Evaluation of the Effects of On-Demand Dynamic Transportation of Employees to Their Workplaces in Ljubljana

Marko Bohanec
marko.bohanec@ijs.si
Jožef Stefan Institute, Department of Knowledge Technologies
Jamova cesta 39
Ljubljana, Slovenia

Marko Guček
marko@goopti.com
GoOpti d.o.o.
Ljubljana, Slovenia

Davor Kontić
davor.kontic@ijs.si
Jožef Stefan Institute, Department of Environmental Sciences and Centre for Participatory Research

Karina Sirk
karina.sirk@ipop.si
Institute for Spatial Policies
Ljubljana, Slovenia

Bernard Ženko
bernard.zenko@ijs.si
Jožef Stefan Institute, Department of Knowledge Technologies

Martin Žnidaršič
martin.znidarsic@ijs.si
Jožef Stefan Institute, Department of Knowledge Technologies

ABSTRACT

On-demand dynamic transportation is an innovative information-technology supported service that enables passengers to book and configure their rides. It is foreseen as a promising service to improve the sustainable mobility of citizens and alleviate traffic problems. In this paper, we present the results of a three-month pilot implementation of dynamic transportation of employees from their homes to their workplaces. The transports were managed by the company GoOpti, d.o.o., they were free and took place using vans on the routes connecting the cities Kamnik and Kranj with two areas (BTC and UKC) in Ljubljana. The project was very successful in terms of sustainable mobility: it attracted users that normally drive passenger cars, travel times were comparable to conventional modes of transportation and users were very satisfied with the service, while substantially reducing (from 30% to 70%) the harmful emissions of CO_2, NO_x and solid particles. However, two challenges for the future still remain: improving the occupancy rate of vehicles and bridging the gap between the economic price and users' willingness to pay for the service.

KEYWORDS

sustainable mobility, on-demand dynamic transport, employee transportation, Ljubljana Urban Region

1 INTRODUCTION

Within the last thirty years information technologies (IT) profoundly changed many aspects of our life and the society. IT provide us with tools that enable creation of new services, which have the potential to significantly improve our every day lives. One of such services is on-demand dynamic passenger transport [11], which typically makes use of vans or mini busses that operate without fixed itineraries or fixed stops, enabling passengers to book their ride and select their pick up and drop off locations. On-demand dynamic transport bridges the gap between the conventional public transport and private car transport, and promises to reduce green house gas and other pollutant emissions, improve modal split, reduce traffic congestions and alleviate related problems.

The focus of this paper are not the IT needed to implement an on-demand dynamic transport (e.g., mobile apps, databases, scheduling and optimization systems), but rather we present the results of a real life evaluation of such a system that has been carried out in Ljubljana Urban Region, Slovenia, within the SmartMOVE project [10]. SmartMOVE addresses the challenges of sustainable mobility in the Ljubljana Urban Region with the capital city of Ljubljana, which is the primary destination of daily migration flows in Slovenia.

The aim of this study is to answer two questions that are crucial if such a service is to be implemented in practice: (1) Can on-demand dynamic transport really help in reducing harmful emissions and traffic congestion? and (2) Under what conditions can such a service sustainably operate in a given economic environment? It is important to note that before this study no evaluation of on-demand dynamic passenger transport in comparable environments has been done, and its benefits and limitations used to be assessed only theoretically through simulations [1].

2 RELATED WORK

Ljubljana is home to over 220,000 jobs, which accounts for over 25% of all jobs in Slovenia. As a result, over 120,000 people flock to Ljubljana daily from elsewhere. This means approximately 100,000 vehicles entering and exiting Ljubljana on a daily basis (with an average occupancy of vehicles at 1.2 pers/car). Since the majority of this is associated to the personal car transport, the main goal is to transfer the car drivers/passengers to public transport. However, the road public transport is faced with the same problems as car transport – congestions due to absence of dedicated lanes, low travel speeds, poor occupation of vehicles.

The problem of public transport in Ljubljana was tackled by studies that focused on various aspects. Some of them outline the overall context of the problem and the related phenomena [4]. The current public transport organization in Ljubljana is reflected well in a paper that describes the public transport plans from a decade ago [6]. There are studies about the state of the public transport in Ljubljana, such as accessibility [12], speed [7], studies about the effects of public transport management measures [13] and about its potential future developments.

