Design and Implementation of a Demand Responsive Mobility as a Service

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Abstract

Low population areas and low income people often face unreliable public transport characterized by long waiting times. Meanwhile, a private vehicle in the same area, on average, will remain inactive for long periods of time. Recent research in shared mobility systems addresses this situation. Specifically, Demand Responsive Transport, DRT, a transport alternative between a bus and taxi, and which has many specification variations, has pioneered provision of an alternative transport solution geared to reach under-served minorities. Solutions to DRT trip scheduling and costing mechanisms usually include constraints specific to the variation of DRT specifications.

We aim to maximize use of a vehicle and we propose a design of a DRT-based Demand Responsive Mobility as a Service, DRMaaS, model that provides centralized management and ICT support in in delivering multiple services in a vehicle. Our design adds time constraints of vehicle schedule to the DRT problem. We also consider cost sharing mechanism.

We focus on reducing waiting time and propose a trip scheduling and cost sharing algorithm. We base our approach on a DRT heuristic algorithm. We also consider time windows. We propose a new cost sharing mechanism, based on traditional distance costing techniques but considering, seat capacity, an approach unique to the specifications of our design.

A simulation experiment validating the algorithm showed a decreased waiting time, at 2 minutes, from previous research, 14.4 minutes. We developed a web and android application, running the algorithm, to test the solution in a pilot study in Dhaka, Bangladesh for 4 months. Actual waiting time was estimated at 3 minutes, an improvement from previous DRT heuristic algorithms.

Keywords: Shared Mobility, Demand Responsive Transport, Mobility as a Service

1. Introduction

Most cities all over the world are serviced by a system of public transport that includes train, bus and taxis [1]. Present public bus services in developing countries are, however, inefficient, unproductive, and unsafe characterised by long waiting time, delay on plying routes, long boarding time, overloading, discomfort and long walking distance from the residence/work place to bus stop [2][3][4]. For instance, buses in Dhaka, Bangladesh are mostly over-crowded, which is often not accessible for the elderly or disabled people as well as being unsafe for women due to eve-teasing. Moreover, the frequency of bus service (headway) is quite low. A research carried out in Dhaka city found that most of the city residents are satisfied with the cost of travel but very unsatisfied with the waiting time as they have to wait for the bus sometimes up to an hour [5]. Other transport alternatives like taxi, motorised vehicles and rickshaws are unaffordable for the average user especially as a frequent transport alternative.

The cost of a car is prohibitive for many living below the poverty line. In fact, in most developing countries, car ownership is considered a luxury many cannot afford. However, the benefits of a car cuts across all economic and social status. The need to move from one point to another for economic gain, health care, education or even personal reasons is valid for all, rich or poor. While those at the top of the pyramid can easily access these social services given their economic status, the people at the bottom of the pyramid (BoP, people with low purchase power), have distance and economic power limitations in accessing the social services [6].

Given the recent growth of the shared economy, potential exists to accelerate shared mobility strategies that address the specific mobility issues of low-income communities [7]. Historically, public transit, land use policy and planning have often resulted in significant mobility obstacles for low-income people in cities. Indeed, low-income communities typically face longer commute times and higher fares than their middle and upper income counterparts.

An alternative approach to the public transport deficit is to focus on the causes of mobility[8] and reduce the frequency of transit. The primary need for mobility is to access social services like healthcare, education and commercial gain. Addressing this, a scheduled community car based on a Demand Responsive Transportation (DRT) model can fulfil this need by bringing the services to the low-income people [7]. Demand Responsive Transport (DRT) is a form of transport between bus and taxi services involving flexible routing and scheduling vehicles by incorporating transport requests from customers. Several DRT scheduling, dispatching and routing approaches have been researched, however, there has not been enough discussions in the area of multiservice DRT approach.

Posing a hypothesis that a demand responsive transport based solution would provide quality transport (in time and comfort) at an afforbable cost, we designed a multiservice community car model, Demand Responsive Mobility as a Service (DRMaaS) that provides centralized management and background ICT support of the vehicle operations and services. We called this concept Social Services on Wheels. The Social Service on Wheels (SSW) concept was designed by Kyushu University in collaboration with Grameen Communications to bring ICT based services to unreached communities. SSW is managed by DRMaaS. Users send their transit and service requests to the system managed in the central office in the back end. These requests are met by a vehicle being sent to offer the transport or service requested. Software Services on Wheels (SSW) delivers services and provides transportation to passengers in the front end. SSW, the DRMaaS, front-end community service, comprises a vehicle, service delivery point, personnel and an array of smart devices. The service delivery at the front-end is both schedule based and demand based, targeting different users in urban and rural settings. Scheduled services targets office workers and college students and healthcare delivery.

We investigate how to make our DRMaaS approach more efficient and focus on trip and cost scheduling. The solution should provide transport alternative between bus and taxi based on introduced time constraints of vehicle prior schedule and a cost constraint that considers a quorum, minimum number of passengers for the service to be offered.

2. Demand Responsive Transportation

Demand Responsive Transportation are a new-generation means of transportation that conforms to the wishes of its riders [16]. Fixed-route buses travel along a fixed route according to a time schedule, stopping at each designated bus stop. Because the system is easy to understand, passengers have little trouble using the system. On the other hand, the fixed-route bus has many disadvantages. For example, because the operate according to a fixed time schedule, it is not possible to simply get on at a time of your convenience. For example, practically anyone has had experiences like "I had to wait at the bus stop for ten minutes" or "There's no really good bus for me to get to that meeting. And there is the fact that quite frequently, the bus will run its designated route at designated times even though there are no passengers. This is certainly not good for the environment, and means that there is quite a lot of waste in operating the bus system.

