Reaching Destination on Time with Cooperative Intelligent Transportation Systems

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Abstract

Research on Intelligent Transportation Systems is so far focussed on decreasing the travel time of vehicles and avoiding congestions. However the importance of reaching on time is different for different vehicles and depends upon the purpose of the journey. In a human operated queue, it is generally considered courteous to give priority to people running very late. They may be running late to catch a flight or may be in an emergency for a medical check-up. There is a very small discomfort to the other people as long as the number of people in an emergency and running late are low. However such prioritization is an invaluable help to the people running late. In this paper the same behaviour is modelled, wherein the transportation system is made biased towards the vehicles on an important task and running late. The paper presents the mechanism by which a vehicle may judge its running status, decide whether to ask for cooperation and decide how much of cooperation to ask for. The vehicle lane changes and traffic lights operating policy are made cooperative. Experimental results show that such a cooperation leads to lesser number of important vehicles reaching their destinations late.

Keywords: Intelligent Transportation Systems, Cooperative ITS, Routing, Start Time Computation, Cooperative Overtaking

1 Introduction

Increasing efforts are being put to make the transportation systems intelligent. The rise in traffic level motivates the adoption of intelligent transportation systems in real life. The day is not far when many of the researched concepts would be seen to operate in real life transportation systems. Routing is one of the key problems under research. The problem deals with computing the route for a vehicle and to adapt the route as per changing traffic conditions. The routing decisions are based on real-time data and traffic predictions. The routing systems may be centralized [1], which attempt to plan all the vehicles simultaneously; or decentralized [2] where every vehicle is planned separately based on some assumptions about the other vehicles. The centralized systems are applicable only for a small number of vehicles which can communicate with each other or the central system, and are hence not practical. Decentralized solutions are widely used.

The aim of any routing technique is to minimize the time spent in congestions and to minimize the travel time. The traffic may be recurrent [3], wherein the traffic trends repeat or show some patterns which can be learnt for prediction; or non-recurrent showcasing new trends or unexpected behaviours. Any traffic is a combination of both recurrent and non-recurrent trends. While planning one's journey in advance, normally only recurrent trends are considered, while some safety time is left as a precaution to the non-recurrent trends. The non-recurrent trends can be dynamically handled when information about them is obtained or predicted. This paper, dealing with advance planning at the first instance, considers only the recurrent trends.

The literature largely focuses on minimizing the travel time and taking efficient routes. The overall attempt is to maximize the use of the available transportation infrastructure. However the availability of the transportation infrastructure is always a limitation. A transportation system can only perform under a strict threshold of the maximum bandwidth. Another task associated with the efficient operation of the transportation systems is to distribute the traffic at different times of the day so as to maximize efficiency, which is the focus of this research. This aspect of the problem considers the ways to schedule different vehicles at different times of the day, apart from the regular problem of increasing the driving efficiency of a pool of vehicles in the transportation system.

This paper is motivated from a prior paper [4] by the author, which undertook the task of computing the journey start time and route for the vehicles. A person is given a pre-decided time to reach the destination (like catching a flight) and the person has to certainly reach on time. The algorithm had to compute a suitable start time and route. Broadly, the system attempted to schedule the journey such that a person can start late, drive fast and reach the destination on time, at the same time ensuring that the probability of reaching on time (given the stochastic nature of the traffic) is high. A summary of the work is given in Section 3.

The problem with the approach was that it discouraged a user from leaving too early and waiting at the destination for long times, as it was clearly sub-optimal, while such a decision may be important accounting for sudden and un-predictable non-recurrent trends. A parameter of the algorithm, dependent only upon the assurance of reaching on time, could be used to keep a large spare time and hence result in algorithm compliance. However considering that most of the times such trends would not be observed, the prolonged time spent in waiting would be unjustifiable. The prior work gave a start time and a route for the user to start. However if the user was running late, there was nothing that he/she could do. Imagine leaving your home well on time so as to reach an important meeting or to catch a flight, only to realize that somehow the traffic seems to be a little slower. A common reaction is to marginally exceed the speed limits which is neither legal nor advisable.

This paper extends the concept and enables the user to ask for cooperation from the other vehicles. The cooperation helps the user to reach on time, despite running late. The aim is to select a modest start time and a route, judiciously keeping some spare time to combat traffic uncertainties using the prior approach [4]. Once the user starts the journey, the proposed approach enables him/her to combat any large uncertainties while driving. This eliminates the need to have a very large spare time. The general architecture of the overall system is given in Figure 1.

General traffic is mostly under the occupancy of vehicles going for leisure, catering to appointments which are a little flexible, meeting everyday schedules where being a little late does not mean a huge loss, or on an important appointment being comfortable on time. In a queue of people it may be acceptable for a person running very late and for an important task to ask for cooperation from the other people. This would lead to the others being at a little loss, but would be of a great help to someone running very late. It is acceptable as long as the number of people running late form a small part of the entire queue.

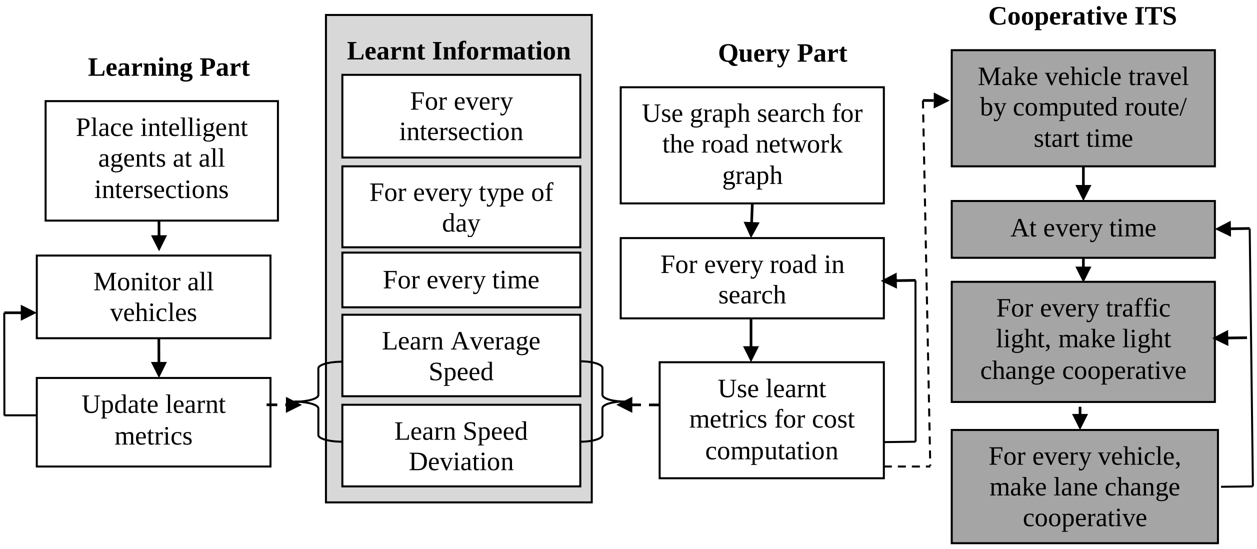


Figure 1: The General Algorithm Framework (adapted from [4])

