Evaluating Location Alternatives for Electric Vehicle Re-charging Infrastructure Using a Distance Constrained Equilibrium Assignment Model

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Word Count

4,700 +4 Figures and 4 Table = 6,700 total words

Submitted for Presentation and Publication
at the 93rd Annual Meeting of Transportation Research Board

Abstract

Plug-in electric vehicles (PEVs) represent a rapidly evolving technology which relies on electric power rather than petrol. A new such energy dependence requires the development of an infrastructure system for en-route re-charging options, be that fast charging stations or battery swap stations. Optimally locating re-charging infrastructure requires knowledge of PEVs' spatiotemporal travel patterns, which are inherently dependent on PEV users' travel behaviour. Furthermore, a limited battery capacity results in a distance constraint for PEV drivers, inevitably impacting their travel and activity patterns, and thus, the performance of the transport system. To properly evaluate re-charging infrastructure design decisions the constraints on PEV users' route choice must be incorporated into transport planning models. Using a novel distance constrained user-equilibrium-based assignment model which allows re-charging requirements to be incorporated into the traditional traffic assignment problem, we evaluate the impact of PEV traveller's en route re-charging needs on the network system performance under various re-charging station location options. We quantify the potential system performance improvement achievable by optimally locating re-charging stations, and also identify key scenarios in which infrastructure planning decisions result in sub-optimal network performance. The analysis motivates the use of modified traffic assignment models when designing re-charging infrastructure systems within transport networks with PEVs.

1. INTRODUCTION

Plug-in electric vehicles (PEVs) have attracted much attention as a potential alternative vehicle technology to help reduce both greenhouse gas emissions and reliance on fossil fuels. However, to successfully integrate this new technology into current transport systems, researchers and industry alike need to overcome many key barriers. One such issue results from the limited range of fully electric vehicles. A PEV's driving range is a function of the battery capacity and engine efficiency, both of which will increase as the available battery technology improves. For PEV drivers, the range limitation will restrict the set of route options available to them. Additionally, without widely available re-charging capability, a limited driving range may result in range anxiety for potential PEV users, thus providing a disincentive to purchase the new vehicle technology. To address these issues, it is vital that planners utilize appropriate tools when evaluating options for re-charging infrastructure, specifically regarding the question of where to locate re-charging stations.

The availability of PEV re-charging stations will likely be a key determinant in the ultimate success of these vehicles, both in terms of initial uptake, and once they are established on the road network. The location of the re-charging stations may impact drivers' route choice decisions, which will in turn impact the performance of the transport system. Therefore this paper focuses on evaluating the impact of re-charging station location on the overall performance of the regional transport system. This study relies on a novel distance constrained user-equilibrium-based assignment model proposed by Jiang et al (*1*) which allows re-charging requirements to be incorporated into the traditional traffic assignment problem. Various re-charging station location alternatives are proposed and evaluated based on the system performance metric - total system travel time (TSTT). We quantify the potential system performance improvement achievable by optimally locating re-charging stations, and also identify key scenarios in which infrastructure planning decisions result in sub-optimal network performance. The analysis motivates the use of modified traffic assignment models when designing re-charging infrastructure systems within transport networks with PEVs, and future research to develop a heuristic capability of solving the more computationally intensive problem of optimally locating re-charging stations in a large scale transport network. The electric vehicle technology addressed in this work is plug-in electric vehicles (PEVs) which rely solely on recharging a battery for energy, sometimes called battery electric vehicles or all-electric vehicles. Furthermore, we assume a subset of the travel demand are PEV users, whom are subject to distance constraints, and the remainder of the demand consists of traditional internal combustion engine vehicles (ICEVs) with no distance constraint imposed.

The remainder of the paper is structured as follows: Section 2 provides a literature review, Section 3 describes the problem definition and solution methodology, the numerical results are presented in Section 4, and conclusions are presented in Section 5.