Demand Responsive Transportation is a relatively new concept that resolves that combines flexibility of taxi services with low cost nature of bus services (figure 1). Demand Responsive Transportation operate in a way that meets the demand of its riders, picking them up at the times and places they request. Demand Responsive Transportation services have another special characteristic; ride-sharing. Ride sharing is when passengers who are travelling along similar routes share the same vehicle. Taxis can take a maximum of four passengers from an origin to a destination. But because Demand Responsive Transportation has the ride-share function, they can deviate from their route slightly and pick up additional passengers. This is one aspect that differentiates them from taxis. Demand Responsive Transportation can help buffer metropolitan areas from traffic congestion.

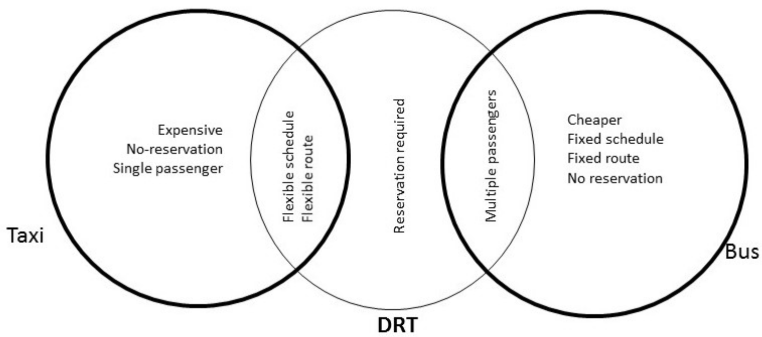

Figure 1: Distinguishing Demand Responsive Transport from taxi and bus service

DRT models distinguish from traditional shared mobility services in that they incorporate flexible routing, flexible scheduling, or both. These services operate much like jitneys of the past but are enhanced with information technology [15]. Existing microtransit operators target commuters, primarily connecting residential areas with downtown job centers. Microtransits use of smartphone technology avoids traditional and costly methods of booking rides, such as call centers or even booking websites. The use of advanced technology has the potential to lower operating costs for services that target special populations, such as disabled, older adults, and low-income groups. Table 1 distinguishes some shared mobility services.

Table 1: Demand Responsive MaaS compared to existing public transport

	Car Sharing	Ride sourcing (private)	Ride sharing (public)	DRT	Taxi	Bus
Vehicle Ownership	company owned	privately owned	company fleet	company fleet	company fleet	company fleet
(Min) No. of Reservations	1	1	set minimum	1	1	0
(Max) No. of Reservations	1	capacity	capacity	capacity	1	capacity
Reservation	required	required	not required	required	not required	not required
Schedule	irregular	irregular	irregular	irregular	irregular	regular
Routes	-	fixed	fixed	fixed/ flexible	flexible	fixed
Charge	very high	high	low	average	very high	low
Charges based on	time	distance	distance	undefined	distance	distance (zones)
Control of usage	user	user	operator	user (limited)	user	operator
Driver	user	operator	professional	professional	professional	professional
Comfortability	very high	high	low	average	high	low

2.1. The DRT Problem: Effectiveness of Demand Responsive Transport

Initial approach to DRT was telematics based, users would call an operator who would manually check vehicle availablity, assign a passenger to a suitable vehicle trip and inform the driver on the trip information. Since then, advancements in use of internet technologies have automated most of the DRT operations as discussed in the previous section. The automation problem having been solved to some extent, the DRT problem is now how to make the system more effective in time and cost. Lots of literature has been covered in approaches in scheduling DRT using, time windows, agent-based solutions, genetic algorithms, exact and searching algorithms including heusristic algorithms. Cost effectiveness for DRT, however, has not been extensively researched as DRT solutions are usually heavily subsidized.

2.1.1. Trip Scheduling Approaches

Guidelines for computational experiments to test heuristic methods have been identified in [21]. To evaluate the capacity and optimum service 3 time interval of a demand responsive transit feeder service [22] used three step local search algorithm for the vehicle routing problem with a heterogeneous fleet of vehicles and soft time windows. In [23] an insertion heuristic for scheduling Mobility Allowance Shuttle Transit (MAST) services was developed. In their work a MAST system is characterized by the flexibility to allow vehicles to deviate from the fixed path in order to serve customers within a service area. A set of simulations are performed. The results show that the insertion heuristic approach developed could be

used as an effective method to automate scheduling of Demand Responsive Transport. The impact of complicating constraints on the efficiency of insertion heuristics for the standard vehicle routing problem have been discussed in [24]. The complicating constraints identified were significant as they affect the feasibility and the efficiency of the schedule. The constraints considered were the time windows, shift time limits, variable delivery quantities, fixed and variable delivery times, and multiple routes per vehicle.
Jaws et.al [25], described a heuristic algorithm for a time constrained version of the many-to-many Dial-A-Ride Problem (DART). The algorithm described as the Advanced Dial-a-Ride Problem with Time Windows with service quality constraints, identifies feasible insertions of customers into vehicle work-schedules. An incremental cost of each insertion is evaluated through an objective function. The cost is the weighted sum of disutility to the customers and of the operating costs. The solutions provided did not have any optimal solutions to compare with as no exact algorithms existed to solve problems of similar size. In [26], authors analyze heuristic algorithms for the single vehicle many-to-many dial-a-ride problem (DARP), i.e. designing a route for a vehicle carrying customers between specified pick-up and delivery points to minimize the total travel distance.
Approaches to real time demand responsive transport have been researched based on time constraint. The concept of estimating bus passenger waiting times from incomplete bus arrivals data has been explored in [27] whereas the impact of real-time bus arrival information using the passenger wait time perceptions at bus stops has been evaluated in [28]. In [29], authors performed the travel time studies by using global positioning system (GPS) and geographic information system (GIS) technologies.
Concerning travel time schedules, the ability to select certain occupations in specific industries is relative to the ability to select work schedules [30]. Some jobs that need to start during off-peak hours might indirectly prevent employment of those who cannot reach the employment locations at that time. Demand-responsive services are most likely to receive the highest ranking among all flexible transport services. The commuting patterns of newly built towns are discussed intensively [31] . Research has found that the proportion of people working or studying in urban area is proportional to the age of the new town. Moreover, cross-district commuting to work is more prevalent than to school. Comparison of weekend and weekday activity patterns found that the weekend travel patterns are quite different from weekday travel patterns in many aspects such as time of day, mode, and the total volume [32].

