective function. Examples of minimizing travel time, maximizing passenger satisfaction, etc. can be mentioned.

Second: Assuming passenger satisfaction, there are limitations such as capacity, while stable methods mainly aim to reduce the time delay due to distortion, which indicates the existence of disruption in the metro rail network. Over the years, many works have been published that have been able to model issues related to nominal fashions and thus solve its problems.Kakiani et al. (2015) in their research entitled ›› Stable Timing Tables; Challenges and Problems ›While addressing the issues related to nominal scheduling tables and expanding the challenges and issues related to them, they have mainly focused on periodic and non-periodic time tables and have designed a solid model to solve the mentioned problems (Kakiani Et al., 2015).In another study by Nachtigal and Wujit (2000) entitled "Taking advantage of the genetic algorithm approach in updating the railway industry scheduling periods", researchers have developed and implemented a schedule with a minimum passenger in which the time interval The movement of trains and waiting time in the rail network are modeled periodically and then the researchers propose to present a method based on a hybrid genetic algorithm that with a greedy exploratory approach and optimization methods based on it, alternatives to scheduling problems Nachtigal and Wujit, 2000.(In another study entitled 'Solid Modeling of Periodic Event Planning Issues in Train Schedules and Related Issues', Liebchen and Moring (2011) explain the role and importance of integrated decisions in train scheduling through the use of a periodic schedule. Have shown how the scheduling problem model for periodic events (PESP) can be developed to optimize timelines (Liebchen and Moring, 2011).another study entitled "Periodic Schedule Tables in the Rail Transportation Industry with Event Flexibility Approach" conducted by Kaimi et al. (2014), researchers explored common issues in periodic event-based scheduling tables (PESP) to explain the dimension. They deal with Flexible Event-Based Scheduling Tables (FPESPs) to find the right travel time and movement for trains on the rail network, the right time for a train to leave a station, and a good time to get to a destination. In this study, instead of performing calculations to obtain results through samples in the real world, they have proved the validity and effectiveness of their model (Kaimi et al., 2014).Also, in the study of Crohn and Peters (2006) entitled "Introducing a variable trip planning model for periodic schedules in the rail network", an integer linear programming (ILP) model for formulating traffic planning is presented. To solve the problems of periodic schedule tables, researchers have compared and explained non-periodic schedule problems. The results of this study often indicate that non-periodic programs have more advantages than the first type. A competitive market in rail transportation that aims to produce optimal tables and maximize overall profit (Crohn & Peters, 2006).Branlund et al. (2001) in their research entitled "Rail Network Scheduling Using Lagrangian Theorems" presented an ILP integer linear programming model to obtain optimal scheduling tables to maximize profits from the subway train fleet .اند.In this study, researchers have used Lagrange methods to provide solutions to scheduling problems in which constraints related to rail track capacity and bottlenecks have been considered as research constraints in the optimization model (Branlund et al., 2001).Caprara et al. (2005) in their study "Modeling and Solving Train Scheduling Problems" developed a theoretical and graph-based model for formulating traffic planning through the ILP approach to maximize the total revenue generated from train planning. The mathematical formulas of TIS in the model have shown that this is achieved through Lagrangian methods by considering the constraints associated with diagram nodes (Caprara et al., 2005).Kachiani et al. (2013) in their study entitled ‘‘ Non-periodic and non-rotational timetables of rail network trains ’’ to explain comparative diagrams for designing and presenting non-periodic and non-rotational relations and formulas in train timetables for maximum Profit delivery in terms of compatibility of rail routes through a T-chart in the ILP approach and by analyzing the results of the model have presented a new model for solving problems (Kachiani et al., 2013). In another study entitled "A Study of Non-Periodic Scheduling Problems and Its Impact on Regular Train Receipts at Station Platforms", the same researchers (2018) provided methods for solving TTP problems from a tactical perspective by presenting some standards and They have been implemented and shown that integer-based programming approaches can optimize the schedule (Kachiani et al., 2013).In another study by Hu et al. (2021) entitled "Optimizing Schedule Tables to Provide Lean Passenger Services through Joint Fleet and Passenger Volume Control Methods" in one of the subway lines, especially passenger peak and saturation mode, using The integer linear approach deals with the linear optimization of timing tables. In this study, researchers have presented a synchronous and simultaneous method for optimizing the schedules of train trains and the process of boarding and disembarking