2. LITERATURE REVIEW

This section provides a brief background on various aspects of the problem addressed. The role of re-charging stations in the successful adoption of PEVs is discussed, followed by equilibrium assignment models which incorporate PEV users, and lastly, a summary of relevant literature related to PEV infrastructure design, specifically those which incorporate traffic assignment models.

2.1 Challenges posed by electric vehicles

Much speculation exists in regard to the future of PEVs. Despite the environmental advantages that PEVs offer, they are currently subject to many barriers impeding their mass adoption. One of the most important issues is that PEVs have a limited driving range compounded by a lack of public re-charging infrastructure available.

Although internal combustion engine vehicles (ICEVs) also have a limited range, refuelling stations are abundant, negating any issues that may be imposed by fuel tank capacity. Numerous studies have identified re-charging infrastructure availability to have a significant impact on potential PEV consumers' purchasing decisions (*2*).

PEVs in Australia face a similar outlook. While trials in Perth have found that early adopters of PEVs are satisfied with their vehicles (*3*), still a majority of all trips were less than thirty kilometres in distance; this may partially be a reflection of range anxiety and a lack of re-charging infrastructure. Additionally, both Allan (*2*) and Speidel et al (*4*) identified similar challenges to PEVs in Australia: high operating and initial costs, technical limitations such as range anxiety, the lack of re-charging infrastructure, managing the added power demand on the electric grid, regulation and policy, and public education about PEVs. This work intends to motivate the importance of the re-charging infrastructure problem while acknowledging the issue of a distance constraint in PEV driver route choice.

2.2 Distance constrained network equilibrium assignment model

The traditional network equilibrium assignment models used in the trip assignment stage of the traditional four step transport planning process are incapable of incorporating the distance constraints imposed by new PEV vehicle technology. Traditional assignment models assume that users have perfect information and that they will choose the least cost path available to them (*5*), disregarding the added consideration of PEV drivers, ensuring that the path does not exceed the distance constraint of their vehicle. The models are therefore unable to capture the behavioural differences of PEV users regarding route choice.

Previous studies have examined the impact of a new class of PEV users without accounting for the changing behaviour of the drivers (6,7). In order to incorporate the travel distance constraints imposed on PEV drivers a new type of equilibrium assignment model is needed to analyse networks in which PEVs are present. Jiang et al (*1*) address this issue by developing a distance constrained network equilibrium assignment model, which can be applied to networks with PEV users to model their travel choices when subject to distance constraints. The model assigns a range limitation to PEV users so that a route can only be chosen if the limit is not exceeded. It also allows PEV drivers to replenish their fuel when a re-charging station is available. , The equilibrium assignment model follows a Wardropian equilibrium principle, wherein PEV users' route choice is captured using an efficient *distance constrained shortest path* algorithm. Like the traditional network equilibrium assignment model, the model proposed by Jiang et al (*1*) provides network wide travel patterns and corresponding travel times which can in turn be utilized to quantify system level performance. Jiang et al (*1*) presents the mathematical model and solution method, and illustrates how the path constraints impact the equilibrium conditions and resulting traffic flow patterns. The model was further extended to include a destination choice model (*8*).

2.3 Re-charging Station Location Optimization

Previous studies investigating optimal re-charging station locations for PEVs has addressed various objectives including maximising the demand covered by the re-charging stations (*9;10*), maximising service provided by the re-charging stations (*9*), minimising the cost spent on constructing the re-charging stations (*11*) and minimising average vehicle travel time in the network (*12*). Studies which estimate the PEV demand for re-charging stations have generally relied on data obtained from household travel surveys, with few studies incorporating a traffic assignment model.

Kuby and Lim (*11*) used a variation of the set covering model to solve for the optimal location of refuelling stations for vehicles, in the context of a vehicle routing problem, assuming that the vehicle flows are known a priori. The goal was then to provide refuelling to as many vehicles as possible while minimizing the total cost of constructing the infrastructures. This approach was adapted to PEVs by McPherson et al (*13*) and presented in the context of Australia.