The transportation system currently has no mechanism by which such a priority can be given. The proposed approach discusses the mechanisms by which the other vehicles and the traffic lights can be made cooperative. An example of priority is taken from the emergency vehicles. Other vehicles make every attempt to allow the emergency vehicles to overtake. Emergency vehicles can cross a traffic crossing irrespective of the traffic light state, and assume priority in intersections and pedestrian zones. While a simple implementation of the concept would be to allow a vehicle running late to flash some emergency light, such a solution is not acceptable since the cooperation of the other vehicles for emergency vehicles usually comes with some breach of traffic rules which badly affects the other vehicles.

The key contributions of the approach (which add to the contributions of the prior approach) are:

- The notion of cooperative traffic lights is introduced which is biased towards the vehicles running late.
- The concept of cooperative lane changes is introduced, by which a lane change attempts to minimize some vehicle from running late.
- Different states of a vehicle which desire to be on time are designed. This include being comfortable on time, running a little late (may still reach even without cooperation), running very late (difficult to reach without cooperation) and impossible to reach (given up).
- A cost metric is designed which maps the different states of a vehicle running late to a consciousness of being late, used for decision making regarding all cooperative measures.

2 Literature Review

A detailed description of the related works can be found in [4]. Here some of the most relevant works are presented. Kim et al. [5] modelled a similar problem as a Markov network and used real life data for computing the transition probabilities. Such probabilistic searchers are obviously too computationally expensive for large sized maps. Miller-Hooks and Mahmassani [6] solved the routing problem considering a stochastic and time-varying road network graph. The problem has multiple opposing objectives for which the authors found the pareto front, or the set of solutions where each solution is at least as good as the others on at least one objective, and hence the distinction between the solutions cannot be done unless preferentiality between the objectives is defined. The choice between the solutions was done based on decision making algorithms. Similar work exists in [7].

Other routing systems include the work of Claes et al. [8] where every possible route was worked out, while at every possibility the traffic density and hence the anticipated speed was predicted. Similarly Weyns et al. [9] used traffic microsimulation for computing the speed using a similar modelling. van Hinsbergen et al. [10] attempted to predict the travel time using Bayesian Neural Networks. Historic traffic patterns were assumed to be available and were fed as input signals. Neural network approaches are also widely used [11-14]. Such predictive systems lead to very large uncertainties when the planning is done much in advance, which is practically the case for this problem.

The proposed approach measures the magnitude by which the vehicles are running late and uses the same to make the transportation system cooperative. The latter problem is widely solved using the notion of reservation, including lane reservation and intersection reservation. The proposed approach stresses on soft cooperation in contrast to hard reservation. A good overview of the various approaches for lane reservation can be found in Fang et al. [15], who particularly designed a reservation strategy to minimize the impact on the non-reserved traffic. In a similar work Liu et al. [16] used the concept of tokens while an intelligent reservation agent was proposed for management of the reservations and tokens.

Reveliotis and Roszkowska [17] modelled the road infrastructure as resources and proposed algorithms for judicious resource allocation for collision-free and judicious travel. Dresner and Stone [18] used reservation for intersections, wherein a vehicle with reservation could pass an intersection irrespective of the state. Reservations were made after collision-checking. The model was extended to incorporate learning and market economics [19-20]. Vasirani and Ossowski [21] also presented a market economy model for a similar modelling.

3 Computing Journey Start Times

This section summarizes the work in [4]. The problem is to compute the preferable start time (T_s) that a person should leave the source (S) and the route (R) that the person should take, in order to reach a destination (L) before or at the desired time (T). Let G be the road network graph of the city. The start time and route should be such that the certainty of reaching L on or before T is high. Let T_t denote the travel time and T_f denote the time of reaching the destination, which gives $T_s + T_t = T_f$. Since the traffic is stochastic, the values of T_t and T_f are probabilistic in nature for any given T_s. Let $P(t \le T \mid T_s, R)$ denote the probability of reaching on or before time T (or $T_t \le T - T_s$) for a given T_s and R. $P(t \le T \mid T_s, R)$ is a probability distribution while T_f and T_t are unit samples from the distribution.

The objectives of the algorithm are: (i) Maximize start time (T_s). (ii) Minimize travel time (T_t). (iii) Maximize the probability of reaching on time ($P(t \leq T|T_s, R)$). (iv) Minimize waiting time if the person arrives early at the destination (*if* $T_f \leq T$, *minimize* $T - T_f$, *a high penalty otherwise*).

It is assumed that there are intelligent agents at every intersection which learn the average speeds and the associated variance. The speeds are assumed to be the same at same times of the day and the daily patterns are assumed to be similar on some similar days of the week. Let $speed(V_1, V_2, t, d)$ denote the average speed from an intersection V_1 to an intersection V_2 at time t of the day and at a particular day type d of the week. For any vehicle A, seen at times t_1 and t_2 by V_1 and V_2 respectively, the average speed is given by equation (1). The average speed includes the average time of wait at the traffic lights.

$$speed(A) = \frac{\| V_2 - V_1 \|}{t_2 - t_1} \tag{1}$$

Here $\|V_2 - V_1\|$ denotes the distance between the intersections V_1 and V_2. The factor $speed(V_1, V_2, t, d)$ is learnt by the agent at V_2 from a continuous stream of speed data provided by the vehicles, given by equation (2).

$$speed(V_1, V_2, t_1, d)^{new} = (1 - lr) speed(V_1, V_2, t_1, d)^{old} + lr.speed(A) \tag{2}$$

lr denotes the learning rate ($0<lr<1$). The standard deviation $\sigma(V_1, V_2, t, d)$ is also measured for probability computations and is given by equation (3).

$$\sigma(V_1, V_2, t_1, d) = \sqrt{\frac{\sum_{\text{previoussimilar } \delta \text{ days}} \left(speed(V_1, V_2, t_1, d)^{new} - speed(V_1, V_2, t_1, d)^{old} \right)^2}{N}} \tag{3}$$

The deviation is taken for all the vehicles in the previous δ similar days. The problem is intended to be solved using a graph search algorithm. Let $T(V_i)$ be the latest time at which the vehicle must be at V_i in order to reach the destination on time. Since the metric for goal is known, $T(L)=T$, and that needs to be computed for the source, an inverted search is used. Graph search further works on a single objective function and hence the algorithm objectives need to be fused into one. The algorithm objectives to minimize travel time, minimize delay and maximize start time T_s are similar; and all are opposite to the factor $P(t<T|T_s, R)$. Further, graph search only works for deterministic systems while the problem is stochastic.