passengers, in which traffic control strategies in one of the busiest subway lines have been studied and the aim is to find solid methods. To solve traffic problems, schedule trains. In this research, the practical issues of train movement planning have been stated. Also in this study, the delays that occur at the operational level for real and non-nominal scheduling tables have been studied and the feasibility of implementing nominal tables has been investigated. The results of this study show that designing a train schedule can firmly reduce the amount of deviation between the planned and actual tables through train optimization strategies and basic traffic planning methods. In this method, many solid scheduling issues have been considered (Hu et al., 2021).Kroon et al. (2011) in their study entitled "Random methods of improving the cycle of schedules of train schedules and movements in the railway network" emphasized that the traffic operations of railways are exposed to real-time sequential and random disturbances. . Therefore, a model has been proposed based on which the optimization model of stochastic methods to improve the stability of metro periodic and rotation schedules can be obtained by allocating time supplements, which is referred to as "buffer". The results of this study have shown experimentally that the average train delays can significantly reduce continuous and relatively minor changes in timetables (Kron et al., 2011).In another study entitled "Introduction of Stochastic Optimization Models and Sturdy Algorithms for Finding Suitable Alternatives to the Problem of Scheduling Trains on Two-Way Routes" Random for the purpose of minimizing the total planned travel time and minimizing the objective function to minimize the waiting time on the platform and delay. In addition, in this model, researchers have examined the efficiency of the model by testing real data on the Beijing-Shanghai Railway in China (Khan and Zhou, 2013).Kachiani et al. (2015) in a study entitled "Conducting an Exploratory Lagrangian Method for Sustainability of Train Schedules" have presented an exploratory method through solid scheduling alternatives that, in addition to explaining traffic issues, Lagrange exploration has been done to generate solid alternatives and improve scheduling tables (Kachiani et al., 2015).Young et al. (2013) in a study entitled "Problems of train schedules on single-lane rail lines in terms of fuzzy passenger demand" have examined the problems of stable train scheduling and considering the uncertainties caused by passenger demand, table problems Scheduling has been studied with fuzzy passenger demand. In this study, demand covers a total of two fuzzy goals, the first of which includes the waiting time of passengers and the second is the total delay time per number of passengers who board or disembark each train. In this study, metro stations are formulated as a random variable in a complex integer programming model of zero and one and a branch algorithm is designed and proposed to solve the model (Young et al., 2013).In some studies, the schedule of trains and the maintenance of maintenance and repairs in the railway network have been considered together. In addition to scheduling issues in the rail industry, problems related to the maintenance and repair of rail infrastructure have also attracted the attention of many researchers. During the last two decades, a lot of research has been done in which the maintenance plan in the railway industry has been extensively covered as an effective component of stability. In a study by Higgins (2000) entitled "Optimization of maintenance and repair planning activities of railways and their crews", researchers aimed to determine the optimal maintenance and repair activities on one-lane routes so that trains are scheduled and diverted. Unnecessary maneuvers and round trips of trains on the rail route are minimized and relevant alternatives to reduce buffering time are provided through a nonlinear model and exploratory search.In another study by Buddha et al. (2009) entitled "Preventive planning to optimize maintenance activities of the railway industry"; Operations research models for maintenance and repair planning and general fleet performance management as well as solving railway infrastructure maintenance and repair problems have been studied. In this study, an optimal model for improving rail maintenance decisions through a greedy exploration algorithm to solve traffic problems in order to minimize costs due to maintenance factors and repairs of lines and trains in the rail network is proposed and then the researchers use algorithm. Fuzzy-based exploration has solved the problems of maintenance planning and preventive repairs as one of the firm dimensions in scheduling tables (Buddha et al., 2009).In another study by Leiden and Joborn (2019) entitled "The Dimensions of Time Windows for Maintenance of Railway Infrastructure and Cost Efficiency in Subway Network Traffic Issues"; Researchers study cost models, transportation and traffic, passengers and the optimal model for evaluating the effects of maintenance and repair time windows to improve transportation costs and to investigate the effects of different maintenance and repair window time on maintenance and repair costs and its effect on time tables. Data and have offered robust alternatives (Leiden and Joborn, 2019).In