This work specifically examining the problem of battery switch stations. McPherson et al identify trips that are greater than 120 km in distance as the criteria for locating optimal battery switch station locations. While this approach does not account for behavioural changes due to the new re-charging stations, it does present a number of interesting, and relevant results, finding that in Melbourne and Sydney, about ten re-charging stations could capture 60% of long distance trips. Frade et al (*9*) performed a case study to determine the best locations for PEV re-charging stations in a neighbourhood in Lisbon, Portugal. The goal in this case, however, was to maximize the demand covered by re-charging stations when the demand was calculated from census data and the number of re-charging stations to be built in the future was determined by the government. Therefore the total cost of the re-charging stations was not taken into account in this study. Xi et al (*10*) addressed the planning problem using a simulation model that maximised re-charging station service rates. This model was then applied to a case study in the mid-Ohio region. The input data of this model, collected from vehicle usage data in 2010, was quite extensive. The analysis was done for maximising the amount of energy served and for maximising the number of PEVs serviced. However, the PEV flows on links were determined by assigning a PEV adoption probability to current vehicle owners. The candidate locations for re-charging stations were determined to be locations where users stay for extended period of time, such as shopping centres, work places and universities.

Worley et al (*14*) proposed an algorithm to find the optimal location for refuelling stations and the optimal set of routes for vehicles using an integer programming model to solve the refuelling problem and the routing problem together. However the problem uses the classic vehicle routing problem instead of travel assignment. Hess et al (*12*) evaluated the optimal locations for re-charging stations in a real network using a genetic algorithm. They demonstrated this approach on the city centre network of Vienna, using the Krauss car following model for simulation. To reflect the range constraint of PEVs, additional decision logic was added in the Krauss model. This triggers the users' decisions to look for the closest re-charging station when their battery charge levels are low. The average trip time of electric vehicles, given by the sum of travel time and the re-charging time spent was minimised by the aforementioned algorithm in this case study.

Chen et al (*15*) conducted a case study to identify optimal re-charging station locations with the objective of minimising the total system travel time for potential PEVs in the Seattle region for the Seattle region. The PEV demand was assumed to be proportional to the current demand of light-duty vehicles, which was obtained from a household travel survey. The effect of land use attributes, parking durations and trip characteristics was also taken into account. Hanabusa and Horiguchi addressed a similar problem using a traffic assignment model. Hanabusa and Horiguchi (*16*) developed an analytical method to identify optimal re-charging station locations using a stochastic user equilibrium assignment model. The objective was to minimize travel time of each PEV, including the waiting time spent in re-charging stations. An additional criterion was that the level of service for each re-charging station was also to be balanced. The range constraint imposed on PEVs was accounted for by applying an extra penalty cost on the link travel time.

In this paper we address a similar problem, to locate PEV re-charging stations such that the total system travel time is minimized. The novelty of this work lies in the novel routing algorithm proposed by Jiang et al (*1*) which is implemented within the equilibrium assignment model to address the distance constraint. In this paper the re-charging stations locations are pre-specified rather than optimized. The total system travel time savings achievable based on the selected location is quantified. The evaluation framework is valuable for ranking various re-charging station infrastructure design alternatives.

3. PROBLEM DEFINITION

The proposed model relies on the assumption that installing a re-charging station in a transport network will impact PEV driver’s route choice, thus altering the link flows, and hence the performance of a network. A potential improvement in network performance exists because the availability of re-charging stations allows PEV users the opportunity to re-charge their batteries en-route, thus increasing the set of feasible travel routes available to them. The model requires re-charging station locations to be specified at certain nodes a priori. Given the set of known re-charging stations, equilibrium link flows are quantified using Jiang et al's (*1*) distance constrained equilibrium model. The model output includes average link travel times and link travel volumes. The performance measure used in this study is the total system travel time (TSTT), which is the sum of the travel time experienced by all users in the network to travel between their respective origin and destination. The link cost function defines the relationship between the number of users travelling on a particular link and the cost to travel that particular link (cost can be travel time, money, etc). While any link cost function can be substituted, a common link-cost function used in transportation literature and practice is the Bureau of Public Records (BPR) formulation (*17*), and is the function used in this paper for demonstration purposes. The BPR function is defined below:

$$t_a = t_f(1 + \alpha \left(\frac{v}{C}\right)^{\beta})$$

where *t* is link travel time, t_f is free-flow travel time, *v* is hourly volume, *C* is hourly capacity, and α and β are parameters that depend on link geometry. It is assumed that $\alpha = 0.15$ and $\beta = 4$ for the analyses in this paper.

The impact of re-charging station location on network performance is demonstrated through a selection of infrastructure design scenarios varying in number and location of re-charging stations. An evaluation of the network performance under each design scenario reveals the potential network performance improvement achievable. Sensitivity analysis is also conducted to evaluate the impact of varying speed and travel demand on the system performance.

4. NUMERICAL RESULTS

To motivate the use of constrained assignment models when planning for public re-charging infrastructure we begin with a simple network, similar to the Braess's Paradox network (*18*). This network serves to demonstrate the potential benefit that can be achieved by installing a re-charging station in a network, while capturing travel behaviour which results from the imposed distance constraint. The model was coded in C++.

4.1 Demonstration

The 4-link demonstration network is shown in Figure 1. The capacity is equal to 4000 veh/hr on all links, and the link free flow speed and link lengths are noted in the figure. In this simplified demonstration we assume all vehicles are PEVs, and the potential improvement in system performance achievable by installing a re-charging station at node 2 is quantified.

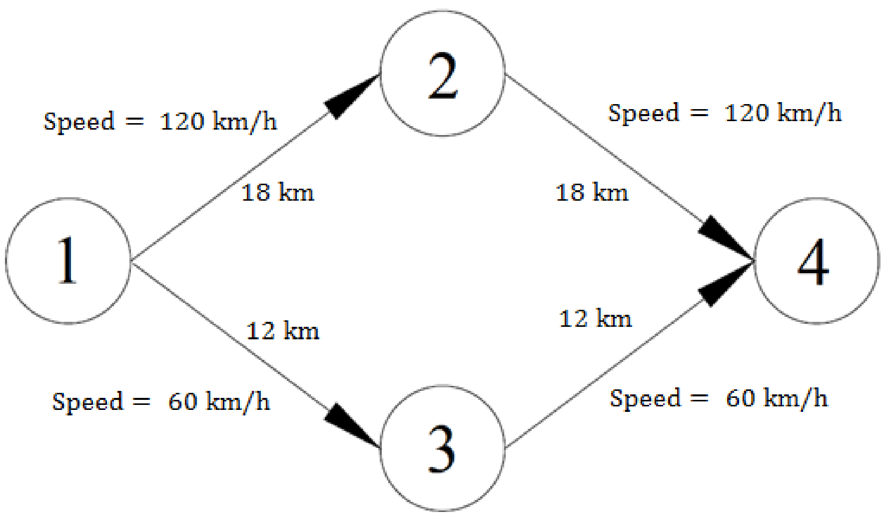

FIGURE 1 Demonstration network with link lengths and free flow speeds

Path 1-2-4 represents a highway option with a longer distance, but higher free flow speeds. However, when there is no re-charging station in the network, the path 1-2-4 exceeds the range of the PEVs so no one selects it, and therefore all 4000 PEV drivers must take path 1-3-4. In this case the resulting travel time for any individual driver is 27.6 mins. The total system travel time (TSTT) is 1840 veh-hrs. Now, if a re-charging station is installed at node 2, the path 1-2-4 can be utilised because PEVs can recharge at node 2. Because of the higher free flow speed, at equilibrium all 4000 PEV drivers will switch to path 1-2-4. The individual travel time is now 20.7 min, and TSTT = 1380 veh-hrs, representing a TSTT savings of 25%. This example highlights the ability of re-charging stations to offer alternative routes to PEVs, which may have reduced travel times, and can therefore improve the total system performance.