Hence the approach is that the user fixes some minimum probability based on the purpose of the journey. The time computations are made which showcase the best strategy to achieve the specified probability. In other words maximize T_s for a given minimum $P(t \leq T|T_s, R)$. This is used for the graph search. Consider an edge $<V_2, V_1>$ during the expansion of a node, such that $T(V_1)$ is already computed. Travel time between V_2 to V_1 is given by equation (4) and correspondingly $T(V_2)$ is given by equation (5).

$$Tm(V_1, V_2) = || V_1 - V_2 || / \left(speed(V_2, V_1, T(V_1), d) - \alpha.\sigma(V_2, V_1, T(V_1), d) \right) \tag{4}$$

$$T(V_2) = T(V_1) - Tm(V_1, V_2) \tag{5}$$

The average speed is given a little slack depending upon the deviation. This slack speed results in a slack time which can be used when the vehicle gets late due to travel uncertainties. The slack is discounted by the factor α, which is a tolerance factor for the slack. Higher values of α encourage keeping more slack time increasing the probability of reaching on time while also making the person wait for a prolonged duration at the destination, and vice versa. The factor is set to tradeoff between the two opposing factors of probability of reaching on time and the maximization of start time. The factor is an algorithm parameter, which is set by the user based on the purpose of the journey and the needed guarantees of reaching the destination on time. It is a task specific parameter and can only be set by the user. This task dependency on decision making is a key contribution of the work.

Costs computed by the A* algorithm [22] for graph search consist of time $T(V_2)$ given by equation (5), time from node to goal or $T_d(V_2)$ given by equation (6), heuristic time to origin or $T_s(V_2)$ given by equation (7) and the total cost or $T_j(V_2)$ given by equation (8).

$$T_d(V_2) = T_d(V_1) + Tm(V_1,V_2) \tag{6}$$

$$T_s(V_2) = \| V_2 - S \| / velmax \tag{7}$$

$$T_j(V_2) = T_d(V_2) + T_s(V_2) \tag{8}$$

Here S is the origin node and *velmax* is the theoretical maximum average speed.

The A* algorithm maintains a priority queue of the nodes to be processed, where the priority is the total expected cost given by equation (8). The heuristic function component of the cost given by equation (7) helps to reduce the number of nodes processed without compromising on the optimality of the solution. Here backward search is used which starts at the destination and ends at the origin node. At every iteration the lowest cost node is expanded to discover the children which are added as per their own costs. The algorithm stops on reaching the origin and the results are computed.

4 Cooperative Transportation Systems

It is assumed that the traffic system has a number of vehicles which need to get to the destination on or before the pre-decided time T. The current problem definition assumes that these vehicles are on a real time operation and hence getting to the destination after T is regarded as worthless. For the complete transportation system the sole objective is to minimize the number of vehicles reaching late, given whatever time they actually start.

The transportation system attempts to make the vehicles cooperative such that the different vehicles enable each other to go through as per their needs. The first task is to measure whether the vehicles are running late and if they are, by what time (section 4.1 and 4.2). The second task is making the system cooperative. This is done using two methods: traffic lights (section 4.3) wherein the changing order of the traffic lights is altered so as to allow the vehicles running too late to travel first; and lane changes (section 4.4) wherein a vehicle may make a lane change so as to enable some other vehicle running late to travel faster or overtake so as to get more comfortable with time.

4.1 Vehicle Travel State

The traffic system at various times has different vehicles running late by varying degrees, depending upon which the cooperative measures are applied. Consider that a vehicle is moving using a pre-computed route R which consists of a set of intersections. Say that the vehicle crossed an intersection V_i at time t. There are three times associated with the intersection V_i.

The first time (*expected time* denoted by $T(V_i)$) is the latest time by which the vehicle should reach the intersection V_i in order to reach the destination on time with the pre-decided probability. This time accounts for the average speeds along with the safety factors measured from the knowledge of the deviation. The second time (*late time* denoted as $T_L(V_i)$) is the latest time by which the vehicle should reach the intersection V_i, after which it would become very difficult to reach the destination unless the traffic clears unexpectedly or some cooperation is offered. The third time (*cancel time* denoted by $T_C(V_i)$) is the latest time by which the vehicle should reach the intersection V_i at any cost, after which the vehicle may not expect to reach the destination, no matter whatsoever cooperation be offered. The times are explained in Figure 2.

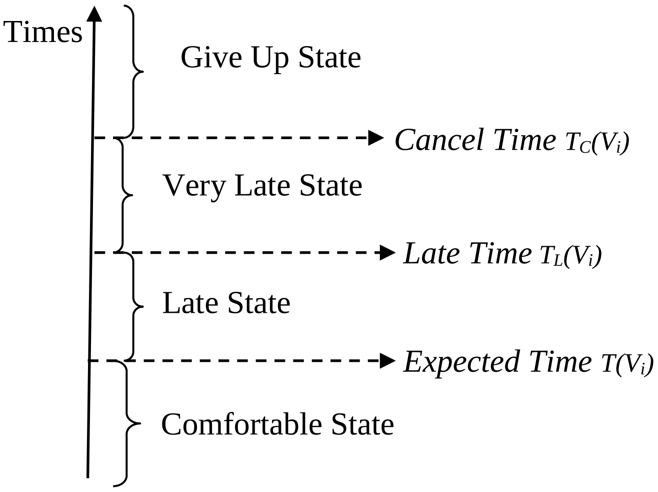


Figure 2: Times and States associated with the algorithm

This gives rise to various states that a vehicle may be associated with at any time. The first state is a *comfortable state* ($t \leq T(V_i)$) which denotes that the vehicle is being navigated as expected and should reach the destination on time. The second state is a *little late* state ($T(V_i) < t \leq T_L(V_i)$) which denotes that there is a need to worry as the vehicle is running late; but it should be possible to reach the destination either without cooperation with the expected situations but with a slightly lesser probability, or with some cooperation from the transportation system or with improved conditions. The third state is a *very late state* ($T_L(V_i) < t \leq T_C(V_i)$) which denotes that the vehicle is running very late and cooperation is very badly required in order to reach on time. Alternatively the vehicle may reach its destination if the subsequent traffic is a lot better than expected. The last state is a *give up* state ($t > T_C(V_i)$) which denotes that the vehicle cannot reach its destination on time, no matter how much cooperation is offered.