2.1.2. Cost Sharing Approaches

Demand responsive transit (DRT) systems provide flexible transportation services where individual passengers request door-to-door rides by specifying desired pick-up and dropoff locations and times. Multiple shuttles (or vans or small busses) service these requests in shared-ride mode without fixed routes and schedules. DRT services are more flexible and convenient for passengers than busses since they do not operate on fixed routes and schedules, yet cheaper than taxis due to the higher utilization of transportation capacity.
The DRT (cost-sharing) problem has been neglected in literature, which might be due to DRT providers being highly subsidized and most passengers thus enjoying transportation

services at affordable fares, typically determined by flat rates within service zones that do not cover the operating cost. Without subsidies, the fares would substantially increase and passengers would then be more concerned about how the operating cost is shared among them in a fair manner.

Trip scheduling and cost-sharing problems are highly interrelated since the routes and schedules of the shuttles determine the operating cost that needs to be shared, while the cost-sharing mechanism imposes constraints on the routes and schedules that need to be optimized because the fares of passengers should not exceed the fare quotes. How passengers should share the operating cost is a trivial problem for the following reasons: Passengers do not arrive (that is, submit their ride requests) at the same time but should be provided with incentives to arrive as early as possible since, this way, the DRT systems have more time to prepare and might also be able to offer subsequent passengers lower fares due to synergies with the early ride requests, which might allow them to service more passengers [33]. Passengers have different pick-up and drop-off locations and times and thus cause different amounts of inconvenience to the other passengers, which should be reflected in the fares. Passengers should be quoted fares immediately after their arrival because, this way, they have no uncertainty about whether they can be serviced or how high their fares will be at most and the DRT systems reduce their uncertainty about passengers dropping out and can thus prepare better. This requires DRT systems to make instantaneous and irreversible decisions despite having no knowledge of future arrivals [34].

Cost-sharing literature in general is substantial, though solutions specific to DRT systems have not been extensively researched. Cost sharing for DRT systems has to cope with an on-line setting (due to sequentially arriving passengers) and non-decreasing marginal costs, different from the assumptions typically made in the cost-sharing literature [35]. The operating costs of DRT systems also depend on the ride requests, different from the assumptions made in the context of recent online versions of cake-cutting [37] and resource-allocation[36] which do not take positive and negative synergies between ride requests into account.

Proportional Online Cost Sharing (POCS) provides passengers with upper bounds on their fares immediately after their arrival, allowing the passengers to accept or decline. Thus, passengers have no uncertainty about whether they can be serviced or how high their fares will be at most, while the DRT systems reduce their uncertainty about passengers dropping out and can thus prepare better. Yet, they still retain some flexibility to optimize the routes and schedules after future arrivals. The sum of the fares of all passengers always equals the operating cost. Thus, no profit is made and no subsidies are required. POCS provides incentives for passengers to arrive truthfully since the fares of passengers per mile of requested travel are never higher than those of passengers who arrive after them. Thus, the DRT systems have more time to prepare and might also be able to offer subsequent passengers lower fares due to synergies with the early ride requests, which might allow them to service more passengers. Passengers also have incentives to arrive truthfully since the likelihood of transportation capacity being available tends to decrease over time, which alleviates the issue that the best strategy of every passenger is to arrive truthfully only under assumptions that are only approximately satisfied by POCS [38].

Overall, POCS is a very first step toward addressing some of the problems raised by missing knowledge of future arrivals. However, lots of issues remain to be addressed by more advanced online cost-sharing mechanisms, including integrating more complex models of passengers, shuttles and transit environments. Our current simplifying assumptions include, for example, that the availability of shuttles does not change unexpectedly, that all passengers arrive before the shuttles start to service passengers, that fares depend only on the ride requests and no other considerations (for example, that DRT systems do not face competition), that all passengers evaluate their trips uniformly according to the criteria quantified by the alpha values (for example, that all passengers consider travel time to be equally important), that DRT systems provide fare quotes to passengers without predicting future arrivals (for example, that DRT systems do not reject hard-to-accommodate passengers even though they increase the shared costs of subsequent passengers and might make subsequent passengers drop out), that passengers try to decrease their fares only by delaying their arrival (rather than, for example, by colluding with other passengers or entering fake ride requests under false names) and that passengers honor their commitments (for example, that passengers do not change ride requests, cancel them, show up late or do not show up at all).

3. Social Services on Wheels

The Social Services of Wheels (SSW) concept was designed by Kyushu University and Grameen Communications Global Communication Center (GCC) to provide safe mobility and reliable access to basic social service for low-income subjects in unreached communities [50][51]. It consists of back-end of data servers and a front-end community service comprising a vehicle, service delivery point, and an array of smart devices. The front-end smart devices communicate with the back-end using mobile network coverage and Internet. The SSW back-end comprises GCC GramWeb software applications and database. The GCC GramCar software schedules various services and GramHealth software processes medical records such as patient Electronic Health Records (EHR) and ePrescriptions. Registered SSW clients and service records are stored in the Gram database. The SSW front-end consists of a vehicle, service delivery points, and smart devices used to access and attain social services. The vehicle is a minibus (Toyota Hiace) and provides scheduled transport to female college students. A service delivery point is the physical environment where SSW team interacts with its rural clientele and provides four services: portable health clinic, blood grouping, online IT service and training, and purchasing opportunities (ecommerce and product delivery). The smart devices include: medical sensors used in the Portable Health Clinic briefcase, blood grouping devices, tablets for IT services, and price catalogue for online purchasing. The SSW operation model is based on a Village Car Entrepreneur (VCE) who manages a small team (driver, healthcare worker and IT assistant) and ensures that services are delivered at specific points within an agreed timetable. Service delivery is dependent on the vehicle daily and weekly schedule. On a daily basis, the vehicle picks up female students from predefined collection points and drops them at the college. It then picks up the medical experts, ICT experts and social goods providers from nearby urban centers and drops them at a service point (a small room or desk). On a weekly basis, the vehicle visits six mobile service points in six different days a week; hence the community gets access to the social services once a week near their doorsteps.