On-demand dynamic transportation, which is in the focus of this paper, shares several characteristics with carpooling [14]. However, we could find no previous studies about on-demand

Information Society 2023, 9–13 October 2023, Ljubljana, Slovenia

dynamic transportation in Ljubljana and even in general, the studies of on-demand dynamic transportation are to a large extent dedicated to theoretical models [8, 5] and simulations [2, 1]. A good showcase of dynamic transport practices are the on-demand airport shuttles, which have indicated a potential solution to the downsides of regular public lines; they support the users' needs and commodity as one of the most important factors for choosing the preferred means of transport.

3 STUDY DESIGN

The main objective of this pilot study was to test using on-demand dynamic transportation of employees as a sustainable alternative to existing modes of transport, especially in comparison with using passenger cars. The study took place in the trial period from February to April 2023, when selected passengers were transported free of charge by the company GoOpti, d.o.o., employing vans that can carry up to eight passengers. Transportation costs were covered from the SmartMOVE project. Two pilot routes were established that connected two nearby cities Kamnik (14,000 inhabitants, about 23 km from Ljubljana) and Kranj (38,000, 28 km) with the areas of two large employer organisations located in Ljubljana: UKC and BTC. UKC, the University Medical Centre of Ljubljana, is with 8,000 employees the largest employer in Slovenia; daily, it is visited by additional 20,000 people. BTC, the Business Trade Centre, is the largest shopping area in Slovenia. It does not have many direct public transportation links, but is located close to a highway, inducing high volumes of car traffic.

Before the study, the opportunity to join the experiment was advertised using different channels, particularly in the UKC and BTC areas. Among more than 500 interested individuals, 131 were eventually selected and invited to participate. All the operation, including the IT solution, customer management and logistics, was carried out by the project partner GoOpti.

Two data sources were collected during the study:

- *Traffic data*: Collected by GoOpti while providing the service. This included detailed data about the travelled routes (distances, times and GPS locations) and provided services (anonymized individual user's rides).
- *User survey*: Collected using a survey questionnaire once per each individual user at the end of the study period. The questions mainly addressed users' current mobility habits (with more detailed questions for users using cars) and their experience with the service. A full version of the questionnaire (in Slovene language) is available in [3].

Using this data, we carried out the following analyses: basic traffic and demographical statistics, average occupancy of vans and individual users' rides, users' current mobility habits, and user satisfaction with and willingness to pay for the service. By combining the data sources, we estimated the differences between the current and dynamic means of transportation in terms of travelling time and contribution to lower emissions of CO_2, NO_x (nitrogen oxides) and PM10 (particles with a diameter of 10 μm or less).

In order to assess environmental burdens, we analyzed the difference in air emissions between the "BaU - Business-as-Usual" scenario (i.e., trips without the introduction of dynamic transport) and the GoOpti service. We took into account the distances traveled by the types of transport that users used before the introduction of GoOpti: mainly driving passenger cars of different types (gasoline, diesel), taking into account the age of the vehicles and corresponding average emissions. Data sources included the Statistical Yearbook of the Republic of Slovenia [9] and EU emission standards (EURO standards[1]). We considered the users' distances from home to workplace and the number of journeys they would have made if dynamic transport had not been employed. As a weighting factor for the calculation, we considered whether the users mainly drive with personal vehicles (several times a week) or perhaps combine the drives with other modes of transportation to work (public passenger transport, bicycle, etc.). The emission factors for GoOpti vehicles were obtained from the manufacturer's specifications.

Table 1: Basic ride statistics.

Route	Passengers [total]	Distance [km]	Time [min]	Speed [km/h]	Occupancy [%]
Kamnik	5440	21.20	42.81	29.72	38.0
Kranj	1742	33.66	45.62	44.27	25.9
Total	7182	25.18	43.70	34.57	34.1

4 RESULTS

4.1 Traffic Data Analysis

Traffic statistics. In three months of the pilot study, there were 2,629 rides of the total distance of 66,199 km and time of 1,915 hours (almost 32 days). Here, each "ride" means picking up the passengers at one or more origin locations and dropping them down at one or more destination locations. Table 1 shows, grouped by the routes and in total, the total number of passengers and average ride distances, times, speed and vehicle occupations. The term "passenger" refers to one ride of a single person.