The different states are easy to understand from a human driving experience perspective. Imagine leaving your home for a meeting and for a long time thereafter one is in a *comfortable state*. If one encounters a traffic signal which did not change for a long time due to congestion, there happens to be a little worry but the driver may not show any change in the driving behaviour which marks a *late state*. Subsequently if there is a high traffic congestion which eventually gets cleared, the drivers tend to drive fast or make rapid lane changes which indicates a *very late state*. A *give up* state is rather hard to observe in a human perspective, wherein even if one is running very late, there is always a hope that some way things would get better. From a more practical perspective this state is modelled.

Computation of different times is done while computing the route and the start time. The graph search happens in the same way with the same costs involved. Computation of different times associated with an intersection V_2 with parent V_1 may hence be given by equations (9)-(12). The equations have the same form as the equations (4) and (5).

$$Tm_L(V_1,V_2) = \| V_1 - V_2 \| / \left(speed(V_2,V_1,T_L(V_1),d) - \beta.\sigma(V_2,V_1,T_L(V_1),d) \right) \tag{9}$$

$$Tm_C(V_1,V_2) = \| V_1 - V_2 \| / \left(speed(V_2,V_1,T_C(V_1),d) - \gamma.\sigma(V_2,V_1,T_C(V_1),d) \right) \tag{10}$$

$$T_L(V_2) = T_L(V_1) - Tm_L(V_1,V_2) \tag{11}$$

$$T_C(V_2) = T_C(V_1) - Tm_C(V_1,V_2) \tag{12}$$

While α controlled the tradeoff between the two opposing factors of early start and reaching probability, the factors β and γ do the same for cooperation. High values of α and β lead the vehicle to ask for too much cooperation too early (apart from the role of α in computation of the start time) which may not be good for the other vehicles, at the same time leading to a better chance of the vehicle actually reaching its destination on time. Smaller values of these parameters may lead the vehicles to ask for too small cooperation too late. A high value of γ may lead the vehicle to give up too early while small values may make the vehicle give up too late. A vehicle giving up too late may be disadvantageous for the other vehicles which may be uselessly cooperating. Typically $\alpha > \beta > 0 > \gamma$.

An important aspect is that three different times are maintained instead of using a single time (say $T(V_i)$) and computing the other times from $T(V_i)$ using fixed sized time windows. The implemented approach is better for planning long journeys, wherein computing the latest times by α, β and γ may lead to very different times at which the predicted speeds may be very different ($speed(V_2, V_1, t, d)$). Hence monitoring time t for the different strategies is needed.

4.2 Lateness Consciousness Cost

The transportation system makes a vehicle running late to be preferred over the other vehicles. In practice however a number of vehicles may be running late and may be found in different groups. Hence it becomes an important question to designate a cost with every vehicle which indicates the magnitude by which a vehicle is conscious of running late and hence the transportation system must prioritize it. The cost is given by equation (13).

$$Late(t,V_i)=\begin{cases} 0 & \text{if vehicle is not for a real time task} \\ \varepsilon & \text{if } t\leq T(V_i) \wedge \text{vehicle is for a real time task} \\ \varepsilon+(t-T(V_i)) & \text{if } T(V_i)<t\leq T_L(V_i) \wedge \text{vehicle is for a real time task} \\ \varepsilon+(t-T(V_i))+\varepsilon+(t-T_L(V_i))^2 & \text{if } T_L(V_i)<t\leq T_C(V_i) \wedge \text{vehicle is for a real time task} \\ 0 & \text{if } t>T_C(V_i) \wedge \text{vehicle is for a real time task} \end{cases} \qquad (13)$$

The cost is only valid for the vehicles which need to compulsorily reach their destination on time. An important aspect is that a small cost ε is given even if the vehicle is moving comfortably. This gives it some extra time for anything uncertain in the future at the cost of the other vehicles which do not mind running late. During a vehicle's travel, a rough span of time may come in the future which makes the vehicle reasonably late. It is more risky to make the vehicle late and then take it out with cooperation. Rather the algorithm does a little to give it enough time well in advance.

4.3 Cooperative Traffic Lights

The first manner of making the transportation system cooperative is by the installation of cooperative traffic lights. Consider a traffic light operating at an intersection V_i with a queue of vehicles at every road *j* which leads to the intersection. For every road two quantities are recorded. These are the total lateness ($Late_j$) and the earliest emergence ($emer_j$). Total lateness ($Late_j$) is the importance of preferring a road *j* due to the lateness of all the vehicles combined. The quantity is given by equation (14) where $Late_j^k$ denotes the lateness of a vehicle *k* in the queue of vehicles formed at road *j*. Emergence of a vehicle *k* is denoted by t_j^k and measures the arrival time of the vehicles prior to waiting. Earliest emergence is the time associated with the earliest entering and consequently the most waiting vehicle, given by equation (15).

$$Late_j = \sum_k Late_j^k \qquad (14)$$

$$emer_j = \min_k t_j^k \qquad (15)$$

The traffic light changes to green for the road *j* with the largest lateness. If two roads have the same lateness, emergence is taken as the secondary criterion with a preference given to an earlier emergence. This means that preference is given to the road with the vehicle which has been waiting for the largest time (for the light to change to green) in a First Come First Serve mechanism. The traffic lights are changed after a threshold number of vehicles, or when the queue gets empty and there are vehicles on the other road waiting to pass through.