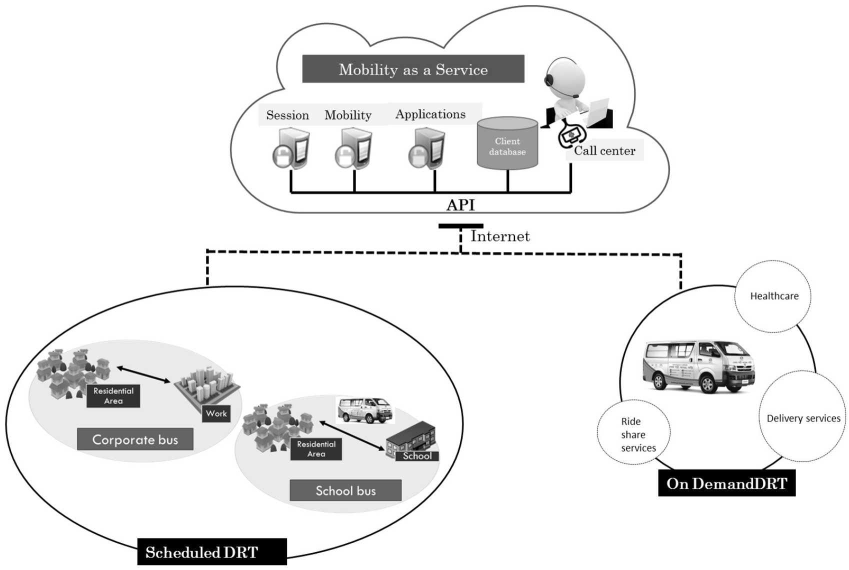

Figure 2: Demand Responsive Mobility as a Service

A centralized back-end data cloud can manage multiple instances of the front-end smart community service. The front-end includes a college bus service, health clinic, blood grouping testing, online learning, and online shopping managed by back-end servers. The level of technologies and the villagers experience with the ICT applications is different for each service (figure 2). Access to education A college bus service provides access to education. The bus service is offered to female students to counteract the eve teasing and violence. The passenger signs up for the service online and checks the vehicle time schedule and any adjustments to the schedule online. The bus service will collect the female students from pre-determined pick up points and ferry them to their college.

The Portable Health Clinic (PHC) provides access to healthcare. A healthcare worker registers all patients and uses PHC medical sensors and a portable server to ascertain the level of morbidity (poor health). Based on a triage stratification algorithm, patients identified to be at risk are connected to an online doctor for a remote health consultancy. The patient online doctor consultancy involves the standard medical procedure with diagnosis and issuance of ePrescription. These Electronic Health Records are stored in the database and can be referred to in the future [52].

Wi-Fi tablets connected to the Internet provides access to learning. An ICT trainer gives instructions to villagers on how to use the Internet to search for information relevant to their lifestyles; such as agriculture information on which pesticides to use and when to plant and harvest their crops. It is intended to give certified online entrepreneurship training in the future.

A catalogue provides access to online purchasing opportunities. To overcome any illiteracy issue, a catalogue with pictures and prices are shown to the villagers. The customer selects which items he or she wishes to purchase and the driver makes the order online on the customers behalf. The ordered products are delivered to the service point one week later by the SSW vehicle.

Whilst waiting at the Service Point, the SSW vehicle and driver are available for realtime DRT resquests. To request the service, the customer needs to make an on-line booking. The customer is also notified of the cost and time limits online and confirms to accept the conditions. Over experiment period, on demand vehicle hire has been used to take patients to hospital and for wedding and social events.

3.1. Demand Responsive Mobility as a Service

To achieve the hybrid multiservice objective, the vehicle does a school and corporate office run in the morning as a scheduled service [53]. It also delivers healthcare service at a predetermined location based on user requests. During the idle time, the vehicle provides transportation on demand. Meaning that the vehicle will only operate at this time if there are passenger requests, figure 3. Users pre-register for the scheduled services in advance. A ride (seat) is assigned to each new request as it arrives for both scheduled and on demand ride sharing options.