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another study by Zhou et al. (2020) entitled "Presenting a robust model using a dynamic multi-objective genetic algorithm (multi-population) in optimizing the periodic (rotational) design problem of the train fleet". The rotational optimization model to minimize the total travel time as well as the maintenance and repair costs using the Multipurpose Genetic Algorithm (MPGA) for the high-speed rail have been studied in terms of the performance components of the proposed model and algorithm. Zhou et al., 2020.(In another study by Aken et al. (2020) entitled "Designing train schedules according to the maintenance and repair of infrastructure in the rail transport sector"; The problems of train timetables (TTAP) in maintenance and repair conditions have been investigated through the mixed integer linear programming model and a buffer time generation approach has been used for the timetable (Aken et al., 2020).In another study by Leiden and Joborn (2020) entitled "Introducing an Optimal Model for Integrating Transport Planning with Intercity Rail Maintenance Systems", researchers developed an alternative schedule with minimal deviation from the set table. Nominal and real; They have presented a hybrid time planning model and, using the integer programming approach, have set up medium-term tactical planning, considering both train services and rail network sequencing. In this model, focusing on maintenance and repair of the rail network, large-scale examples of subway traffic management are presented (Leiden and Joborn, 2020).In a study entitled "Optimizing Traffic Scheduling through the Integration of Preventive Maintenance Scheduling and Train Scheduling" conducted by Levan et al. (2020); Researchers have proposed a way to optimally integrate train schedules and rail network maintenance systems. In this research, researchers have implemented an integer linear programming model considering maintenance and repair tasks in the network space of train traffic regulation and have presented a model based on heuristic and Lagrangian methods to solve the problems of this section (Levan et al., 2020).In another study entitled "Rewriting train schedule schedules to comply with preventive maintenance measures" by Arnas et al. (2021) to control and monitor the movement of trains in the rail network using a complex integer linear programming algorithm Researchers have provided a model for robust metro schedules and dealing with unexpected deviations. The demand and capacity created by maintenance for a micro approach to scheduling problems has also been considered as an innovation (Arnas et al., 2021).In a study entitled "A recurring approach to reducing the effects of train delays through the maintenance of rail network performance infrastructure" conducted by Vanstein Wigan et al. (2019), researchers examined the effects of infrastructure failure. Riley and the results of robust scheduling as a goal in the absence of infrastructure related to traffic planning to maintain the desired level of passenger service and stated that scheduling should be considered as small and agile as possible. To solve related problems, they have used iterative approaches and developed algorithms to make small changes in order to route and create scheduling tables based on solid methods. In this study, researchers also investigated the effects of maintenance planning on traffic scheduling and train scheduling based on a two-stage exploratory plan and developed a robust train scheduling program based on an integrated optimization model (VansteinWiegen, Partners 2019).One

of the most important features of this research is the existence of innovation and distinctiveness of the title in the subject areas, geographical territory and time domain, which has distinguished it from other studies.
Some aspects of novelty and innovation in this research are as follows:

 Ability to create coherence between the dimensions and components of the train schedule with different parts of the rail network such as signaling, maintenance and infrastructure to reduce metro network delays and create a stable approach

 Convergence of traffic management models in train scheduling, instead of reducing the diversity and multiplicity of models for compiling train schedule in the metro network and using it optimally to create stability in timetables

 Possibility of supporting other creative models of sustainable development of train schedules in the metro network with emphasis on a sustainable approach

 Enabling integration, alignment and coordination between the outputs of the robust model Train schedule schedules and the results of reducing delays and the integrity of maintenance through the use of potentials in the process of improving the metro network schedule in a robust approach

 Possibility of achieving the benefits and achievements of passenger satisfaction and organizational productivity for metro stakeholders through the establishment of a robust model

 Ability to identify and explain the technical and economic consequences of rail delays and deviate from the schedule developed in the metro by using the dimensions of a stable model.