User statistics. The service was used by 131 individual users, who used the service daily or less. The most active user used the service 121 times, and the average was 54.88 times per user. Female users prevailed over males (73% vs. 27%). The prevailing age groups were 31–42 (43%) and 45–64 (46%), while the distribution of users' education levels was close to uniform.

Vehicle occupancy. As large as possible vehicle occupancy is essential for the effectiveness of dynamic transportation. Figure 1 displays the occupancy achieved in the study.

4.2 User Survey Analysis

The survey was completed by users at the end of the trial period, so that each user completed the survey at most once. Out of the 131 users, the completed survey was submitted by 88: 30 travelling from/to Kranj and 58 in the Kamnik direction.

Current mobility habits. Figure 2 shows relative proportions of transportation modes used by the survey respondents. The prevailing mode is using personal cars: 70% as sole drivers and 20% as fellow passengers. The train and city bus come next at approximately 30% each, the bicycle at 10%, while the remaining modes are barely indicated. Both routes exhibit similar usage patterns.

The respondents that use cars estimated their average occupancy at 1.37 per ride. Most of the cars have diesel or gasoline engines (about 45% each). Hybrid and electric cars account only for about 2%. The average age of cars is 9.15 years (7.28 on route Kranj and 10.04 on route Kamnik).

User satisfaction. The users were generally very satisfied with the service. They most appreciated the easiness and comfort of

[1] Euro 1 (1992): 91/441/EEC, 93/59/EEC; Euro 2 (1996): 94/12/EC, 96/69/EC; Euro 3 (2000): 98/69/EC; Euro 4 (2005): 98/69/EC (& 2002/80/EC); Euro 5 (2009): 715/2007/EC; Euro 6 (2014)

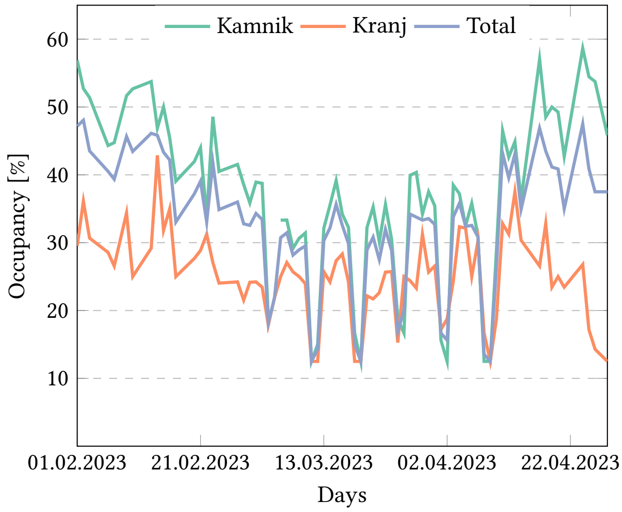

Figure 1: Average vehicle occupancy, per days and routes.

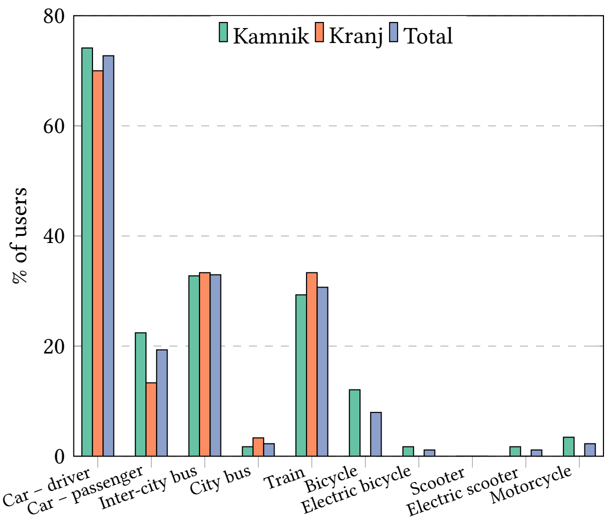

Figure 2: Current modes of transportation, normalized by the number of respondents. Since multiple answers were possible, the values shown are not true relative values and do not add up to 100%.

this mode of transport, its reliability, the proximity of stations, the possibility to effectively use the time for themselves and the fact that they did not need to search for the parking place. Complaints, on the other hand, were scarce and mainly addressed too long collection/drop-off times, variable collection times and the need to check the collection information every day. When asked to compare their usual means of transportation with the dynamic one (Figure 3), they evaluated the latter better in all points except the flexibility. It is very likely (on average 9 on the 0–10 scale) that the respondents will recommend the service to their friends and relatives.