4.4 Cooperative Lane Changes

The other manner of making the transportation system cooperative is by the use of lane changes. The speed of a vehicle depends both on the speed of the vehicle it is following and the distance between the vehicles. If a vehicle is running late, it may hence be useful to have the vehicle in front change lane. Further, it would be painful to have another vehicle change lane and come right in front, even if it is acceptable from a safety perspective. These factors have to be accounted for while making any lane change.

The basic mechanism for a lane change is assumed to be an overtaking based lane change [23]. It is assumed that the traffic operates using a 'keep-left' rule and overtaking takes place on the right. The left and right indicators are reversed for countries which follow a ‘keep-right’ rule. In low traffic density a vehicle (on seeing a slow vehicle ahead) moves to the lane on its right in order to aim an overtaking, and later returns to the left so as to allow the other vehicles to overtake if interested. If jumping to the right lane is not possible or not more efficient, the overtaking is attempted from the left side. The clause handles the exceptional cases wherein a slow moving vehicle is on the right overtaking lane, prohibiting overtaking. In all cases time to collision is used as a metric to check whether it would be better to change lane or stay in the current lane. Safety distances from the vehicles must be available for the lane changes to happen.

Cooperative behaviour is added on top of this mechanism. A vehicle has to make a lane change if it finds a vehicle running late behind (or a vehicle running late by an amount larger than itself). The lane change enables the vehicle running late to speed up which hence improves its chances of reaching the destination on time. Time to collision metric is used to decide which side the lane change must take place, if both the sides are possible. Further, any lane change computed by the strategies above (either due to the general lane change rule or while cooperating with another vehicle) can only happen if the vehicle by its action of lane change does not happen to come in front of another vehicle which is running late by a larger amount. These rules make the transportation system cooperative where a lesser late vehicle (or a non-real time task vehicle) clears the way for a vehicle running late.

The lane change rule can be easily implemented if all the vehicles are connected by a communication framework. However general traffic is filled with both semi-autonomous and human driven vehicles. Hence a relaxed format of this rule is proposed, wherein a vehicle running late may flash its state for information to the other vehicles. If the vehicle has communication facilities, it may communicate the lateness cost as well. The lateness cost largely depends upon the state and hence the human driven vehicles may easily estimate the cost from the state. In any case it is not mandatory for any vehicle, with or without communication, to cooperate.

5 Results

The simulation primitives are the same that were employed in [4]. The map of Reading, UK is taken for the simulations (shown in Figure 3) and obtained from Openstreetmap [24]. The speed of the vehicles was limited to 40 miles/h (64 Km/h). The vehicles were moved using the Intelligent Driver Model [25]. The first task is learning the average speeds and deviations, which is done using simulations detailed in [4]. The simulations involve generating vehicles with random times, origins, goals and modifying their parameters at every run to add uncertainties. Additional vehicles are added to impart some non-recurrent trends.

Additional vehicles were used for testing and reporting the time metrics, for a pre-specified ideal arrival time. The simulations were repeated for a number of vehicles over a number of scenarios. The experiments were further repeated for a number of values of α. The values of β and γ were fixed to $\alpha/4$ and $-\alpha/4$. It is reasonable to require that these values scale in proportion to α. Deviation from the time to reach goal was used as the metric of study. A positive value of the metric meant that the vehicle was late, while a negative value denotes waiting at the destination.

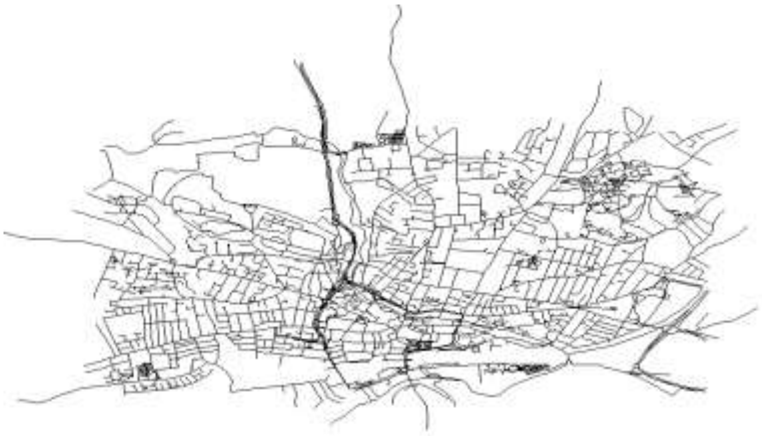


Figure 3: Map of Reading, UK used for experimentation (from [4])

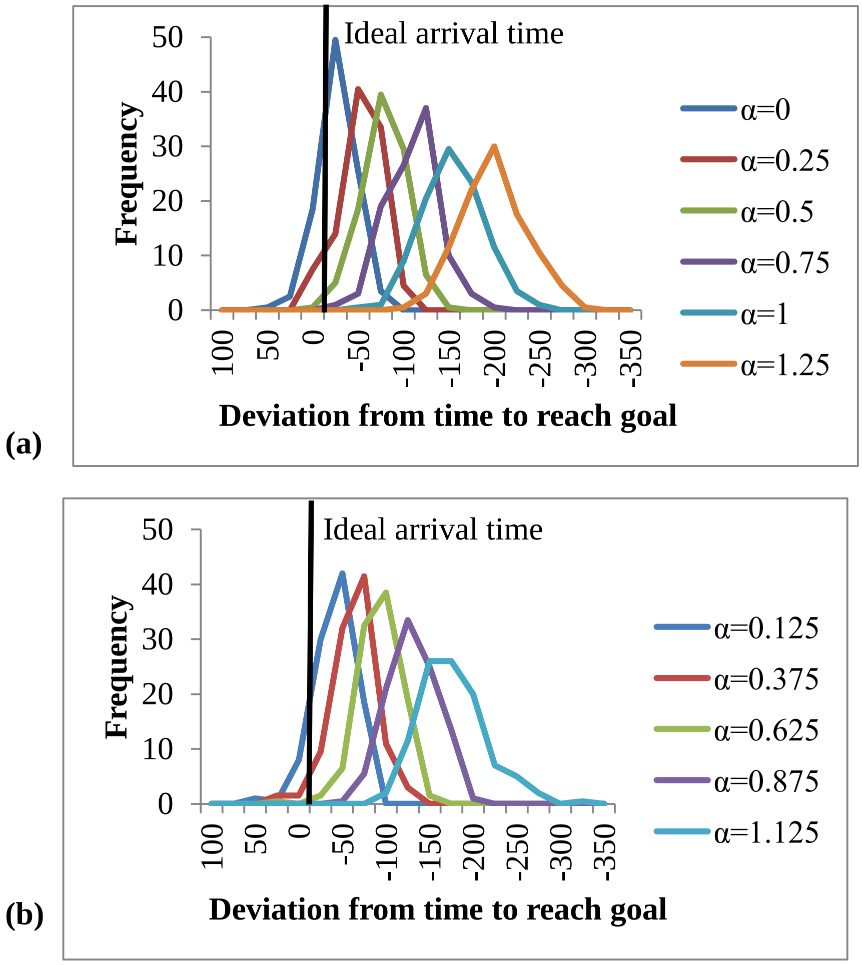


Figure 4: Histogram for deviation from time to reach goal for the transportation system with cooperation (adapted from [4])

