Performance of Multiagent Taxi-Dispatch on Extended-Runtime Taxi Availability: A Simulation Study

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***Abstract*— An empirical and comparative evaluation of multiagent taxi-dispatch with extended (E) runtime taxi availability is presented. A taxi in operation is said to be E-runtime available if it has a passenger alighting in $\delta x > 0$ minutes' time or is empty, but has no new committed taxi request to service next. In a multiagent architecture, we consider a new operation policy that agents of E-runtime available taxis are allowed to negotiate in individual groups of size N for new taxi requests. The main objective is to present an evaluation of the multiagent system performance gains provided by different times-to-arrival of δx, under a discrete range of demand rates for several N-group sizes, as compared with the base case when $\delta x = 0$. It is shown that the proposed policy can effectively reduce customer waiting time and empty taxi cruising time, and respectively by up to about 60% and 96% when the service demand is high for a 1000-strong taxi fleet. It is observed that the value selection for the policy parameter δx is an important aspect for improving the general performance of multiagent taxi-dispatch.**

I. Introduction

In passenger land transport-service, taxis are a convenient means in many countries that fills the gap between mass transit and other modes of land transport such as buses [1]. To match customer service requests and taxis, whose respective arrival and availability might be sporadic or not known a priori, a taxi dispatch system is required. As customers are sensitive to service-time efficiency, just as human taxi drivers are to service-cost productivity, an efficient dispatch system must be able to quickly dispatch available taxis to customer pick-up locations.

The promise of multiagent-based approaches has been demonstrated in several areas of intelligent service transportation (e.g., transport logistics [2] and route guidance [3], [4]). These approaches are due particularly to the attractiveness of negotiation [5] as a powerful metaphor for developing active software entities called agents, and motivated by the availability of multiagent technologies such as JADE [6] that vastly simplifies their implementation. Aimed at improving operational efficiency, recent work [7], [8] proposes a novel multiagent approach to dispatch taxis in a distributed manner. A taxi agent is an active software entity residing in an in-vehicle computing unit of a taxi. The proposed multiagent architecture (Fig. 1) would invariably provide a set-up to harness the existing power of multiple intelligent transportation technologies, such as vehicle routing [9] and route guidance [10], automatic vehicle location [11], mobile phone location determination [12], and palmtop-based navigation [13].

In this approach, collaborative taxi agents acting on behalf of taxi drivers can cooperatively negotiate to decide among themselves their different requests to service. By cooperative negotiation, several taxi agents collaboratively search and jointly arrive at an agreed (request-to-taxi) assignment solution. Empirical results show that the multiagent dispatch approach [7] can dispatch taxis with significant improvement in operational efficiency over a centralized approach.

In the base multiagent taxi-dispatch architecture proposed [7], a taxi in operation is (runtime) available provided it is empty with no new committed taxi request to service next. In this multiagent operation, the policy is that only the agents of available taxis are allowed to negotiate for new taxi requests.

In this paper, we extend the notion of taxi runtime availability to taxi extended (E) runtime availability. A taxi in operation is said to be E-runtime available if it has a passenger alighting in $\delta x > 0$ minutes' time or is empty, but has no new committed taxi request to service next. Herein, we propose a new operation policy that agents of E-runtime available taxis are allowed to negotiate for new taxi requests. Intuitively, this should result in more taxis being available for negotiation at any one time to handle the service demand, providing an important avenue for performance improvement. The extent that the proposed policy lends to improving fleet performance over the base case when $\delta x = 0$ is investigated empirically by simulation for a discrete δx range of times-to-arrival (of a taxi at its passenger's destination).

The performance of multiagent taxi-dispatch in terms of operational efficiency boils down to assessing customer waiting and empty taxi cruising times. Customer waiting time is measured from the moment a customer raises a request to the moment an assigned taxi arrives to pick up the customer; and generalizing that defined in [7], empty taxi cruising time is measured from the moment it becomes empty, forward to the moment it accepts (or commits to service) a new negotiated assignment, and is otherwise 0 if it has accepted the new assignment before it becomes empty.

The rest of this paper is organized as follows. Section II reviews the multiagent architecture of the proposed taxi dispatch system. Section III presents and discusses a microscopic simulation study evaluating the performance of multiagent dispatch for different times-to-arrival of δx under a discrete range of demand rates for several N-group sizes, and in comparison with the base case [7] when $\delta x = 0$. Section IV concludes the paper and points to some future work.

