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Study of Vehicle Traffic Optimization Techniques: A Review

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Abstract: To achieve the economic growth in any country transportation system act as backbone and optimized road network with least congestion and optimal distance is highly expected by the people of the area under consideration, as it reduces the transportation time and energy. Various researches has been proposed that describes single objective and multi objective traffic route optimization techniques for the transportation network. In this paper, existing approaches for road traffic optimization techniques and their prospect for solving real world transportation problem are summarized.

Keywords: Traffic Route Optimization, Evolutionary Algorithms, Single-Objective, Multi-objective, Pareto-Optimality.

1. Introduction

Transport system has proved itself as lifeline of the cities, all over the world. In metropolitan cities of India, choice of optimal path is heuristics task. Various navigation API's, GPS, etc. are facilitating the choice of path between Origin –Destination pair. It is quiet helpful to know about path, but the optimality is still remain a question to solve. Initially the research was focused on single-objective optimization i.e. the shortest path. Later on, it was observed that the traffic route optimization is NP-hard & hence the multi-objective techniques for traffic route optimization evolved for two or more objectives. Evolutionary algorithm became an obvious choice for calculating shortest-path. There should be balance between User Equilibrium and System Optimum, during evaluation of shortest path. Pareto-optimality, being based on multi-objective optimization, achieves both the above said constraints at systematic level.

2. Agents Based Systems

In 2009, Buscema D, Iganaccolo M, et.al,[3] proposed a study which aimed at finding the proper route recommendation strategy in real time vehicle routing system and its impact on network's Total Travel time. The agents based systems which are autonomous in nature and capable of taking actions embedded with NETLOGO platform, was used for simulating the concerned environment. The route recommendations effect on total travel time was analyzed by using a well known "Braess" paradox road network. For the defined model two behavioral patterns were described as, "the user's choice among those available for fixed origin-destination pair" and "once the path is chosen, to the microscopic motion of each vehicle as a function of leader vehicle among the each link of network". The architecture of the system was divided into layers as "Tactical level to control the rules of motion of vehicles" and "Strategic level path choice where agents have in a proactive way". The performance of network, computed at the end of each simulation run, was measured in terms of Total Average Time Travel calculated by taking the ratio between the sum of all vehicles travel time and the total vehicles passed through that network. The resultant obtained were used for calculating optimal information and contributed to the online management of the intelligent transportation networks.

In 2009, Ljubovic V.,[10] developed an Agent-based Traffic Model (ABM) where vehicles could communicate with each other, with low processing systems and higher computational speed, modeled using semaphores,. The decision making ability, based on their own perspective, was provided to the agents. The source and destinations path pairs

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were described for agents, where all the paths had minimal traversal cost, and agent's choice to opt any path was based upon "Wardrop Principle". Two types of models, Models based on Cellular Automata and Agent-based Models for traffic, were described. Due to the simplicity of code development and speed of execution, the agent based modeling for traffic network was taken into account. Two-way coordinated semaphores were compared with non-coordinated system for validating the model. Three hypothetical models of road network along with two types of semaphores were described for conducting experiments and analyzing the model's output. The computational resulted, the road network being stochastic in nature, in reduced possibility of jam on intersections and improved throughput.

In 2015, Lujaka M., Giordani S, et al.[11] proposed an optimization modal to bridge the gap between the User Optimum and System Optimum. A traffic flow pattern at steady state was considered for the representing the flow and various Origin –destination based pair were chosen, and uni-direction roads were signified with a set of arc in each direction with any pair of node. The cost of individual path not only depends upon a single vehicle but also influenced by the number of vehicles passing through a particular arc. To obtain an optimized path, a normalized mean path duration cost and maximum latency flow was introduced. A good solution was proposed for concerning with the individual agents but overall system efficiency was deteriorated, thus utilitarian social welfare was to be introduced to sum up all the agents utilities in a given allocation. Two divisions were made, named upper layer decision making and lower layer decision making, while implementing the architecture. The O-D pairs were computation and path allocation was made at upper layer whereas a satisfactory variable was introduced at lower layer decision where the objective of minimization of travel cost was calculated in terms of satisfactory variable, based on past path assignment. Matlab's "Delaunay Function" was used for creating graph and "CPLEX" was called for variable optimization.