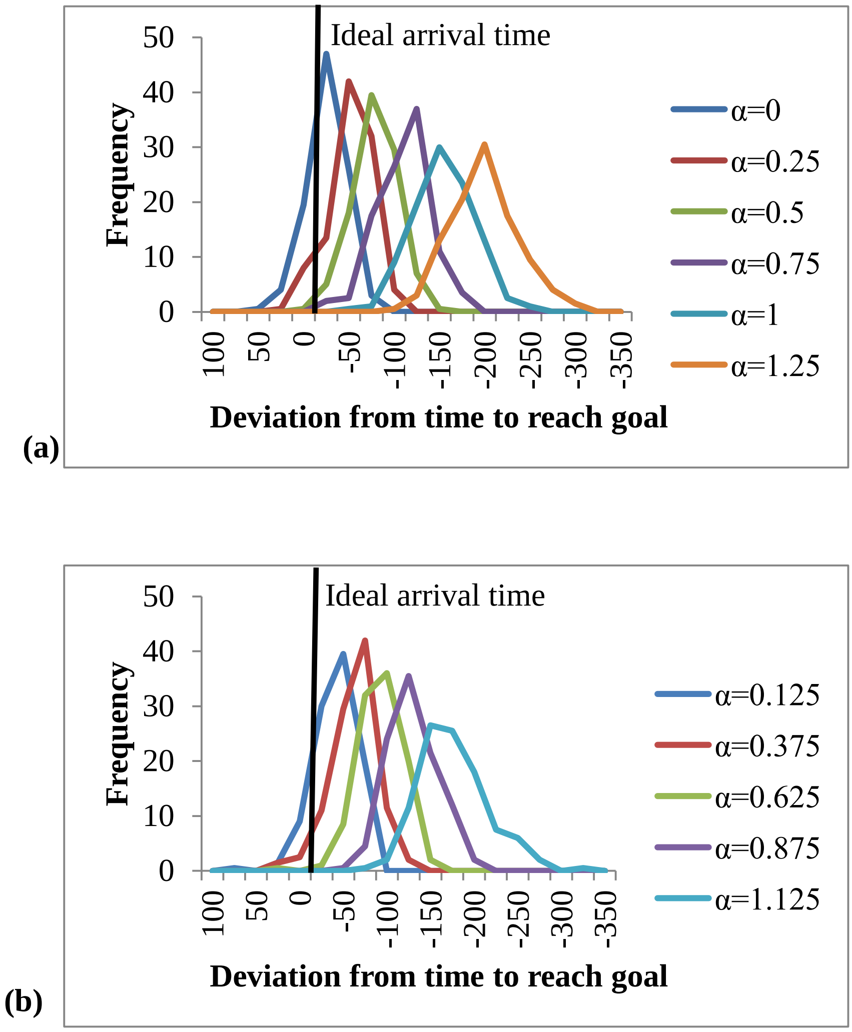
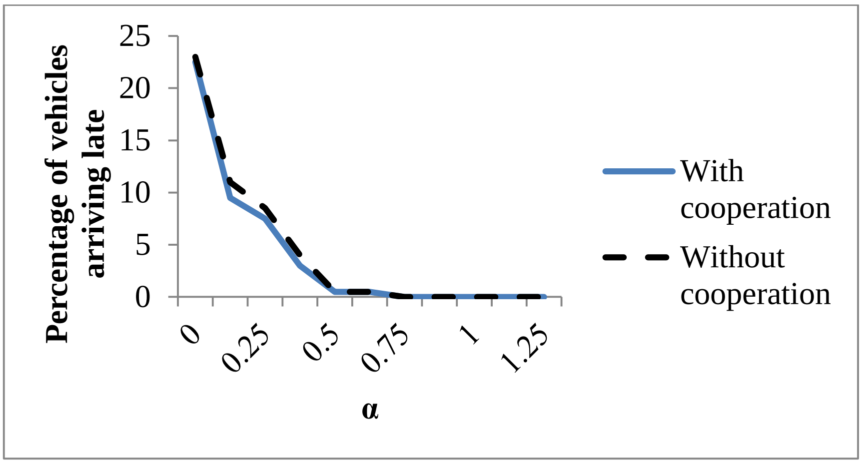
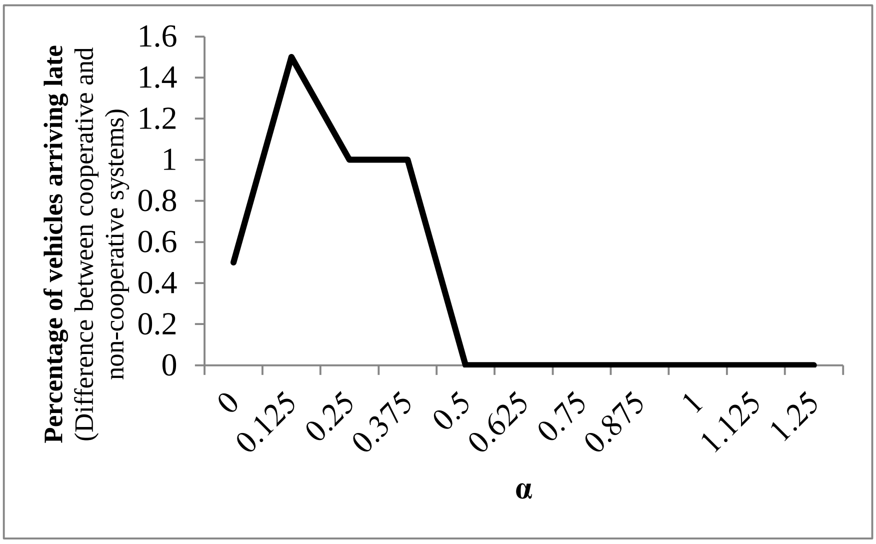