II. Multiagent Taxi-Dispatch System

A. Collaborative Taxi Dispatch: A Review

Fig. 1 shows the multiagent architecture called *N*TuCab dispatch proposed to support distributed taxi dispatch [7]. It is populated with taxi agents that negotiate through a decentralized mechanism called MA^3-LM [14], efficiently assigning every taxi agent with a different taxi request - essentially a linear assignment problem (LAP) [15] - but addressed in a collaborative fashion among the agents in individual groups of size $N \geq 2$. In a dispatch cycle, the dispatch center and the taxi agents interact and perform essential tasks that help organize the available taxis and incoming service requests into different N-groups for intra-group negotiation and request-to-taxi assignment, the details of which can be found in [7].

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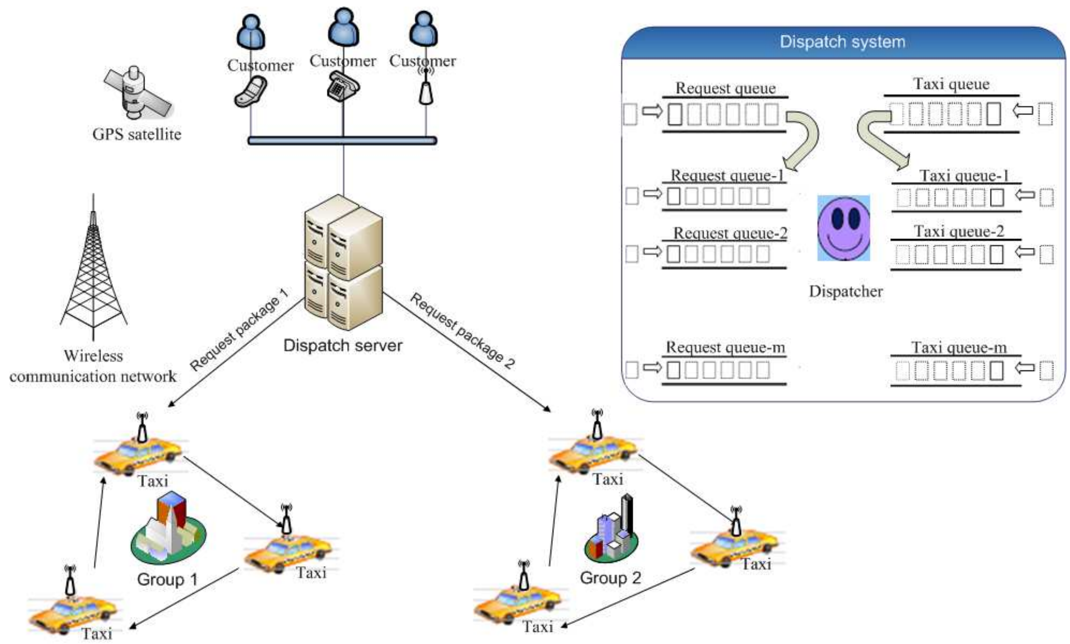


Fig. 1. Proposed *N*TuCab dispatch system

Below, we briefly review the core issue of collaborative LAP in this multiagent taxi-dispatch system:

Consider an ad hoc group of agents $\mathcal{A} = \{a_0, a_1, \cdots, a_{N-1}\}$ of size N tasked with a group of different taxi service-requests $\mathcal{O} = \{r_0, r_1, \cdots, r_{N-1}\}$ of size N. Initially, agent $a \in \mathcal{A}$ only has knowledge of the A-QoS (*application quality-of-service*) it can offer for each request, defined by $d[a,r]$ for all $r \in \mathcal{O}$. In taxi dispatch, we formulate A-QoS $d[a,r] < 0$ as the negation of the expected shortest travel time for a taxi (represented by an agent $a \in \mathcal{A}$) to move from its designated or current location to the pick-up location of a customer (who initiated the pending request $r \in \mathcal{O}$). The expected shortest travel time by the taxi for every request is computed using real-time traffic information as proposed in [16].

Formally, our core objective of taxi dispatch is to find, for every $N \times N$ LAP, the particular (total) assignment $\Pi : \mathcal{A} \rightarrow \mathcal{O}$, a one-to-one mapping of agents to requests [17], [18] that attempts to maximize the total A-QoS $\sum_{i=0}^{N-1} d[a_i, \Pi(a_i)]$. The taxi agents negotiate using MA^3-LM [14] in a finite number of negotiation rounds, to compute and leverage on the possible overall A-QoS increments achievable through reassigning requests among themselves. Agents using MA^3-LM will always reach a solution that is often highly efficient, though not necessarily optimal [17], [18]. Relevant details of their collaborative reasoning per negotiation round in a decentralized manner [14] are reviewed in [7, p. 1049-50, Appendix].