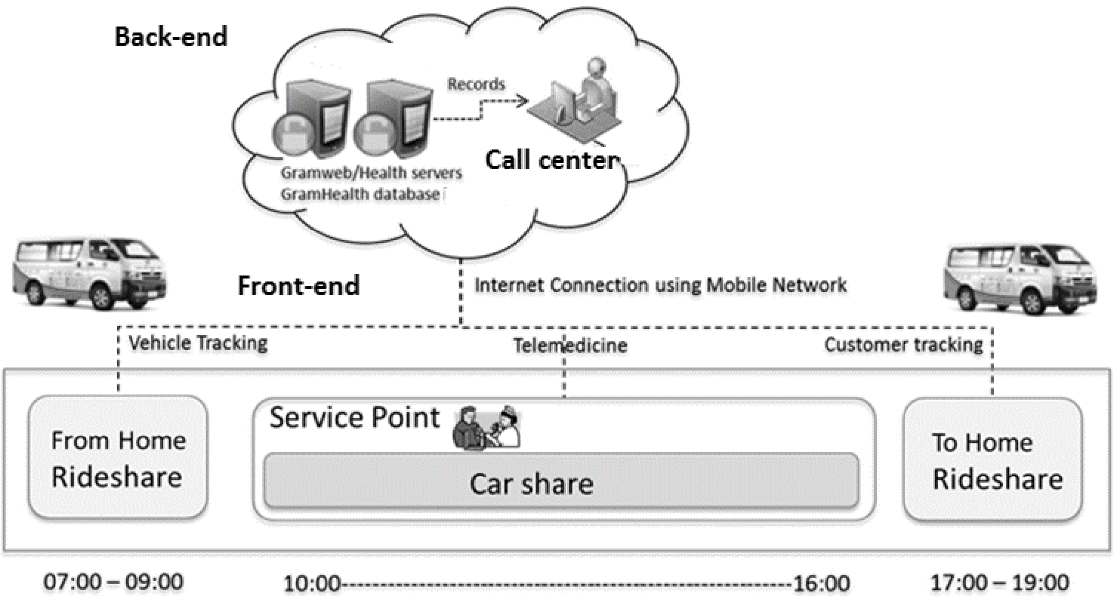

Figure 3: Shared Vehicle Usage

The vehicle incurs varying operation costs in providing these multiple services. To make the concept a viable business, we schedule the vehicle to achieve maximum revenue while minimizing idle time. Users of the service can request the DRMaaS system for either ride share or service delivery to their door steps/residential area. Users of the ride share service send their pick up point, destination, intended arrival time and acceptable delay. The trip scheduler groups these users according to matching destinations and arrival times within respective time windows. Then the scheduler selects a vehicle based on seat capacity, vehicle availability and attainability of a quorum. The scheduler then calculates proximity of passengers to most optimum route and reassigns pick up point if necessary and sends cost of ride, estimated pick up time to the user. The same information of all passengers is sent to the drivers on board unit. The DRMaaS collects information on users location, specific type of service and their expected time of delivery. Once all requests of the day are received, a complete schedule is published by the system for reference by the DRMaaS operator side as well as the driver on his on board terminal, figure 4.

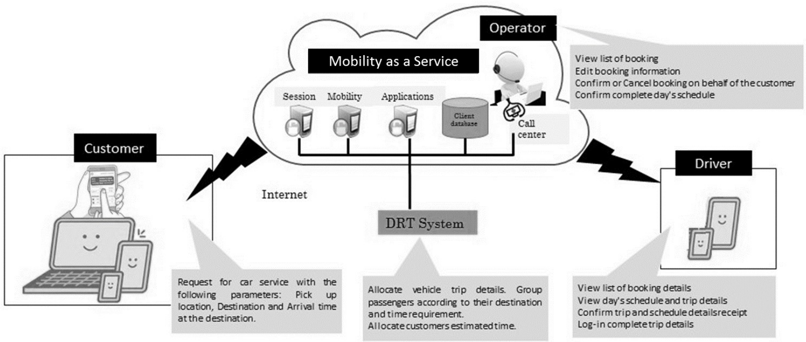

Figure 4: Demand Responsive Transport architecture

3.1.1. Vehicle Reservation

The Session Application Server keeps track of a customers activity across sessions of interaction with the service system. A session can include customers account activation, customer reservation booking, customer service use and customer account registration. Customer account activation is a private contract where the customer registers personal details (age, address, contact details) and may choose a service plan such as medical care. Customer reservation booking is service dependent. For ride-share use case, the subscriber will use Mobile Phone SMS or APP and give Requested Drop-off Time (RDT), Requested Pick-up Time (RPT), pick-up location and Destination. The system will inform the customer to wait whilst it calculates the request. It checks on how many other clients have made a similar pre-request (live near, similar RPT, RDT and destination). If there is a sufficient demand, the vehicle seat allocation can be checked. The scheduler calculates the demand and once a minimum number of requests for the trip based on the trip details is reached, makes an offer to the subscriber. The offer will include pick up service point, RPT, and RDT at destination. The price is also included. The offer details may be different from the customer original requirements. If the customer books a seat, the scheduler allocates the seat in the vehicle and gives the customer a Booking ID (figure 6).

For car-share use case, the customer gives the date and duration. MSP calculates the car availability and makes an offer. The offer will include the date, service point (pick up and drop off) and price. In developing countries the car-share will come with a driver. The

MaaS car share cars may be non-dedicated and owned by private individuals fitted a vehicle tracker. The DR-MaaS may offer both a ride share option (cheaper cost) and car share option (more expensive) for individuals who may want more destination options.