Figure 5: Histogram for deviation from time to reach goal for the transportation system without cooperation (adapted from [4])

For every value of α, a histogram showing the percentage of vehicles is given by Figure 4 for the transportation system with cooperation and Figure 5 for the transportation system without cooperation. The histogram is produced in pockets of 25 seconds. As it can be seen, higher values result in lesser vehicles getting late, at the same time resulting in more waiting time at the destination. Figure 6(a) shows the percentage of vehicles arriving late for different values of α. Figure 6(b) specifically plots the difference between cooperative and non-cooperative systems for a better visual display of the improvement. The percentage is high for very low values, while it dies off very quickly for very large values. The figure further shows that making the system cooperative results in a lower percentage of vehicles running late. The mean deviation from the time to reach destination for different values of α is shown in Figure 7(a). The higher values of α make an average vehicle reach its destination very early as compared to the lower values of α where the average vehicle more or less reaches at the specified time. It is difficult to observe the difference between cooperative and non-cooperative traffic systems from Figure 7(a) due to the large scale of the graph which nearly hides the minute differences. Hence the difference as a percentage to non-cooperative systems is shown in Figure 7(b). In general, the cooperative transportation system makes the vehicles arrive earlier, while the degree of early arrival is higher for smaller values of α.



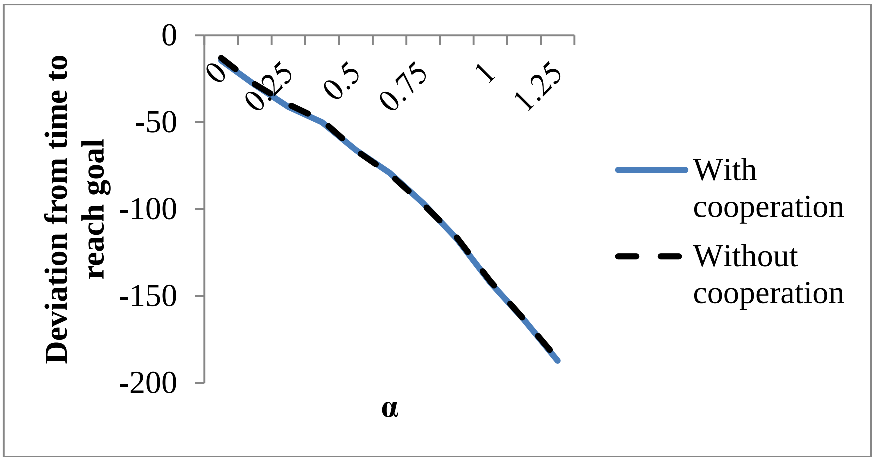
(a) Measured Value



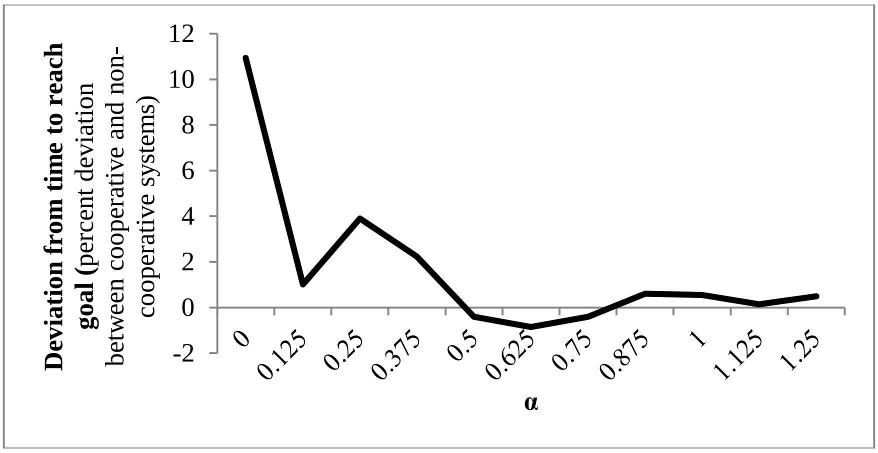
(b) Difference between cooperative and non-cooperative systems

Figure 6: Percentage of vehicles arriving late (adapted from [4])

Another metric is used to study the effect of adding cooperation to the system. The metric of the percentage of vehicles running late does not account for whether the lateness was by a few seconds or by a few minutes. While a good system minimizes the number of vehicles running late, the vehicles arriving late are late by a small time only. Hence a cost metric was used, which was kept as 0 if the vehicle arrived on time and given a penalty equal to the time by which the vehicle was late otherwise. The metric was averaged over the number of vehicles and the resultant graph is shown in Figure 8(a). Figure 8(b) specifically shows the difference between the cooperative and non-cooperative systems. Clearly, cooperation results in lesser number of vehicles running late, while the vehicles which were counted as late were actually late by small amounts. Statistical testing was done on the metric of lateness of the vehicles, which is the best metric to assess the system. Using 5% significance level, the system with cooperation performed significantly better than the system without cooperation for the values of α taken as 0, 0.25 and 0.5. The test cannot be performed for values of α greater than or equal to 0.75 as none of the vehicles arrived late and the value of the metric was 0. Using 10% significance level, the system with cooperation performed significantly better than the system without cooperation for all values of α less than or equal to 0.5.