As first noted in [17], a related mechanism that applies auctioning [19] for the $N \times N$ LAP exists. However, using this auction mechanism would inevitably involve taxi agents having to negotiate with customer (request) agents, and this, at the outset, does not map onto the proposed multiagent architecture that entails taxi agents negotiating *only among themselves* for requests.

B. New Multiagent Operation Policy

In the original operation policy, the moment an agent announces the availability of its taxi in a new area of operation to the dispatch center, its taxi is or has become empty with no new committed taxi request to service next. In the new policy (of E-runtime taxi availability as defined in the introduction), the moment it announces its taxi availability, the taxi has a passenger alighting in $\delta x > 0$ minutes' time or is empty, but has no new committed taxi request to service next. This policy subsumes an agent announcing its taxi availability immediately upon a customer boarding the taxi at a pick-up location, if the taxi's (shortest) travel time remaining to reach the customer's destination is less than the specified δx minutes.

The new policy is feasible in an ITS-enabled communication infrastructure, where each taxi is equipped with some GPS-based real-time routing and guidance system [10]. Assisted by such a system, a computer taxi agent can predict when the taxi is $\delta x > 0$ minutes from reaching the passenger's destination.

Under this policy, the A-QoS $d[a,r] < 0$ for a taxi (represented by an agent $a \in \mathcal{A}$) to move from its current location to the pick-up location of a customer (who initiated the pending request $r \in \mathcal{O}$) is redefined as the negation of the sum of the following two time-components:

1) the remaining time for the taxi, if servicing a committed request, to move from its current location to its passenger's destination (on an already defined road path), and
2) the shortest time from the passenger's destination to the pick-up location of the customer request $r \in \mathcal{O}$.

As an explicit service measure, the redefined A-QoS is logically understood. Note, however, that the first time-component

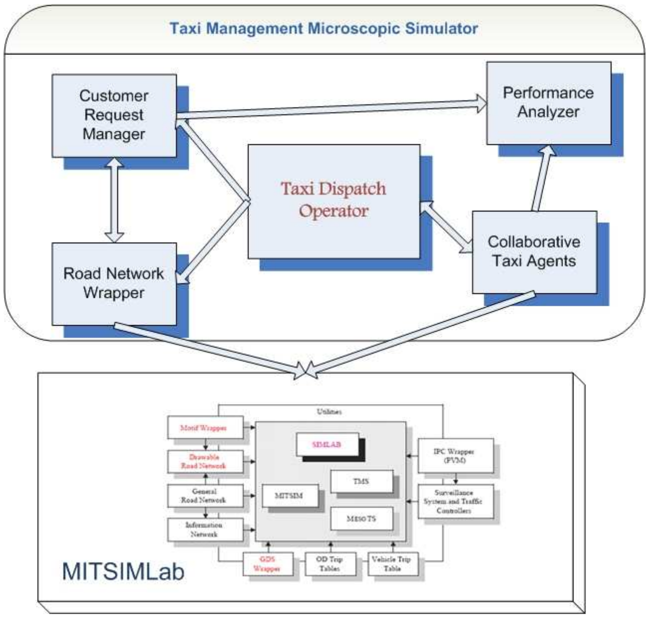


Fig. 2. The TM2S-MITSIMLab simulation model [7]

for each agent $a \in \mathcal{A}$ is the same for every request $r \in \mathcal{O}$. As a result, using only the second time-component as their A-QoS for negotiation suffices, since the taxi agents on MA^3-LM can (be shown to) reach the same assignment solution as that using the redefined A-QoS.