Intuitively, additional route options would either improve performance because a faster route is made available, or have no impact because the additional routes are longer and no one chooses them in which case the travel pattern would be unchanged. However, a paradox exists when there is a mix of PEVs and traditional ICEVs. For example, assume only 20% of the demand are PEV drivers and the rest drive ICEVs. When no re-charging station exists the resulting network flows are as illustrated in Figure 2. The 3200 ICEVs can use path 1-2-4 because they do not have a range limit and the 800 PEVs must use path 1-3-4 because it is within the allowable distance limit. The total system travel time is 80344 mins.

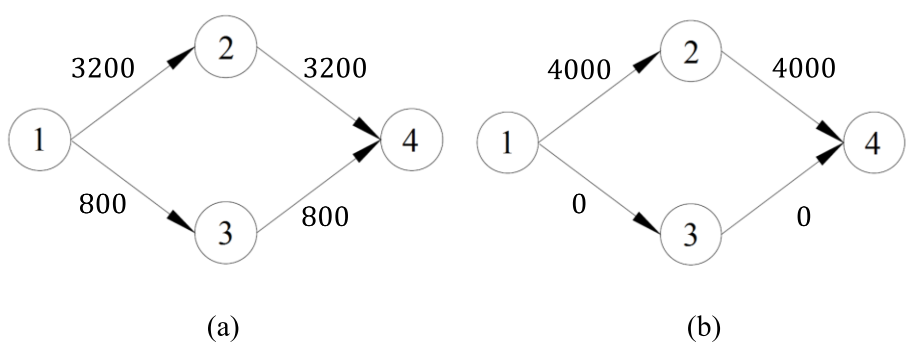

FIGURE 2 Paradox Demonstration: (a) Link flows before the CS is built and (b) after the CS is built at node 2

If a re-charging station is installed at node 2, the PEV users now have the option of using path 1-2-4. In order to minimize individual travel times all vehicles will use path 1-2-4 because it is shorter, resulting in a TSTT of 82800 mins. In this example the TSTT after the re-charging station is installed increases, making the system worse off. This is somewhat counter intuitive, as the re-charging station provided PEV users with an alternative path, and the ability to travel to their destination faster. This example further motivates the need for assignment models which are capable of capturing the complex behaviour of travellers, specifically when they are subject to additional constraints imposed by new vehicle technologies.

Furthermore, the travel patterns are dependent on the network structure and link properties (as is the case for traditional equilibrium assignment models), in addition to the location of the re-charging station. Therefore the benefit achievable from installing a re-charging station is highly sensitive to the network parameters (e.g. free flow speed). To demonstrate this, the speed of links (1,2) and (2,4) are varied to explore the sensitivity of network system performance to link speeds, with and without a re-charging station installed at node 2. When the speed on path 1-2-4 is varied the TSTT saving from installing a re-charging station at node 2 can change drastically. Results are illustrated in Table 2.

TABLE 2 Speed on path 1-2-4 and corresponding TSTT saving when re-charging station is installed at node 2

Speed on path 1-2-4 (km/h)	*% TSTT saving with CS installed compared to base case*	*Flow on path 1-2-4*	*Flow on path 1-3-4*	*Cost of path 1-2-4*	*Cost of path 1-3-4*
80	2.17	178	3822	27	27
90	12.23	2000	2000	24.2	24.2
100	13.04	3710	289	24	24

The speed of path 1-2-4 is increased at a constant increment of 10 km/h. The number of drivers that switch paths following every speed increment is nearly constant. The TSTT saving increase 10% when the speed is increased from 80 km/h to 90 km/h, but increase less than 1% when speed is increased from 90 km/h to 100 km/h. This behaviour results from the convexity of the BPR cost function; when the speed increases from 80 km/h to 90 km/h some users switch from path 1-3-4 to path 1-2-4 resulting in a minor increase in the congestion on path 1-2-4 and a significantly reduced travel time for path 1-3-4. On the other hand, when the speed is increased further from 90 km/h to 100 km/h, almost the same number of users switch to path 1-2-4.