Willingness to pay. When asked about their willingness to pay for the service, the average response was about 70€ per month (64€ for Kamnik and 86€ for Kranj).

4.3 Comparison of Traveling Times

We compared the time of traveling between the dynamic transportation and the usual modes of respondents' transportation.

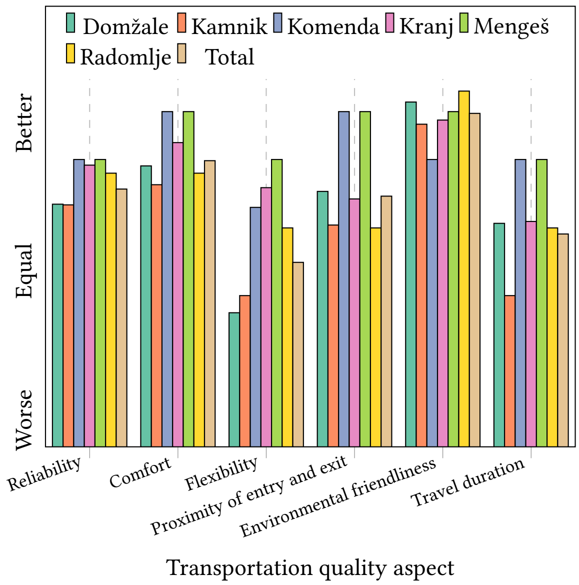

Figure 3: Comparison of the respondents' usual transportation mode with the dynamic one.

Table 2: Comparison of average traveling times, in minutes.

Entry location	Usual transportation	Dynamic transportation	Difference
Domžale	30.97	26.67	-4.30
Kamnik	42.00	44.16	2.16
Komenda	59.00	36.91	-22.09
Kranj	54.72	38.97	-15.75
Mengeš	36.00	27.80	-8.20
Radomlje	40.71	40.09	-0.63
Average	41.22	35.07	-6.15

We used both data sources. It should be noted that the comparison includes only passengers who have completed the survey (otherwise we have no information about their normal time traveling time). Additionally, we had to exclude two respondents because of a mismatch with traffic data. Traffic data do not include any time of walking and waiting for a van. The survey data was collected only once for each passenger ($n = 86$), while there was substantially more traffic data (5,476 passenger rides). Therefore, there is a substantial difference in the amount and quality of the data, and a cautious interpretation is advised.

Results are shown in Table 2. Considering all entry locations, except Kamnik, the dynamic rides are faster (in average by 6.15 minutes). This comparison is not entirely fair because the dynamic transportation times do not include possible waiting and walking times, but we can safely assume that the times are at least comparable.

4.4 Analysis of Environmental Burdens

The analysis of the environmental burdens focused on CO_2 and NO_x emissions and particulate matter (PM) for human health reasons. The results in Table 3 show a significant reduction in CO_2 emissions after the introduction of the dynamic transportation service: reduction of emissions by approximately 27%, or over 50% in case of higher occupancy/exclusive use of the dynamic service. Similar reductions are also expected with NO_x (26% to 68%) and PM (27% to 79%). It is important to emphasize that

Table 3: Comparison of CO_2, NO_x and PM emissions.

	BaU	Dynamic (weighted)	Dynamic (total)
CO_2 [t]	23.90	17.30 (-27%)	10.90 (-54%)
NO_x [kg]	23.21	17.20 (-26%)	5.30 (-69%)
PM [kg]	1.44	1.05 (-27%)	0.30 (-79%)

the absolute values of PM particle emissions are low, since the average vehicle age is about 9 years, when the minimum emission standards for solid particles have already been introduced.