III. Simulations & Performance Evaluation

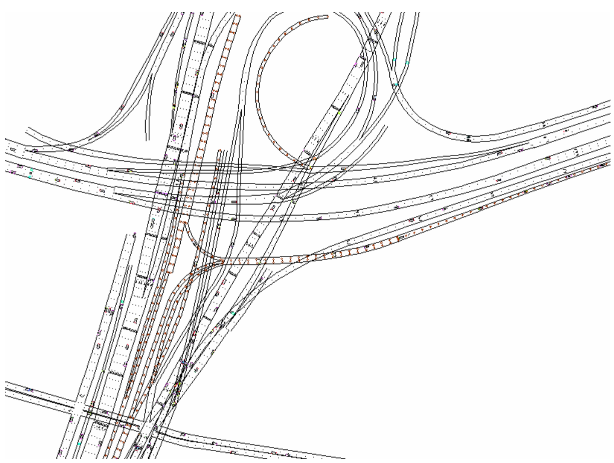


Fig. 3. The urban road network model used

A. Experimental Scope & Investigation

To study the operational performance of the proposed *N*TuCab dispatch system under E-runtime taxi availability, we conducted microscopic computer simulations on MITSIMLab [20], [21] (http://web.mit.edu/its/mitsimlab.html), simulating taxi operations in a selected ITS-managed urban road network of reasonable complexity, as shown in Fig. 3. The network model covers a physical area of about $15km \times 10km$. Different δx times-to-arrival, including the base case ($\delta x = 0$), were

TABLE I

*N*TuCab dispatch: Base case ($\delta x = 0$)

(a) Customer waiting time (in s)

N	Demand rate						
	1	1.5	2	2.5	3	3.5	4
5	128.1	127.0	135.9	165.7	189.0	281.2	479.9
10	109.9	111.4	116.1	141.0	161.3	225.6	371.8
15	110.1	106.6	113.5	136.6	155.5	222.1	352.8
20	112.0	112.9	120.8	144.1	168.6	255.9	422.9

(b) Empty cruising time (in s)

N	Demand rate						
	1	1.5	2	2.5	3	3.5	4
5	2780.7	1973.9	1572.4	885.2	495.1	408.9	303.9
10	2305.5	1544.0	1235.6	697.2	389.2	333.2	247.1
15	2221.3	1519.8	1184.5	688.1	389.2	324.8	239.3
20	2332.6	1487.5	1227.6	709.8	412.7	325.3	250.9

simulated to assess their performance gains as compared to the base case.

For our simulations performed on MITSIMLab [20], [21] through a Taxi Management Microscopic Simulator (TM2S) that we developed (see overall software architecture[1] in Fig. 2), a taxi fleet size of 1000 was simulated for a one-hour duration. The TM2S module assumes that the taxi agents negotiate over a high speed wireless communication network. In calculating the multiagent negotiation time, the module estimates the total negotiation time based on the number of negotiation rounds taken and a conservative estimate of $0.2N$ seconds per round when an ad hoc N-group of taxi agents negotiate.

The 1000-strong taxi fleet is about 30% of the traffic volume that can be simulated on MITSIMLab, and constitutes a reasonable traffic composition in the urban setting considered. The expected shortest travel time [16] for a taxi to reach a customer's pick-up location (the negation of which determines an A-QoS data) was calculated using the route choice model provided by the traffic flow simulator module of MITSIMLab [21].