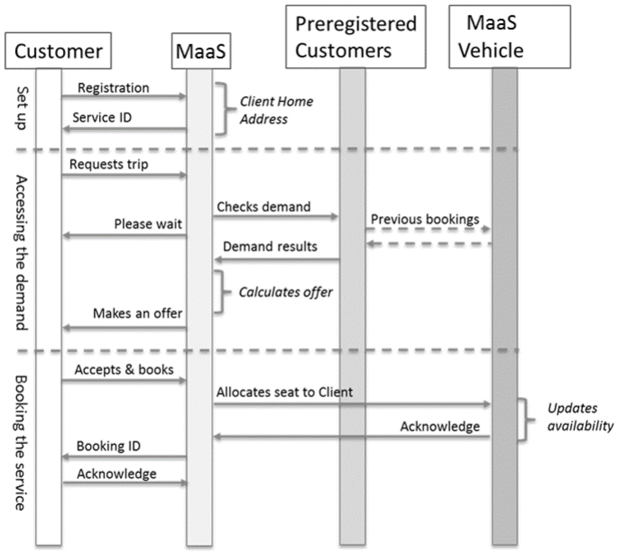

Figure 5: Ride reservation

For wellbeing use case such as requesting for a Health appointment, the customer gives a target time (Estimate Time and date). The scheduler will inform the subscriber to wait whilst it calculates the request. It then checks on how many other similar request (live near her and same target time) have been made. If there is sufficient demand, a service point event with tent and healthcare lady can be established and the scheduler makes an offer to the customer. The vehicle will be booked for the Service Point event. The customer offer will include nearest Service Point Location and date. The price will also be included. The offer details may be different from the customers exact requirements. If the villager books an appointment, scheduler allocates the appointment with the Portable Health Clinic and sends the customer a Booking ID (figure 7).
In all use cases, once the service has gained a critical mass, the MSP can learn the customer behavior promote services advertising rideshare slots, cars hare offers, and check-up reminders. The MSP may search the Electronic Health Records and automatically schedule screening campaigns, diabetes or hypertension in areas of high incidence. From the villager point of view this promotion will seem personalized and at the same time a service campaign will fit the community needs. For all use cases, a no-show/late cancellation policy should be enforced.

3.1.2. Vehicle Scheduling

Once Requests are accepted, a vehicle schedule for the day is created for each vehicle. Further real time requests are captured as per the vehicle availability. For example, in figure 7 a request to Uttara with requested Drop-off Time of 7:45 a.m. can be accepted if his pick

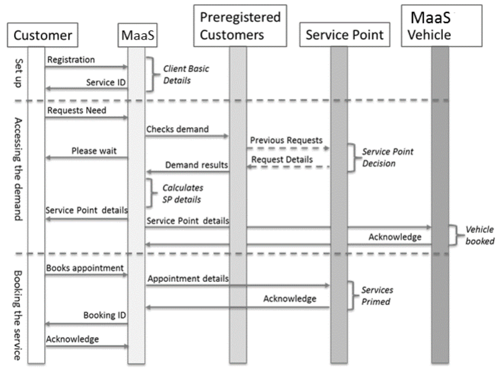

Figure 6: Portable Health Clinic Appointment

up location is within route and if there is seat availability. another scenario, if a request to go in a destination other than Uttara at 1:30 p.m can only be honoured if there will be enough time for the vehicle to return to Uttara on time for the School Transport scheduled trip. Examples of vehicle scheduls are in figures 7 and 8.

	Time	Service	Source	Destination
Start service	06:15 – 06:45	Vacant seats	Mipur	Dhanmondi
SCHEDULED DRMaaS	06:45 – 07:45	School transport	Dhanmondi	Uttara
	08:00 – 09:00	Office transport	Uttara	Mipur
REAL TIME DRMaaS	09:00 – 14:30	Idle time	Mipur	Uttara
SCHEDULED DRMaaS	14:30 – 16:00	School transport	Uttara	Dhanmondi
REAL TIME DRMaaS	16:00 – 16:45	Idle time	Dhanmondi	Mipur
SCHEDULED DRMaaS	18:15 – 19:15	Office transport	Mipur	Uttara
Return to garage	18:15 – 19:15	Vacant seats	Uttara	Mipur

Figure 7: DRMaaS Vehicle 1 Schedule

	Time	Service	Source	Destination
Start service	06:15 – 06:45	Vacant seats	Mipur	Dhanmondi
SCHEDULED DRT	06:45 – 07:45	School transport	Dhanmondi	Uttara
	08:00 – 09:00	Office transport	Uttara	Mipur
	09:00 – 10:00	PHC transport	Mipur	Farmgate
REAL TIME DRMaaS	10:00 – 14:30	Idle time	Farmgate	Uttara
SCHEDULED DRT	14:30 – 16:00	School transport	Uttara	Dhanmondi
	16:00 – 16:45	Vacant seats	Dhanmondi	Farmgate
	16:45 – 18:15	PHC transport	Farmgate	Mipur
	18:30 – 19:30	Office transport	Mipur	Uttara
Return to garage	19:30 – 20:30	Vacant seats	Uttara	Mipur

Figure 8: DRMaaS vehicle 2 schedule

3.1.3. Vehicle Dispatching and Routing

Our approach considers a finite fixed number of vehicles. We deploy two vehicles in urban area and once vehicle each in two rural areas.

Due to the limitation in number of vehicles considered, vehicle dispatching is not paramount to our solution.

Vehicle routing for Scheduled DRMass considers selected stop points (nodes) and routing traverse through these nodes as requested. The vehicle routing approach considers shortest route to travel to next node, not as selected but as requested. That is, if there is no pick-up or drop-off request at a specific node, the shortest route to get to the next node is selected, which could be with or without passing the unrequested node. The travel time from node to node listed in upper triangular matrix will inform the routing calculation.

Table 2: Experiment Configuration

Item	Configuration
Service area	50km radius
Fleet size	2 vehicles
Vehicle Speed	average 30kmph
Vehicle Capacity	10 seats
Vehicle Operating hours	6:00 a.m. to 8:00 p.m.
Stop points	10-20
Stop time	20 seconds
Time window	5, 10, 15, 20
Number of requests	20-100
Demand pattern	low, average, high
Services	Scheduled, transit, idle

For Real time DRMaaS, routing is considered from one node to the next. Since the nodes do not have to be selected from preregistered stop points, routing is made by best search of route to next new node. Since no existing information is available for unlisted stop points, real time DRMaaS reies on Global Positioning System (GPS), a space-based navigation system that provides location and time information for the routing calculation.

4. Experiment Results and Evaluation

To validate algorithm for time scheduling and cost sharing with limited vehicle schedule and quorum discussed in chapter 4, we considered conditions set by our designed DRMaaS discussed in chapter 3. Table 5.1 summarizes the configuration of parameters used in the simulation of the working of the algorithm.
Passenger requests were generated for short trips within vehicle working hours. If the choice of a random number did not give a departure or arrival time within 6 am to 8 pm another random number was generated so that finally the service request was between 6 am to 8 pm. This was primarily based on the assumption that once the requests for using the bus service are validated, the DRTMaaS system would respond with the estimated pick-up/drop-ff times or an error message. The simulation model was run until the last customer was dropped off. Results were generated for investigating the performance of the systems under a variety of conditions outlines in table 2. The requests represented in the simulation involved both advance requests and ad-hoc requests, where passengers would request a fixed route trip in advance or request to be picked up as soon as possible. The requested times were generated based on a uniform distribution over the entire 12 hour period.