Utilizing Delphi and fuzzy techniques along with decision-making techniques to optimize train schedule

Using the practical experiences of experts in addition to scientific resources in developing a robust model of train schedule in the metro network

Existence of very few solid projects in the subject area of research

 Ability to explain the requirements for establishing a stable schedule in the metro network

 Considering all the criteria for optimal adjustment of tables Schedule the movement of trains in the metro network using solid components

Specifically, this study seeks to achieve stability in the schedule of trains in the metro network. Achieving a solid goal in the timeline is achieved by the methods that need to be considered,
Some of these goals are as follows:

-1Inclusion of buffer in the schedule in order to reduce the route load and delays and optimize the travel time and movement of trains on the rail route;

In this case, the robustness of the schedule against minor disturbances can be improved by allocating small time buffers and it can be rewritten optimally. It is one of the buffer times for improving subway traffic. In this method, sequentially and using repeated algorithms, additional buffers are assigned as load reduction during the travel of each train on each route and direction of movement so that this time is considered as part of the train travel time on the rail.

-2Capacity optimization

Stability can sometimes be achieved by improving nominal capacity. This is especially important in the area of metro network infrastructure. The other case involves ways to improve the rate and pace of upgrading the capacity of the rail network. Of course, there is another conventional method that is applied to the metropolitan rail transport infrastructure; The method presented by the International Union of Railways (UIC) in the form of slips [UIC96, UIC04] and the railroad scheduling policy for operators are explained in such a way that in order to obtain the nominal capacity predicted in the first schedule methods, The designation will not be implemented due to the possibility of unexpected events, and this is due to the fact that the railway infrastructure in practice faces several limitations. However, since the railway network infrastructure is the most expensive and costly part of the railway industry, it seems necessary to make the best possible use of it through robust methods and to optimize train timetables. In an interactive infrastructure where the relationships between components have a reciprocal and dynamic format and there is a dynamic interaction between capacity and reliability, stability from the perspective of optimal use of physical resources can maximize the use of capacity and economically optimize the use of capacity as a A key factor in managing the operations and services of the rail network (Bertsimas & Sim, 2007). As can be seen in Figure 5, if the maximum capacity of the existing lines and train fleet is used to the maximum, the risk of secondary delays, which is inevitable due to unplanned rail accidents, will be reduced to a minimum. Therefore, the idea of maximum use of railway network infrastructure (nominal capacity) is faced with limitations in practice. On the other hand, there is no clear standard and no specific mechanism for its realization during the exchange and interaction between the elements of the model. Therefore, the best way to achieve the goal is to use simulation applications that are able to streamline and evaluate the dynamic interaction between capacity and reliability and obtain a stochastic model of operations and its relationship with latency and capacity (Huyshman et al. Boucher, 2003).Another point is the possibility of heterogeneity and heterogeneity in the real schedule based on real data, in which case to reduce the effects of heterogeneity, intra-city rail (metro) traffic traffic is assumed to be homogeneous. What makes the metro schedule universal is the similarity between the technical characteristics of trains, which is specifically observed in a metro line, the average speed is the same and the outputs are calculated through components such as train travel time and stopping at the route and stations. It becomes. However, for large and complex railway systems, the assumption of traffic homogeneity is not fully realized in practice due to the possibility of freight and passenger trains in each block of the railway route. Leads to a phenomenon known as heterogeneous traffic control (Roman et al., 2009).On the other hand, the heterogeneity and heterogeneity of trains in matched infrastructures for long rail distances as well as the resulting control complexities have consequences for the rail network, which can cause small advance times through cumulative effects and scattering probability of propagation. Increase latency to other parts of the rail network and consequently reduce the robustness of line traffic control schedules. In practice, observation of the reports obtained from information and communication technology and its outputs, has shown that the architecture and design of