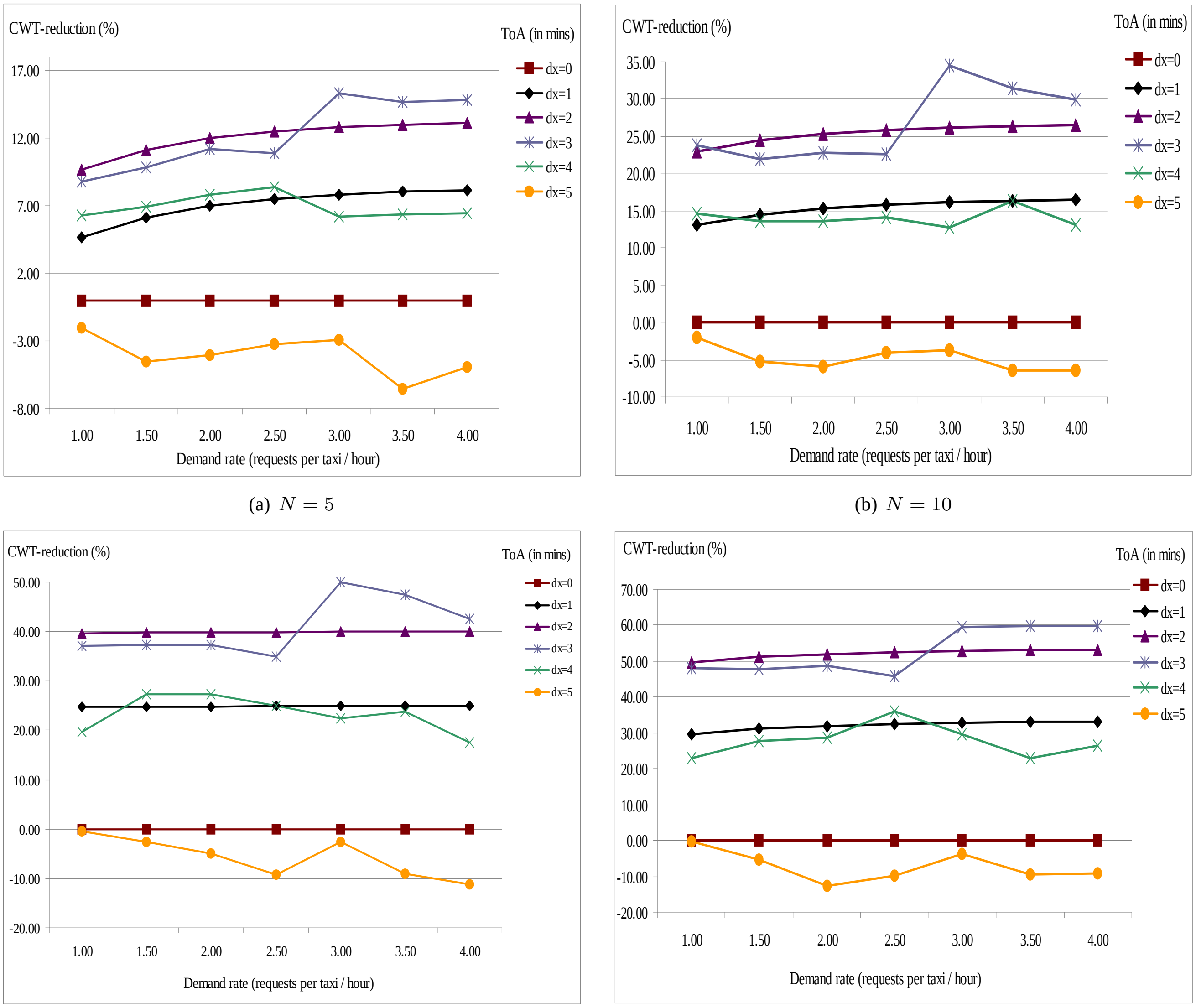
In the same experimental settings as [7], we carried out simulations for a range of hourly demand rates (defined by taxi bookings per taxi per hour). For each demand rate, simulated with incoming requests generated by the request manager, the customer waiting time (CWT) and empty taxi cruising time (ECT) were recorded for collaborative agent dispatch for several group sizes $N \in \{5, 10, 15, 20\}$, under different time-to-arrival (ToA) values (in minutes) of $\delta x \in \{1, 2, 3, 4, 5\}$, with the simulation data (raw customer waiting and empty cruising times) collected from the simulated dispatch operator and taxi agents for off line performance analysis.

B. Analysis of Numerical Results

Table I shows the numerical results for the base case when ToA $\delta x = 0$. The reductions (in percent) depicted in all the figures are computed with respect to these base (average) values.

Customer Waiting Time: For $1 \leq \delta x \leq 4$, the CWT reduction is found to be always positive:

[1]Note that the MITSIMLab part [21] in Fig. 2 is intentionally blurred.



(a) $N = 5$

(b) $N = 10$

(c) $N = 15$

(d) $N = 20$

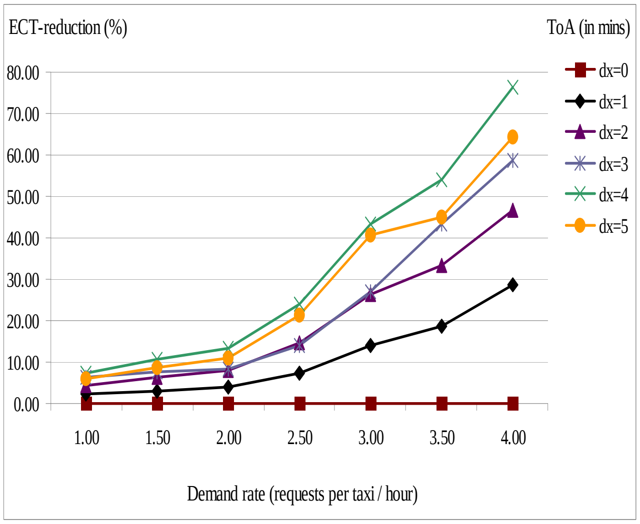
Fig. 4. Customer waiting time: Reduction versus demand rate under different ToA δx