4.1. Time Scheduling

4.1.1. Time Performance

The levels of service in terms of travel time and waiting time were estimated. The travel time ratio, defined as the ratio of the actual journey time to the travel time if the most direct route was travelled was used to investigate the performance for users of the system (figure 9) The percentage of persons experiencing longer travel times decreases as the number of customers increases.

Passengers are assumed to be sensitive to the time between when the service was requested and the time the vehicle arrived to pick them up. We present the average waiting time versus number of passengers who made requests for using the transit service. Time windows were set at maximum of 20 minutes, with requests being in a minimum 10 minutes. Figure 10 shows that all records had service time deviations below time window. Average waiting time was calculated as 2 minutes. While ensuring pick-up and drop-off times are within passenger set travel times, our solution reduces waiting time due to it's increased time constraints.

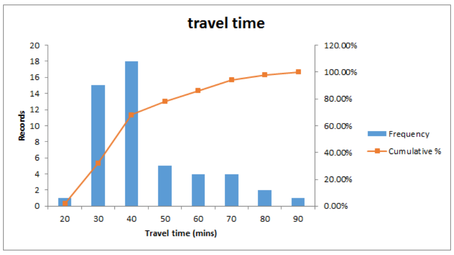

Figure 9: Travel time distribution of simulated data

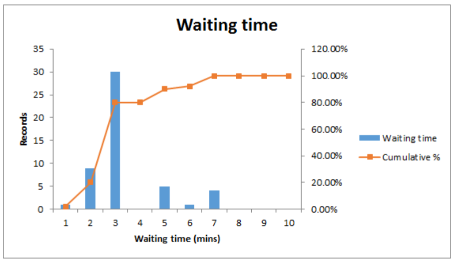

Figure 10: Waiting time distribution of simulation data

4.2. Cost performance

4.2.1. Passenger trips per revenue hour

The effect of the total number of passenger in a trip on the costs for a fixed number of operating vehicles at 10 passengers maximum seat capacity and considering same distance an travel time was investigated. For each run, a distribution of costs was estimated. Figure 11 presents decreasing estimated costs per passenger as the total number of customers increased. At the higher demand levels the costs appear to be reasonable approaching that of traditional public transport services.

4.2.2. Operating cost per revenue hour

The effect of our cost sharing approach in cost per revenue hour was plotted as in figure 12. The person correlation of cost and travel time was .922 based on 100 records. This indicates a positive linear relationship between cost and travel time. Similarly, a correlation between cost and distance showed a positive correlation. It shows that, our model, while being based on number of passengers per trip, it also relates to traditional costing models that relate to time and distance. Hence, the model exhibits a more fair cost sharing model that appeals to both passengers and vehicle entrepreneurs.

5. Demand Responsive MaaS Experiment Test in Dhaka

5.0.1. Overview of transport situation in Dhaka, Bangladesh

Dhaka is the capital city of Bangladesh with a population of 6.97 Million and area of 815.8 km^2. We set out to experiment DRMaaS in a busy city environment with need for a

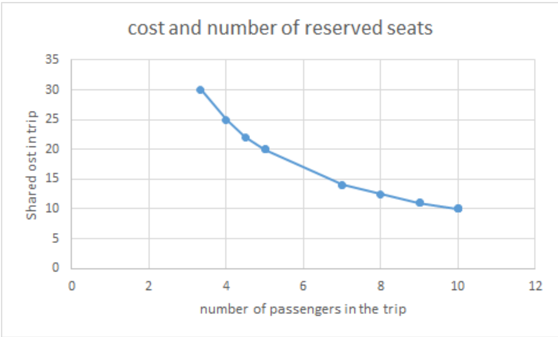

Figure 11: Costs and average number of passengers in a trip

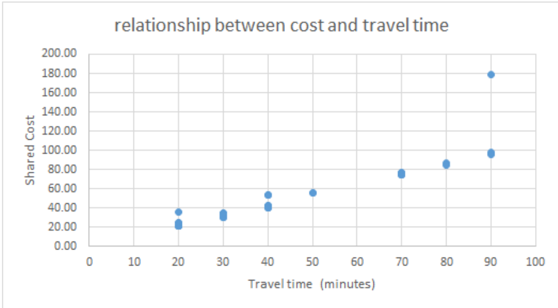

Figure 12: Costs in Travel time

low cost structured transport solution.
This project was funded by Toyota Motor Corporation in exploring how ICT can contribute in solving mobility needs in developing countries. Grameen Communications in Bangladesh provided the project support in conducting surveys and the experiment. The pilot project duration was from August 2015 to January 2016.
A survey to find out transport requirements in different areas of the city was carried out so to establish service area of the DRMaaS vehicle. Survey results indicated major problems in public transport in Dhaka to include; traffic jam, unavailability of seats, improper time management, over crowded, expensive fare, unsafe, unavailability of transport in some areas and uncomfortable vehicles (figure 13).We asked respondents who have frequent transit needs to work/school of availability of scheduled transport. Majority of respondents did not have such services available figure 15. Of those who did have such a service, some did not utilise it with reasons including; having own private car, short travel distance and not wanting to share ride with other staff. We also found that 70% of the respondents are not satisfied with public transport, with 84% wanting safe, comfortable and quality transport alternative, figure **??**.