However the congestion on path 1-2-4 significantly increases, while further reduction in travel time for path 1-3-4 is minimal. Thus, the specific network properties, such as free flow speed, can significantly impact the resulting network performance under various infrastructure designs.

An additional sensitivity analysis was conducted to explore how TSTT savings brought by a re-charging station varied with the percentage of PEV users in the network. The results are presented in Figure 3. The horizontal axis represents an increasing percentage of PEV drivers, and the vertical axis represents the percentage decrease in TSTT as compared to the base case when there are no PEV drivers in the network. The results demonstrate the importance of considering various future PEV uptake scenarios (different proportional mixes of PEVs and ICEVs) when designing re-charging infrastructure, as the benefits of building a re-charging station at a given location can vary drastically.

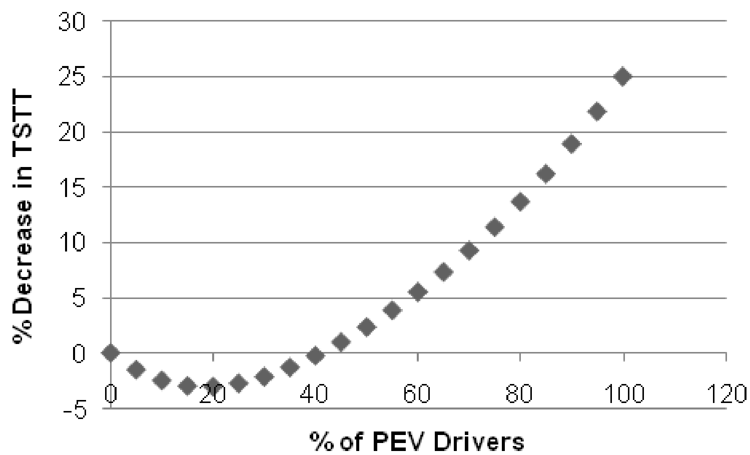

FIGURE 3 Improvement in TSTT versus PEV penetration level

Figure 3 shows that when the vehicle fleet is more than 40% PEVs, building a re-charging station results in positive TSTT savings, and is maximized when all vehicles are PEVs. On the other hand, as the number of PEV users decreases below 40% a re-charging station will result in a decrease in network performance. More specifically, for this example at least 1644 PEV users are required for a re-charging station to provide any system performance improvement.

While these results are based on a very basic network, they illustrate the complex relationship between a new vehicle technology which imposes constraints on the drivers, their corresponding travel behaviour and the potential system benefit (or costs) of installing re-charging station at given locations. More importantly, the impact on the system may be unintuitive; therefore traffic assignment models such as that proposed by Jiang et al. (*1*) are necessary to explicitly evaluate potential design scenarios. The proposed model also has the ability to quantify the penetration level of PEVs necessary for a given infrastructure design scenario to be of value, and similarly, quantify the system improvement possible under a given PEV penetration level.

4.2 Example grid network

The impact of re-charging infrastructure location is further explored on a medium size network with multiple origin-destination pairs and travel paths. The example network is based on the Nguyen-Dupuis (*19*) network and is illustrated in Figure 4. The specific link properties are provided in the Appendix. We assume all vehicles are PEVs, and the potential improvement in system performance achievable by installing a re-charging station at various locations is quantified. Analysis on this medium sized network reveals the computational challenge posed by the re-charging location problem; the number of combinations of location alternatives increases exponentially with the number of charging stations. Furthermore, each alternative design scenario requires an equilibrium assignment model to be implemented for analysis. Therefore, this example also serves to motivate the development of an optimal re-charging station location heuristic.