- Figs. 4(a) to 4(d) show that the reduction increases for $\delta x \leq 2$, and when the demand rate exceeds 2.5 for $\delta x = 3$. The relatively low δx at relatively high demand rates can often result in a taxi being assigned a new request whose customer pick-up location is nearer to its current passenger's destination, and more so for a bigger N that thus effectively enjoys a higher CWT reduction.
- Figs. 4(a) to 4(d) also show that the reduction decreases starting from $\delta x = 3$, when the demand rate does not exceed 2.5, although still larger than that at $\delta x = 1$. The relatively higher δx, or when the demand rate is relatively low at $\delta x = 3$, can often result in a taxi being assigned a new request whose customer pick-up location is further away from its current passenger's destination, and more so for a smaller N that thus effectively receives a lower CWT reduction.

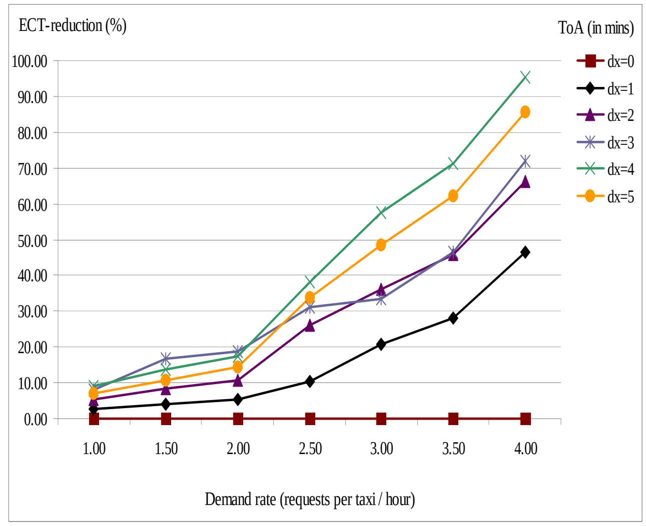
At $\delta x = 5$, there is at best no CWT reduction and often an increase in CWT. The relatively high δx can often result in a taxi being assigned a new request (following an N-group multiagent negotiation), when the taxi itself is still quite far from reaching its current passenger's destination. This contributes significantly towards the increase in CWT, since the taxi must necessarily travel to its current passenger's destination en route to the pick-up location of the newly assigned request.

The best CWT reduction of about 60% occurs at $\delta x = 3$, when the demand rate exceeds 3 for $N = 20$ [see Fig. 4(d)]. For $\delta x \geq 5$, the policy of E-runtime taxi availability becomes ineffective. Following, we infer that the proposed policy is especially effective in reducing CWT when the N-grouping is large and the service demand is high relative to the taxi fleet size. Besides, there is a non-zero ToA threshold value for δx below which a significant reduction in CWT is achievable.

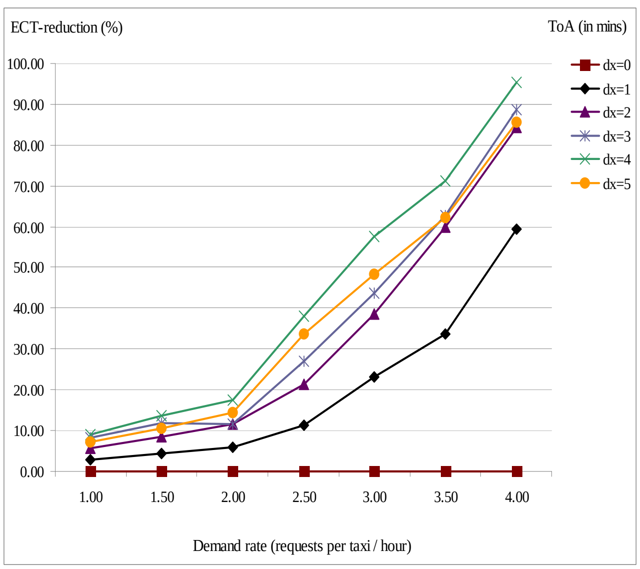
Empty Cruising Time: Using E-runtime taxi availability, the ECT can be reduced since a taxi agent can often start negotiating for a new request in the duration of servicing a current request, and in so doing can often proceed to servicing