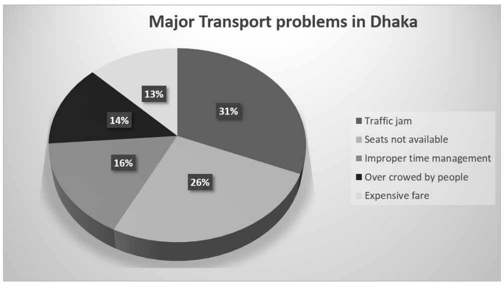

Figure 13: Survey of transport problems in Dhaka

Current cost and duration of road transport options in Dhaka taken at a constant distance were summarised in table 3. Bus transport is most used due to the low cost. CNG, Compressed Natural Gas, is a motorized three wheeler vehicle that used compressed natural gas as opposed to diesel to reduce operation costs. They operate at high cost, similar

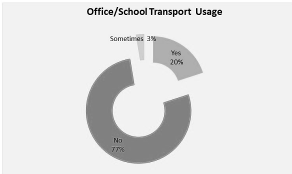

Figure 14: Survey on use of office transport

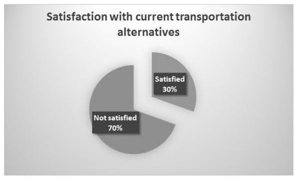

Figure 15: Satisfaction with available transport options

Table 3: Cost and travel time of existing public transport

Transport Medium	**Time (mins)**	**Cost(Taka)**
Bus	68	39
CNG	48	225
Rickshaw	90	120
Others	97	110

to taxi. Rickshaw is a light two-wheeled passenger vehicle drawn by one or more people. Other options include: bicycle, motorcycle and train. There is no schedule for any of the public transport options. Passengers have to wait at designated bus stops until a vehicle plying the route they want to go arrives. Average waiting time was reported at 12 Minutes. Respondents were willing to pay only up to Tk.1630 per month, meaning that they would prefer a quality but low cost transport alternative.

5.0.2. Experiment Profile

The experiment site was identified to cover areas of Uttara na Mipur districts in Dhaka, from residential areas to the central business district. To conduct this experiment, 2 Toyota hiace vans were leased, 2 Portable Health Clinic briefcases were sourced, 4 notebook PCs, 2 driver consoles, remote database, operator and doctor's call center was set up in the central office of Grameen Communications. The experiment provided fixed route office and college transport and fixed transport for PHC service delivery and accepted real time requests for flexible schedules when the car was inactive.

5.1. Evaluation of Demand Responsive MaaS Scheduling

We considered advanced requests for the pilot program. Estimated average waiting time was calculated as 3 minutes. At constant distance, the Demand responsive Mobility as a Service system is compared to average cost and travel time, see table 4. Average waiting time for CNG, rickshaw and other modes of transport have not been identified. Wiaitng time for buses in Dhaka varys from an average of 12 minutes during peak times to up to an hour in off peak times. This uncertainty makes it difficult for passengers to make accurate travel plan. Our approach offers to avail the vehicle for pick-up and drop-off at estimated times, with minimum waiting time.
A comparison of actual and simulated waiting time is shown in figure 16. In both actual and simulated data, passengers generally had reduced waiting time, with few outliers having longer times. Nevertheless, both accounts showed times within set passenger time allowance.

Average waiting time calculation showed actual data at 3 minutes as opposed to 2 minutes in simulated data, a very minimal yet very slightly significant relation.

Table 4: Demand Responsive MaaS compared to existing public transport

Transport Medium	Travel time(mins)	Waiting time(mins)	Cost(Taka)
DRMaaS	72	3	60
Bus	68	12-60	39
CNG auto-motor	48	-	225
Rickshaw	90	-	120
Others	97	-	110

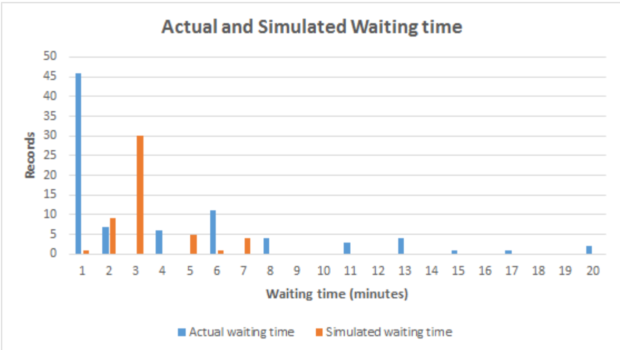

Figure 16: Actual waiting time compared to simulated waiting time

6. Conclusion

We identified a gap in quality and affordable transport alternative especially in developing countries. Access to social services like health, education and economic activities. The study addressed the formal transit needs and the service accessibility needs of the rural communities by introducing a Demand Responsive Mobility as a Service model. It comprises of a minibus and a mobile platform that carries ICT tools to access Healthcare, Education, Learning and Purchasing Opportunities. The need for back-end Mas a Service support is apparent in providing scheduling support, doctor call centre support, ICT support, database storage, backup and maintenance and performance analysis.

The initial field study of Mobility as a Service, Social Services on wheels model needs to be subsidized. We establihed that operational cost can be reduced by proper time utilization and maximizing the income by providing more social services during the cars idle time. We introduced a Demand Responsive Mobility as a Service, DRMaaS trip scheduling and cost sharing approach to make the solution more effective in time and cost. Main contributions of the study was: (i) a design of a multiservice demand responsive transport alternative with both fixed route (advanced requests) and flexible (real-time requests), called Demand Responsive Mobility as a Service, DRMaaS, (ii) Demand Responsive Transport, DRT, based trip scheduling addressing constraints of vehicle time and quorum.

We conducted a simulation experiment to validate the algorithm and found that our proposed solution reduces waiting time due to it's increased time constraints. An actual field experiment in Dhaka, Bangladesh confirms our hypothesis that a demand responsive transport based solution can minimize waiting time.

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