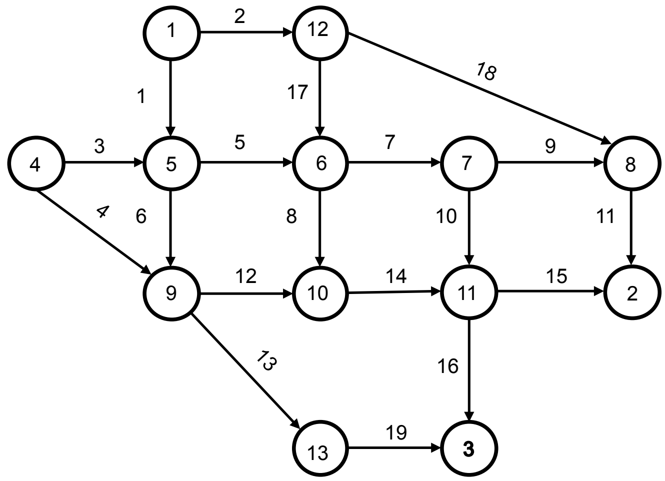

FIGURE 4 The Nguyen-Dupuis network

Similar to the demonstration network, re-charging infrastructure location is shown to have a substantial impact on system performance. The relative improvement in system performance is defined as the TSTT savings (%) when compared with the base case where no re-charging station is installed. In all design scenarios at least one re-charging station is installed in the network. First, the TSTT savings are computed when a single re-charging station is installed. The results are shown in Table 3 for a subset of the nodes, and ordered from highest to lowest. The results illustrate the achievable network TSTT savings can vary significantly dependent on the location where the re-charging station is installed.

TABLE 3 location of re-charging stations and corresponding TSTT saving

CS Location (node)	TSTT (min)	TSTT saving (%)
N/A	110672	N/A
6	97311.4	12.07
7	97323	12.06
11	97508.6	11.89
5	97943.7	11.50
12	98989	10.56
8	101223	8.54
9	109976	0.63
13	109976	0.63
10	110670	0.00

In order for a newly installed re-charging station to reduce the TSTT it must provide alternative route options for PEVs which offer travel time savings to the users, thus providing network wide savings. This is accomplished with the installation at node 6 which is shown to reduce the TSTT by 12%. However installing a re-charging station at node 10 does not improve the performance relative to the base case. This is because node 10 already lies on a highly congested path. While the addition of a re-charging station at node 10 provides new path options to PEV users, re-routing through node 10 would only increase the congestion on the links around the node, increase travel time for all individuals. Therefore users do not choose to re-route, and the travel patterns remain unchanged relative to the base case.

The impact of installing more than one re-charging stations is also addressed. Intuitively two re-charging stations might be expected to provide greater network savings compared with a single re-charging station, though this is not always the case. We evaluated network performance under all possible combinations of installing two re-charging stations, which results in 105 scenarios. The range of TSTT savings ranged from 0% to 12.2%, which is similar to the range from installing a single re-charging station. Therefore installing an additional re-charging station is not guaranteed to provide any further improvement in network performance. Furthermore, in many cases optimally locating one new re-charging station can provide higher TSTT savings than installing two new stations. For example, if two re-charging stations are installed at nodes 9 and 10, only minor TSTT savings are achieved (i.e. less than 1%). In contrast, by installing two re-charging stations at nodes 10 and 8, TSTT savings of 8% are achieved. However, this is still less improvement gained by installing a single re-charging station at node 6 or 7. These results support the need for assignment models capable of capturing PEV user route choice behaviour, such as those implemented in this analysis, when comparing re-charging infrastructure design alternatives.

Impact of Demand Variability

Finally, the impact of re-charging station location under demand uncertainty is briefly explored. Three demand scenarios are evaluated: (i) realized demand is equal to the expected demand, (ii) realized demand is equal 80% of the expected demand, (ii) realized demand is equal 120% of the expected demand. The TSTT savings under different combinations of future demand scenarios and the installation of a single re-charging station location are presented in Table 4.