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railway lines and its heterogeneity and situational effects on timetables have a negative impact on train timing and rail transportation system reliability. (UIC, 2020).Therefore, the homogeneity of the train fleet can increase the degree of stability to some extent, and on the other hand, heterogeneity can lead to a significant reduction in stability. Therefore, the interrelationships of optimization, capacity and robustness as important components affect the stability of tables. Therefore, by repeating the steps of the above algorithm, other scheduling tables with the same amount of buffer time are generated and distributed in other stations, which is referred to as the scheduling table B. The mentioned parameters (stability, capacity and optimality) in Figure 5 interact directly with each other, and as mentioned, the amount of stability can be increased by reducing capacity, optimization and reducing inhomogeneity, and travel time according to various traffic factors in Railway operations such as: commercial stops, necessary overtaking on railways, level crossings, lane changes, etc. have improved, which in turn lead to the production of different timelines as an alternative to returning to normal. Therefore, choosing a solid schedule among alternative timelines with similarity in terms of travel time that is close to the optimal value, requires analysis and utilization of experimental functions to determine the robustness of timelines to achieve better configuration and configuration without penalty for travel time. It is a train. Figure 6 shows an example of two scheduling tables that have the same buffer time. It seems that more robust schedules are more appropriate than other timelines in different ways, and thus several schedules can be produced and the most appropriate choice can be made depending on the needs of the traffic control center manager.

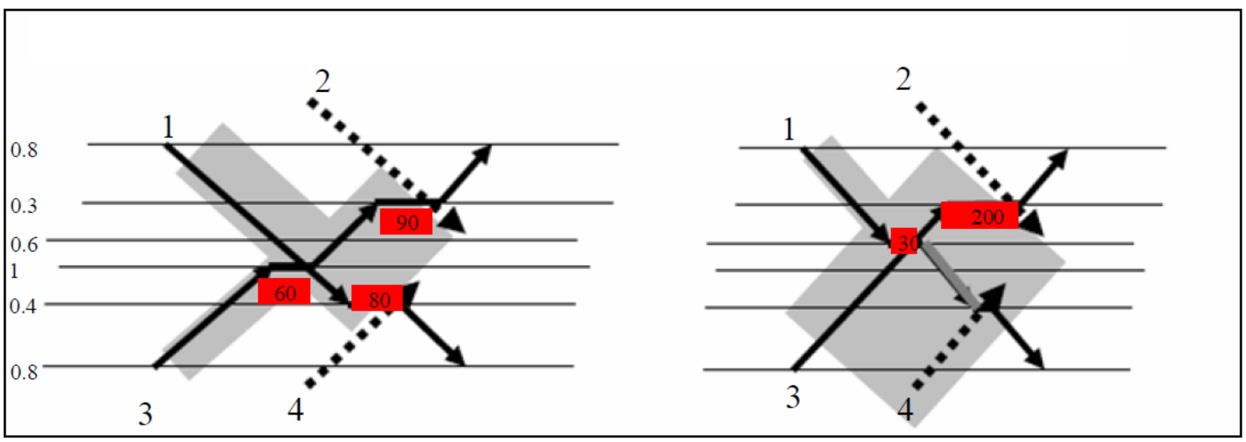

Figure 6) Two timing tables with different configurations and settings but the same buffer time (buffer time for each table is 230 seconds)

Strict stability

Strict consistency in this study models cases in which there are no recovery capabilities. This means that each algorithm has the following characteristics:

$A_{rec} \in A_{rec}$

Stability of Shantig mode (change of train line) in the metro

Stability due to the consequences of shunting mode in the train schedule is one of the effective factors in the stability of train schedules and trains in the network, which is achieved by changing the route and changing the direction of movement.

Stable algorithms

It refers to robust algorithms that are provided to overcome traffic problems in the metro rail network.

The problem of train schedule scheduling (TTP) by name

Typically, in this study, two versions of TTP have been studied, the periodic mode, the non-periodic mode, which are also known in the metro literature as cyclic TTP and non-cyclic TTP, in which, in the first case, each subway train rotates based on a period. This schedule is also usually useful for passengers on the rail network, as they can easily use the train schedule for their own purposes. However, creating a course schedule is usually not permanent. Therefore, non-periodic TTP is often the most appropriate way to set up and design timelines. For this reason, mathematical models can also be used for periodic TTP.

The problem of scheduling trains (TTP) periodically

This method is the most well-known model for periodic TTP, in which the problem of metro event scheduling as periodic (PESP) is introduced by Sarafini and Okovich (2000) (Sarafini and Okovich, 2000).