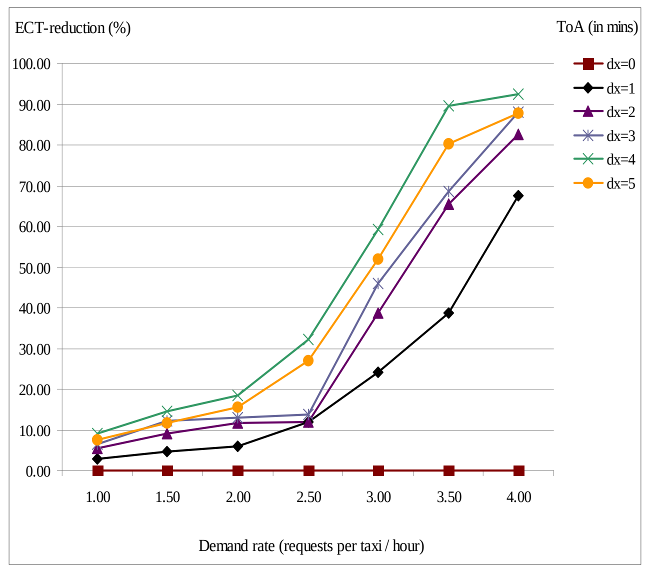
(a) $N = 5$



(b) $N = 10$



(c) $N = 15$



(d) $N = 20$

Fig. 5. Empty cruising time: Reduction versus demand rate under different ToA δx

a new one shortly or immediately after its current passenger has alighted. Figs. 5(a) to 5(d) show that the ECT reduction increases with the demand rate for each N considered, and is higher for a higher δx (not exceeding 4) and a higher demand rate in the range considered. However, Figs. 5(a) to 5(d) also show that the reduction is bounded by $\delta x = 4$: At $\delta x = 5$, the supply of E-runtime available taxi agents in excess of the demand volume in a dispatch cycle becomes more significant. This can explain why the reduction becomes smaller than that at $\delta x = 4$.

The best ECT reduction of about 96% occurs when $\delta x = 4$ at demand rate 4 for $N = 15$ [see Fig. 5(c)]. In fact, the lowest reduction recorded is about 76% for demand rate 4, at $N = 5$ [see Fig. 5(a)]. Following, we infer that the proposed E-runtime taxi availability policy is very effective in reducing ECT when the service demand is high relative to the taxi fleet size.

Finally, a clear observation is that the reduction in CWT and ECT depends on the proper value selection for ToA parameter δx. From the simulation results, the best CWT and ECT reductions are found to occur at $\delta x = 2$ or 3 minutes depending on the demand rate, and $\delta x = 4$ minutes, respectively.

IV. Conclusion

TM2S-MITSIMLab simulations on an urban road network model were run for the *N*TuCab dispatch system under the operation policy of E-runtime taxi availability, a new notion introduced and studied in this paper. The results show that significant reduction in CWT and ECT can be achieved. Given a taxi fleet size, this depends on the proper value selection for the policy ToA parameter δx, which is an important aspect for improving the operational efficiency of multiagent taxi-dispatch in general.

In conclusion, leveraging on the shortest-time paths computed using real-time traffic information, the proposed *N*TuCab dispatch system has been shown empirically in [7] to achieve higher efficiency in terms of CWT and ECT, when compared to a commonly adopted centralized dispatch approach. Importantly, this paper has demonstrated the effectiveness of E-runtime taxi availability in raising further this standard time-criterion efficiency, which is based essentially on the taxi-proximity (of a customer pick-up location) as modelled by the current A-QoS formula. Future work will consider mixed-criteria efficiency. Towards this end, we will investigate a new A-QoS formula that combines taxi-utilization level with taxi-proximity level in a fuzzy rule formulation - an approach that has been investigated in [22], [23], albeit only for centralized taxi dispatch.

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References

[1] Z. Liao, "Taxi dispatching via global positioning systems," *IEEE Transactions on Engineering Management*, vol. 48, no. 3, pp. 342–347, August 2001.

[2] K. Dorer and M. Calisti, "An adaptive solution to dynamic transport optimization," in *Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS'05): Industry Track*, Utrecht, The Netherlands, July 2005, pp. 45–51.

[3] J. L. Alder and V. J. Blue, "A cooperative multi-agent transportation management and route guidance system," *Transportation Research Part C: Emerging Technologies*, vol. 10, no. 5-6, pp. 433–454, October-December 2002.

[4] J. L. Adler, G. Satapathy, V. Manikonda, B. Bowles, and V. J. Blue, "A multi-agent approach to cooperative traffic management and route guidance," *Transportation Research Part B: Methodological*, vol. 39, no. 4, pp. 297–318, May 2005.