(a) Measured Value

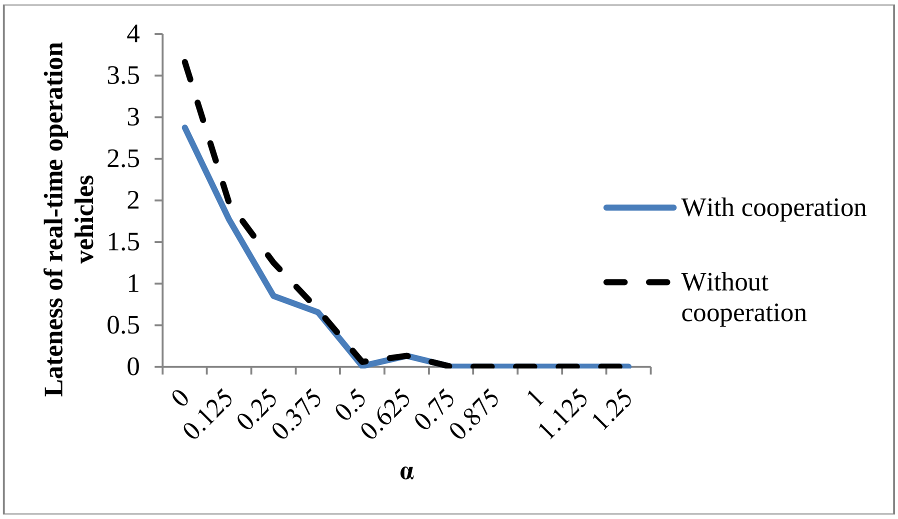


(b) Percentage with respect to non-cooperative systems

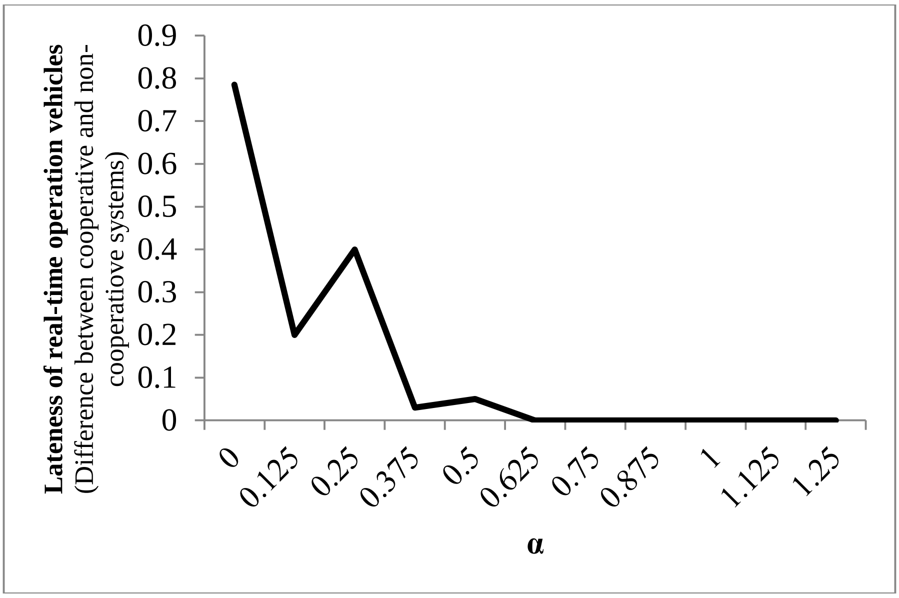
Figure 7: Deviation from time to reach goal (adapted from [4])

6 Discussions

A problem associated with the entire approach is that there is an incentive to falsely mark oneself as running late by the highest degree in order to get a priority over all the other vehicles. People may do this in order to reach as early as possible. Since the vehicles are being monitored, it is easy for the transportation authorities to set some global thresholds on the maximum monthly/yearly lateness or a cost may be incurred. Hence it is possible to control cheating or charge a price for priority. The important events like urgent meetings, important appointments, etc. may be pre-verified by the transportation authority and only registered vehicles for the pre-verified events may be allowed to ask for priority. Policies for registration of such events may be made. In terms of cost, it is important to tradeoff the price based on the expected benefits. Traffic simulations, like the one developed here, may be used to indicate the advantages of asking for cooperation and accordingly a price may be demanded. The price may be higher if the cooperation results in a significant guarantee on reaching on time. Alternatively, the price may be insured and only charged if the person succeeds in reaching on time, wherein the price may be based on the number of vehicles affected by the offered cooperation and the amount by which the vehicles were affected.



(a) Measured Value



(b) Difference between cooperative and non-cooperative systems

Figure 8: Net amounts by which real-time operation vehicles get late (adapted from [4])

Further the approach currently does not take the importance of different types of vehicles based on the number of people affected, task of the vehicle and the social stature of the vehicle. Public transit vehicles can be given higher priority than the single passenger vehicles, since a large number of people use public transit. Further, the task of the vehicle is an important criterion in deciding priorities. A vehicle carrying a witness of some court proceedings may be given a higher priority than a vehicle carrying an employee for an official business dinner. It may be imperative to give more priority to vehicles having a higher social stature. As an example, the head of state may be given more priority than a person running late for work. Priority modelling is hence a complicated feature, catering to all these mixed requirements. It is important to first collect data for each of these factors. While the number of people travelling in a vehicle can be estimated by the size of the vehicle, the task and social stature is particularly hard to obtain. While the former will require the transportation authority to have mechanisms to register and verify events, the latter can be done by the transportation authority by mapping every important personality with his/her vehicle number. Accordingly prioritization may be done.

Also the approach only suggests the vehicles to cooperate which may decide whether to cooperate or not. There is a possibility that the vehicles decide not to give priority to the vehicles running late, thereby saving any minute discomfort that giving priority causes. It is mandatory by law to give way for the emergency vehicles. A possible solution is to note the defaulter vehicles that do not readily give way, even in the most urgent cases, and to take actions upon crossing a threshold. Alternatively the vehicles giving priority could be incentivized by giving them higher priority when they are late. So the more you cooperate with the other vehicles when they are running late, the higher you are prioritized when you are yourself running late. Giving monetary incentive on offering cooperation is also a possibility.

7 Conclusions

The paper aimed at making the transportation system cooperative to favour the vehicles on a real time task and running late. The attempt was to help the vehicles reach their destination on time, even if some unaccounted delay may have happened on the way. The vehicles on a real time task may be in a state of being comfortable on time, a little late, very late or given up. The traffic lights and lane changes were made cooperative to prioritize the vehicles running late. It was seen that a higher number of vehicles reached their destination on time using the proposed approach.

In the experiments, the improvement due to cooperation was somewhat small as majority of the roads were single lanes (where cooperative lane change phenomenon cannot be displayed) and the traffic was uniformly directed (which meant late running vehicles were uniformly found at all roads of a traffic light). That said, the cooperation was eminent and the cooperation did result in more vehicles reaching their destination on time and the lateness was smaller as compared to the simulations without using any cooperation. Experiments on large cities with many multi-lane roads and experiments where the traffic is much directed during different parts of the day, may showcase more interesting results. Future attempts would be to record some real-life data, which for the specific problem is unavailable, and use the same for experimentations. The cooperation needs to be extended to re-routing and other means of handling non-recurrent traffic. Creating a market economy model or a similar model for asking for cooperation also needs to be worked over.

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