The problem of train schedule (TTP) on a non-periodic basis

The relationship used to set the train schedule in this study is the non-periodic TTP proposed by Caprara et al. (2005) (Caprara et al., 2005). In order to achieve solid solutions, the methods proposed by Kaschiani et al. (2017) are used and in this way the time tables are strengthened.

TTP is stable

Finding solid yet efficient alternatives to optimizing train schedule schedules in the subway is a practical and major step. The important point here is that if TTP alternatives can prevent delays in the rail network as much as possible, they are usually considered solid. A common and practical way to obtain such a robust schedule in the planning stage is to introduce buffer time, which can be absorbed at the operational level by anticipating possible delays.

Stability in the train schedule

In a study conducted by Schwister (2000), a concept has been proposed which has been referred to as decisive firmness. Accordingly, in a comprehensive mathematical model, the concept of stability of scheduling tables depends on the existence of an alternative that considers all possible scenarios and seeks to minimize the consequences of the worst case scenario of an alternative. However, these methods are too conservative among the usual approaches and require consideration of alternatives that can satisfy all scenarios.

Set a random schedule

One of the common approaches used to optimize and robust train schedule schedules is the random scheduling method (Bridge and Lowax, 2011). Crohn et al.'s (2008) study also presents a stochastic model for setting specific rotation schedules that can be implemented and used by operators to control traffic and aims to minimize the weight delays of trains on the rail. .

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Stable and retrievable schedule

Recoverable stability in train timetables was introduced by Liebchen et al. (2012). This approach in the field of TTP refines the concept of recoverable stability and provides a universal and common framework in this field (Liebchen et al., 2012).Optimal recovery is also another term that has been proposed by Gorig and Schubel (2017) using concepts and principles of stability in train schedule schedules, and researchers have emphasized the implementation of non-periodic (non-periodic) TTP, as This way, by determining the optimal alternatives on a small scale, it is possible to retrieve time tables and save the relevant costs.

Light stability

In the study of Ficheti and Monachi (2012), a meta-innovative scheme for stability called light stability is presented, which instead of studying the feasibility of establishing alternatives in all available scenarios, introduces those auxiliary variables that provide the basis for constraints related to Reduce feasibility to a minimum. The goal here is to minimize the sum of the auxiliary variables in the constraint constraint. On the other hand, the application of additional constraints worsens the value of the objective function in the nominal state. Therefore, light stability has been introduced by these researchers as a solution to reduce traffic distortion (Fischiti and Monachi, 2012).

Capacity of railway lines

The maximum number of trains that cross a railway line block at a given interval.

Metro traffic control

It is the supervision and control of the movement, traffic and transportation of rail vehicles along the route of the metro system.

Disorder

Disruption conceptually defines the delay, acceleration, or cancellation of a train passenger on a particular block or set of subway rail blocks, such as delays or accelerations of more than 5 minutes.

Heading (distance transition)

The time between two consecutive trains at one point in the system. The minimum heading is the minimum time between consecutive trains on the basis of which the safety margin must be considered. Scheduled goal is the time between dispatches for different lines in the timeline.

Stop time and train departure time

Stopping time is when the train waits for the passenger to board and disembark or enter the station. Departure time is the time it takes to drive a train on a scheduled basis from one station to another (or between two points in the system).Due to the complex nature of traffic systems, it is not possible to simply use one method (quantitative or qualitative) and gain sufficient knowledge of certain situations. Therefore, in order to find solid factors and tools in the schedules of trains and try to solve their problems, the mixed research method (a combination of quantitative and qualitative methods) is used in this study. Therefore, considering that the problems based on the combination of research paradigms have been used to identify the problems of technical systems in the traffic space in general, and the Tehran Metro Traffic Control Center in particular.It becomes. In this research, a consecutive exploratory mixed research design is used. The main purpose of exploratory research is to identify a situation about which there is no necessary knowledge. In other words, in this type of research, the researcher seeks to

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obtain information that can help them to know the subject well. According to this definition, any research requires a series of exploratory studies, ie exploratory research is the basis for conducting more important and extensive research. Some experts have also called exploratory research estimative research (Galati, 2008). The task of exploratory research is to create a suitable context for a better understanding of various phenomena or a specific issue in which the researcher lacks sufficient information in that field and case. Exploratory research may be done in different ways, such as: reading different texts and writings, interviewing people, consulting with professors and experts, etc. In Figure 7, the steps of conducting research are generally stated.