[5] J. S. Rosenschein and G. Zlotkin, *Rules of Encounter: Designing Conventions for Automated Negotiation among Computers*. Cambridge, M.A, USA: The MIT Press, 1994.

[6] F. L. Bellifemine, G. Caire, and D. Greenwood, *Developing Multi-Agent Systems with JADE*. (Wiley Series in Agent Technology) John Wiley and Sons, Inc., New York, April 2007, JADE software platform available at `jade.tilab.com`.

[7] K. T. Seow, N. H. Dang, and D.-H. Lee, "Towards an automated multiagent taxi-dispatch system," in *Proceedings of the IEEE International Conference on Automation Science and Engineering (CASE'07)*, Scottsdale, Arizona, USA, 2007, pp. 1045–1050.

[8] ——, "A collaborative multiagent taxi-dispatch system," *IEEE Transactions on Automation Science and Engineering*, 2009, accepted to appear.

[9] S. Kim, M. E. Lewis, and I. Chelsea C. White, "Optimal vehicle routing with real-time traffic information," *IEEE Transactions on Intelligent Transportation Systems*, vol. 6, no. 2, pp. 178–188, June 2005.

[10] E. J. Schmitt and H. Jula, "Vehicle route guidance systems: Classification and comparison," in *Proceedings of the IEEE Conference on Intelligent Transportation Systems*, Toronto, Canada, September 2006, pp. 242–247.

[11] N. Papadoglou and E. Stipidis, "Investigation for a global AVL system," *IEEE Transactions on Intelligent Transportation Systems*, vol. 2, no. 3, pp. 121–126, September 2001.

[12] Y. Zhao, "Mobile phone location determination and its impact on intelligent transportation systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 1, no. 1, pp. 55–64, March 2000.

[13] V. de Nitto Personé and V. Grassi, "Performance analysis of caching and prefetching strategies for palmtop-based navigational tools," *IEEE Transactions on Intelligent Transportation Systems*, vol. 4, no. 1, pp. 23–34, March 2003.

[14] K. T. Seow and K. M. Sim, "Decentralized assignment reasoning using collaborative local mediation," *IEEE Transactions on Knowledge and Data Engineering*, vol. 18, no. 11, pp. 1576–1580, November 2006.

[15] H. W. Kuhn, "The Hungarian method for the assignment problem," *Naval Research Logistics Quarterly*, vol. 2, no. -, pp. 83–97, 1955.

[16] D. H. Lee, H. Wang, R. L. Cheu, and S. H. Teo, "A taxi dispatch system based on current demands and real-time traffic information," *Transportation Research Record*, vol. 1882, pp. 193–200, 2004.

[17] K. T. Seow and K. Y. How, "Collaborative assignment : A multiagent negotiation approach using BDI concepts," in *Proceedings of the First International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS'02)*. Palazzo Re Enzo, Bologna, Italy: ACM Press, July 2002, pp. 256–263.

[18] K. T. Seow and K. M. Sim, "Collaborative assignment using belief-desire-intention agent modeling and negotiation with speedup strategies," *Information Sciences*, vol. 178, no. 4, pp. 1110–1132, February 2008.

[19] D. P. Bertsekas, "The auction algorithm : A distributed relaxation method for the assignment problem," *Annals of Operations Research*, vol. 14, pp. 105–123, 1988.

[20] M. Ben-Akiva, H. N. Koutsopoulos, and Q. Yang, "User's Guide for MITSIMLab and Road Network Editor (RNE)," ITS Program at the Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Boston, USA, Technical Report Draft, November 2002, 116 pages.

[21] Q. Yang, "A Simulation Laboratory for Evaluation of Dynamic Traffic Management Systems," Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Boston, USA, Ph.D Thesis, June 1997, 193 pages.

[22] M. Shrivastava, P. K. Chande, A. S. Monga, and H. Kashiwagi, "Taxi despatch: A fuzzy rule approach," in *Proceedings of IEEE International Conference on Intelligent Transportation System (ITSC'97)*, Boston, MA, USA, Nov 1997, pp. 978 – 982.

[23] M. N. Ngo, K. T. Seow, and K. W. Wong, "Fuzzy linear assignment problem: An approach to vehicle fleet deployment," in *Proceedings of IEEE International Conference on Fuzzy Systems (FUZZ-IEEE'04)*, vol. 2, Budapest, Hungary, July 2004, pp. 1197–1202.