TABLE 4 Percentage Reduction of TSTT under deflated and inflated demand

CS Location	Deflated Demand	Expected Demand	Inflated Demand
6	6.03	12.07	16.27
7	6.04	12.06	16.21
11	6.10	11.89	15.96
5	6.03	11.50	14.92
12	5.02	10.56	13.33
8	4.13	8.54	11.34
9	-0.02	0.63	1.92
13	-0.02	0.63	1.92
10	-0.07	0.00	0.02

From Table 4 it is apparent that the achievable TSTT saving can vary significantly dependent on the realized demand. Furthermore, the optimal re-charging station location varies based on the realized demand. For example, node 6 is the optimal location for a single re-charging station under the expected and inflated demand, while node 11 is optimal for a smaller realized demand. This analysis reveals an additional challenge in planning future re-charging infrastructure; an optimal plan based on an expected demand may not be optimal under the actual realized demand in the future. Because future demand in inherently uncertain, it is important to identify re-charging infrastructure design alternatives which will be robust to future changes in demand.

5. CONCLUSION

This work investigates the impact of PEV re-charging infrastructure location alternatives on transport system performance. The evaluation framework presented can be used for planning purposes, specifically to rank design decisions regarding installation of public re-charging infrastructure. A novel user equilibrium based assignment model which accounts for the distance constraint imposed on PEV users was implemented to capture the travel patterns under different re-charging scenarios and quantify system performance.

The benefit of optimally locating a re-charging station was first illustrated using a demonstration network. The demonstration also provided insight into the potentially unintuitive and complex nature of the problem. The impact of re-charging station location choice was further evaluated using a medium sized network. The range of achievable savings was quantified. Results from the analysis point to the following observations:

i. Installing re-charging stations in a network can provide alternative paths for PEV users, potentially reducing the total travel time for all users.
ii. The number of re-charging stations and corresponding locations chosen can have a significant impact on the network performance.
iii. Installing re-charging stations may have a counter-intuitive impact on network performance; some design alternatives may not provide any benefit to the network, and optimally installing a single re-charging station may be able to provide more system savings than installing multiple re-charging stations
iv. The performance of a given re-charging station location is dependent on network properties and parameters such as link speed, realized travel demand and PEV penetration levels.

The analysis presented in this paper reveals the exponential nature of the problem. Therefore future research efforts will explore various heuristic solution methods which can identify optimal re-charging station locations in large networks. Future models can also consider a more realistic proxy for the distance constraint of PEV drivers, such as energy consumption, that is reflective of driving behaviour and network conditions. Finally, factors such as time spent re-charging may also play a role in user route choice, and should be integrated into the distance constrained network equilibrium assignment model implemented in this paper.

Acknowledgments

NICTA is funded by the Australian Department of Communications and the Australian Research Council through the ICT Centre of Excellence program.

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APPENDIX: NGUYEN-DUPUIS NETWORK CHARACTERISTICS

Table: **Origin-Destination Demand**

OD Demand		Destination	
		2	3
Origin	1	1300	1840
	4	1680	1450
Total Demand		6270	

Table: Network Parameters

Link no.	Start node	End node	Length(km)	α	β	Capacity	Speed(km/h)
1	1	5	2	0.15	4	800	60
2	1	12	3	0.15	4	800	60
3	4	5	3	0.15	4	800	60
4	4	9	4	0.15	4	800	60
5	5	6	4	0.15	4	800	60
6	5	9	7	0.15	4	800	60
7	6	7	7	0.15	4	800	60
8	6	10	5	0.15	4	800	60
9	7	8	15	0.15	4	1500	120
10	7	11	16	0.15	4	1500	120
11	8	2	5	0.15	4	800	60
12	9	10	5	0.15	4	800	60
13	9	13	10	0.15	4	800	60
14	10	11	13	0.15	4	1400	60
15	11	2	4	0.15	4	800	60
16	11	3	3	0.15	4	800	60
17	12	6	3	0.15	4	800	60
18	12	8	20	0.15	4	800	60
19	13	3	14	0.15	4	800	60