Result

To conduct the present study, we can point to several tools that are briefly explained below:

First: Analytical methods

In this method, the research tool includes facilities for measuring specific features. Several methods of analysis can be considered to evaluate the stability of the train schedule. But what is certain is that in order to solve the problems of planning the movement of trains on the railway route, it is necessary to determine criteria that determine the degree of stability of each of the alternatives.A method proposed by Alolo and Portman in 2007 includes a precautionary and responsive planning with appropriate and flexible efficiency that can support the train schedule in operational mode through a rail line disruption protection approach. Give. In this method, metric methods are used to count pairs of activities that are not directly related to the occurrence of distortion (Alolo and Portman, 2007).In another method proposed by Kista and Odi in 2000, a metric method based on train traffic profile algorithms was developed to solve the problem of measuring multiple capacity scheduling that could measure the consequences of specific disturbances in a network. Namide (Kista and Odi, 2000).Although analytical methods can provide faster and shorter ways to measure robustness, it is difficult to prove their validity in the metro industry to accurately and comprehensively describe the environmental space governing the timeline. Therefore, measuring the robustness of metro scheduling tables in a more distinctive way using the development of special analytical methods such as SSHR and SAHR to evaluate the homogeneity of the scheduling table with the initial assumption of a significant relationship between perturbation and cumulative delay propagation on a cumulative basis. And the movement of trains that follow the rail in a consistent manner in the time sequences of the metro network. This issue has been explained in detail in the research of Roman et al. (2009) with regard to the reliability and homogeneity of railway services in train and dispatch operations and its quantitative interactions with demand and time (Roman et al., 2009).Kerry and Carville (2000), by studying the role of accurate heuristics in the reliability of train schedule, have suggested that scattering criteria should also be used because of the inequality of program progress times in the movement of trains in the elliptical path of the subway network to measure stability. Scheduling seems useful in two-lane subways (Kerry and Carville, 2000).On the other hand, due to the nature of subway lines where each train passes through each node (station) twice in a complete cycle, it is necessary to make additional measurements to achieve the research objectives, such as the possibility of overtaking high-speed trains Normally cover slide trucks or single-lane lanes well and minimize forced stop times based on time of arrival at the destination while maintaining safety and coordination between the two trains.

Second: Experimental methods

In these methods, the "what if" method is mainly used. Therefore, it is observed that in these approaches, simulation of events in the train schedule and the possibility of retrieval and reprogramming as well as evaluation of the consequences of noise in the final schedules (as the result of the difference between the final table and the initial table) are used.Therefore, the stability of an alternative such as R (x) can be evaluated using the following tools:

A) The average of train delays according to the causes of delays, which can be a set of causes and events that have occurred in the metro railway network for any reason.

B) The difference between the time interval of trains (heading) in the required scheduling tables with the original design to the repair and reconstruction of scheduling tables based on the new conditions of the rail network

Using this method requires the following conditions:

First:

the existence of a comprehensive barrier simulator to simulate real-world events and the rail route in terms of frequency when it can be used to calculate impact delays and thus reprogram schedules.

Second:

the existence of the data set of the initial schedule and its architectural design according to the criteria for identifying and measuring pessimistic events at this stage (in this step, it is necessary to have online infrastructure management to obtain data to be able to receive traffic events in time And refine).

The outputs obtained from this stage can be used to estimate, as well as confirm and reject the results, because the main parameters affecting the train schedule such as train speed on the railway track, heterogeneity or heterogeneity of moving equipment, used capacity of railway lines, signaling system settings and Control, etc. ... evaluates the stability of train schedule schedules and changes affecting it.Therefore, the mentioned parameters can be effective in obtaining analytical results and drawing a robust model against optimization and effective use of capacity and its promotion.

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