2.1 Multi-Agent System

In 2009, Jiang B. and Zhang H. [7] designed a "Distributed Traffic Simulation" (DTS) system, whose multi-agent architectural design was based on "Service Oriented Architecture (SOA)" integrated with "Service Component Architecture (SCA)". The mainly aimed at heterogeneity, expansibility and reusability, where concept of reusability was not based on traditional HLA architecture and its heterogeneity was realized when various modules implemented with SCA , which support "JAVA", "C++", " RUBY", "PHP" and "COBOL" were used in creating distributed simulation environment and optimization. Oracle database was used to store the road map of whole "Haidian" district in Beijing, for DTS System. Several service modules, embedded in DTS system, played a significant role in validating the whole system. The end-user usage was kept in concern, as Object-Relation Mapping (ORM) and Service –Data Object (SDO), were adopted in DTS system. SDO was made to support both Static and Dynamic data sources in form of XML, JMS, etc. Three indexes such as "Total Amount of Buses Passed at every cross (APB)", "Average delay of buses at every time of each bus line" and "Average travel time in each bus lane", which were efficiently computed within 87 seconds, were analyzed while examining the validation of the simulation system.

In 2015, Han Z, Zhang K. et.al.[14] presented a multi-agent traffic simulation system, which was implemented in Netlogo platform. In this system all the traffic components like vehicles, road section, intersection were subjected to agent model, enabled with ability of obtaining knowledge, autonomy, interaction and communication. The traffic flow forecasting was integrated with road vehicles agents which could communicate with intersection agent, enabled with traffic signal control. The signal control function used is implemented by analyzing the real-time predicted traffic flow information from the road and intersection agent. During implementation using NetLogo platform, the vehicle agent was produced on the basis on Turtle Agent and the road and intersection agent were generated from patch agent. The Co-ordinated interaction between all the agents formed a complex dynamic simulation system based on multiple agent simulation system. The resultant simulation proved itself an effective mechanism in reducing the vehicle delay time and controlling signal parameters adaptively. The traffic flow forecasting was not been paid much attention while implementation.

3. Heuristic Approach

Abraham I, Delling D, et.al.[1] performed a systematic study to find locally optimal alternative routes and proposed an algorithm for finding such routes. Based on contraction and relaxation hierarchies, the new algorithm was introduced and compared with the traditional algorithms which performed iteratively for calculating shortest path. For a Pre-defined O-D pair, various paths were obtained and sorted according to their objective function. The sorted pairs of available paths were arranged in form of a tree under "BDV Algorithm's" implementation. The path selection, corresponding to the desired input sets, was done by using "Choice Routing Algorithm (CH)". The unimportant path was eliminated through pruning which results into only single via path based on BDV and CH. The running time, being sub-linear in nature unlike BDV and CH, was computed through time complexity as O(( ). The provided computational and analysis results make the approach efficient for further optimization function such as "Fuel consumption", "Time in traffic or tolls" etc.

In 2013, Xu Y, Kong Q.J et. al, proposed an approach for road network analysis and predicting the short term traffic volume on concerned stations, named MARS (Multi-Variate Adaptive Regression Splines). "MARS is hybrid nonparametric regression approach which can automatically model non-linearity and interactions between high-dimensional predictors and responses. It is a spline regression model that uses a specific class of base functions as predictors in place of the original data."Thus, because of its flexible regression property, it is applied for data analysis problem i.e. traffic volume prediction. The time frame for volume observation at each station is kept 15 minutes at each station. The whole process of analysis was divided into two phases, during first phase an interrelation was established between the historic data and the data obtained during observation on concerned stations (within a particular region selected). Once a suitable dependency relation is established between the data sets, the historical volume on current and the most interrelated volumes were fed into the MARS prediction model to predict the short-term traffic flow. For demonstrating its, effectiveness the results obtained from MARS system were compared with the ARIMA and the PPR methods.

In 2015, Dell'Orco M., Marinelli M and Silgu M.A.[4] proposed a "Quasi-Anisotropic" model for travel-time prediction in discrete time intervals. A Mesoscopic dynamic model for network loading, based on spatial and temporal flow propagation, was used by DTA-based travel time estimation, in which time step and the influence of vehicles that gradually entered a link was decreased but was not ruled out entirely. The parameters like set of feasible paths on the network, the set of vehicles and following paths were considered for model formulization. Two categorizations were made for vehicles grouping as discrete and continuous flow. The approach followed was to optimize the traffic network by considering all the possible paths diverging from that particular node. The bees' departure from their hive and flying through an artificial network, was represented as specific traffic assignment and their path visited was considered as all the possible paths. The decision making process was participate by all bees in their hive, where information was to be exchanged and the next forward pass was processed until the desired solution was obtained. Nodes were considered to have multiple merging and diverging links, thus to avoid the congestion on link, a temporary buffer was introduced. The proposed outcomes, for the given OD matrix, were obtained through QAMM and DYNASMART.

4. Evolutionary Algorithms

Evolutionary Algorithms are always considered to converge to global maxima in case of NP Hard Problems. Two approaches of Evolutionary algorithms i.e. Single Objective and Multi Objective are observed for the solutions of traffic route optimization.

4.1 Single Objective Evolutionary Algorithms

In 2009, Lin C.H., Yu J.L, et.al.[9] used genetic algorithm to alleviate computational cost in route guidance system. The paper explained the necessity for the Optimal solution for route guidance system that was not provided by the existing computational techniques, along with the other variables needed for efficient computation for finding the shortest path. For computing the shortest path, genetic algorithm was applied and in order to test its practical effectiveness, it was implemented in diverse scenarios of real traffic condition and varying vehicles speeds. A theoretical idea was also presented, explaining the effectiveness of the Genetic algorithm over Dijkstra Algorithm for finding the optimal path in complicated real life scenario. The implementation results were based on the handheld device i.e. their computational power and memory space and their limitations were considered during calculation. The results were computed through GA proved more effective than the single-pair shortest path technique, as it intended to converge faster relatively with large amount of data. The number of chromosome was to be increased in order to obtained more appropriate solution.

In 2014, Dias J.C., Machado P., et. al. [5] proposed an Inverted Ant Colony Optimization (IACO) for achieving maximum throughput and minimized road congestion. The drivers individual behavior should not be changed while travelling through the congested path. The two algorithms "Dijikstra and IACO" were combined for solving static (edge distance) and dynamic (car density) natures of traffic networks. The distance was computed using Dijisktra's algorithm to the level of pheromones in that edge. After shortest path computation using Dijikstra's algorithm, IACO was used, that logically inverted the attraction of ants towards the pheromone effect into the repulsion effect. The traffic congestion was stimulated this repulsion effect, in the graph node. The number of vehicle, at each edge was made proportional to the increasing level of pheromone. With the increase in traffic condition at a particular node the weight of that node increased gradually, related with increasing pheromone level and vice-versa. Microscopic simulation environment was chosen for the implementation for stimulating each driver's behavior, using SUMO traffic simulator. In order to prove effectiveness of the modal, computation was made artificial maps like radial network and ring network, and real map of Coimbra. The shortest travel time and impact on fuel consumption and CO_2 emission were also analyzed with the implementation.

4.2 Multi-Objective Evolutionary Algorithms

In 2008, Zhu Z. and Li T.[15], developed a multi-objective optimization model to study optimization method between ETC (Environmental Traffic Control) and TSO (Traffic Structure Optimization) for checking controlling pollutants in air. The ETC computation, varied from area to area, consisted of factors like Regional characteristics, Natural Habitation, Air Quality Standard and Vehicle's pollution emission rate. Various transportation modes and their tools were combined to arrange a metrics signified as TSO. Based on the field data, the model was developed to coordinate the ETC and TSO. The model, being Multi-Objective in nature, was made operational by using Pareto Genetic Algorithm for Optimization. During initialization parameters considered were "Number of Generations", "Crossover Probability", "Mutation Probability", "Number of solutions defined", "Population Size", "Maximum Number of Generations", and "Pareto Set Filter Capacity". The objective functions were defined, sorted according to their population and ranks being allocated to all the individuals. The highly ranked individuals were put in Pareto set filter until the capacity increased the number of solution. Based on Wheel Tournament Selection Operation, Crossover Selection and Mutation Operation, calculation was done and output according to Pareto set. The model was made operational in "Southern City (China)" for NO2 and CO2 air pollutant concentrations.

In 2009, Berradia T and Mouzna J[2], formulated multi-objective path problem in dynamic and stochastic networks using couple mean-variance and dominance. The problem aimed at finding the optimal paths between the source and destination with minimized travel time and travel cost, using a directed graph having N nodes. The level of congestion, differentiate into four segments, determined the travel time, whereas the departure time from source node helped in determining the travel cost. Three computational functions were designed, "Cumulative Function", "Expected Value", "Variance", for path evaluation. Similarly three comparison criteria were described, "Deterministic dominance", "First-Order Stochastic Dominance" and "comparison via expected value", to compare available paths. A simple network topology was defined and genetic algorithm module integrated was with simulation module. In order to prove viability of multi-objective path finding using stochastic network, the simulation experiments were performed, using Pareto front in GA, for a defined set of parameters.

In 2009, Lau H.C.W et.al [8] proposed a multi-objective evolutionary algorithm called fuzzy logic guided non-dominating sorting genetic algorithm 2(FL-NSGA) for vehicles to deliver products from supplier to customer in logistics and supply chain management. Three different scenarios were considered for implementation and performance evaluation of the algorithm, and for each scenario 10 data sets were considered based on the basis of each pair of nodes, supply of every product from every depot, demand for every product by every customer, and volume of each product. In order to obtain an appropriate performance analysis, various MOEA's i.e. NSGA2, SPEA2, FL-SPEA2, MICROGA and FL-MICROGA were compared with FL-NSGA2, for similar set of parameters i.e. crossover operator, mutation operator, chromosome encoding. Various other criteria were adjusted to obtain a fair comparative analysis, i.e. Population size, Generation size, etc. Fuzzy logic dynamically adjusted the crossover rate and mutation rates.

In 2009, Farshbaf M and Derakhshi M. R. F[6] proposed two methodologies, Weighted Cost Function and Pareto Front respectively, for multi-objective optimization in graph partitioning, based upon genetic algorithm. The process of dividing the object-sets into a particular number of partition for minimizing some partitioning criteria was signified as graph partitioning. In first method, all the individuals were aggregated in a single objective function and then the character selection was processed based on decision making. While, the Pareto front, provides us the solution set based on the optimal solution, based on Non-Dominating set. In order to stabilize the subpopulation, "Niche method". During Graph Partitioning new scheme named "Extended NSGA-II" was introduced, based on three principals as "Dividing the objects having closer relationship into the same partition, such that intra-partition relationship is maximized", "Inter-partition relationship should be minimized" and "Balance the partition load over the resultant partition". For particular set of parameters, experiments were performed and the resultant were compared with the NSGA-II and found to outperform the existing technique.

In 2012, Siddiqi U.F., Shirashi Y. and Sait S.M.[13] proposed a multi-objective population based algorithm for finding optimal path on "Pareto-Front" in Electric Vehicles (EVs). The concept of Simulated Annealing (SA) and Simulated Evolution (SimE), being fast and efficient in solving the path optimization problems, were used for solving Multi-Objective Shortest Path (MOSP) problems in EVs. The road network was represented by using a undirected graph and the communication system in EVs, embedded with Navigation system, was made to communicate with traffic control station through GPS and V2I communication. The algorithm was initialized with O-D pairs, Paths, and recharging stations. The Goodness Value, for the set of edges, was evaluated in the "Evaluation Step". The selection procedure was performed on the basis of Goodness Values, which was carried forward for mutation operation, after which Pareto-Optimal solution was allocated to each individual. The computational results, implemented in Visual Studio C#, were compared with NSGA-II, for San Francisco Bay Area (BAY) and Colorado (COL) road networks, was found more efficient.

In 2014, Meshkat A and Vrancken J.L.M,[12] studied the concept of road network partitioning with the help of Multi objective Evolutionary algorithms. The implementation was conducted using two strategies Non-dominated sorting Genetic algorithm (NSGA-2) and Pareto Archived Evolution Strategy (PAES). A synthetic network was used for implementing these strategies. A Python based tool was developed for the synthetic road network creation and implementing the Multi-Objective Evolutionary Algorithm. The synthetic network was made comparable to the real road network by creating it blocky area form. Two objectives were defined for evaluation function that were "minimizing the number of boundary points, while the shortest path between each two nodes of a partition falls within that partition" and "mininmize the number of pair of shortest path laid outside during partition count". Three sections were created for code summary implementationi.e. generating synthetic road network, applying genetic algorithm to the network and graphical user interface. The experimental results for NSGA-II were based on crowding approach while PAES controlled crowding of solutions. PAES proved its effectiveness when converging near true front on the other hand the NSGA-II maintained the diversity of optimal solution.

5. Conclusion

After rigorous study of various researches, it has been observed that Pareto Optimality is required for traffic route optimization. Since route optimization in addition to shortest path also include congestion control and various other factors. Multi Objective Evolutionary algorithms are best fitted for the purpose. So, traffic route optimization is best resolved with Multi objective evolutionary algorithms to converge the global maxima.

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