Generally, the results show a significant reduction in emissions when implementing the dynamic transport compared to the BaU scenario. However, it should be noted that the data refer to the average number of users and that these may vary depending on vehicle occupancy, driving dynamics (driving speed), road conditions (e.g., duration of traffic jams), etc. These are preliminary estimates that do not yet take into account possible errors in data collection and interpretation of uncertainty. The numbers/results correspond to the implementation of the pilot project only – the potential up-scaling analysis would show the actual potential of such measures for solving the urban mobility issues.

5 CONCLUSIONS

The results of this pilot study confirm that on-demand dynamic transportation of employees to their jobs has a great potential for improving the sustainable mobility in the Ljubljana Urban Region. As part of the pilot project, which was taking place from the 1st February 2023 to 28th April 2023, 2,629 van rides were carried out with a total length of 66,199 km and a total duration of almost 32 days. The average ride was about 25 km long and lasted 44 minutes. 131 individual users were involved, who made a total of 7,182 individual commutes. Some used the service in both directions on a daily basis, others less often.

Most users of the service (about 70%) usually use a passenger car for their transport to work. The transition to dynamic transportation puts all these cars "off the road", while only moderately competes with other forms of public transportation. This also causes a significant reduction in harmful emissions of CO_2, NO_x and solid particles into the environment: from 30% to 70%, depending on the substance and transportation. Also, the dynamic transportation is comparable with other modes of transportation considering the speed and time spent. The satisfaction of users was also highly positive, as they liked that somebody else took care of their everyday commute to work, which was done without stress, accurately and reliably. They especially appreciated the "door-to-door" aspect and avoiding the search for a parking lot. However, from the data collected we cannot actually determine to which extent was the users' enthusiasm caused by the fact that the transport was free of charge during the pilot study.

Two problems were identified that might jeopardize the permanent operation of the dynamic transportation. The average occupancy of the vehicles was only around 2.73 passengers per ride (34% of 8 seats). Of the two routes, Kamnik and Kranj, the former were better occupied – by almost one passenger in average per ride. According to GoOpti [3], a higher occupancy (75%) could be achieved during the traffic peak times around the city of Domžale, which lies halfway to Kamnik.

Another problem is the price that the users are willing to pay for the service, which amounts to around 70€ per month. This is significantly less than the economic price estimated at 250€ at 50% occupancy and 160€ at 75% [3]. It seems that car users are not really aware of the actual costs and underestimate their expenses for commuting to work. Better awareness of users would be needed on the costs and environmental impacts of different transportation modes.

In summary, dynamic transportation seems a feasible and effective alternative to using cars for commuting to work. However, in Slovenia, it requires a careful consideration, at the levels of communities, cities, regions and the whole country, of how to attract the users and support the transition to this and other sustainable transportation means. In perspective, it will also require intelligent software for supporting the service. The tasks that are particularly interesting for applying artificial intelligence methods, include the prediction of customers' requests, optimization of costs and dynamic planning of routes.

ACKNOWLEDGMENTS

This work has been funded by the SmartMOVE project, which is co-financed by Iceland, Lichtenstein and Norway funds from the EEA Financial Mechanism and corresponding Slovenian participation within the Climate Change Mitigation and Adaptation programme in the amount of 1 609 167€. The contents of this document are the sole responsibility of the authors and can in no way be taken to reflect the views of the Climate Change Mitigation and Adaption Program Authority.

The authors also acknowledge the financial support from the Slovenian Research Agency for research core funding for the programme Knowledge Technologies (No. P2-0103).

REFERENCES

[1] Claudia Archetti, M. Grazia Speranza, and Dennis Weyland. 2017. A simulation study of an on-demand transportation system. *International transactions in operational research*, 25, 4, 1137–1161. DOI: 10.1111/itor.12476.

[2] Carlos Lima Azevedo et al. 2016. Microsimulation of demand and supply of autonomous mobility on demand. *Transportation Research Record*, 2564, 1, 21–30. DOI: 10.3141/2564-03.

[3] Marko Bohanec, Marko Guček, Davor Kontić, Karina Sirk, Bernard Ženko, and Martin Žnidaršič. 2023. Vrednotenje učinkov dinamičnih skupinskih prevozov zaposlenih na delovna mesta. Tech. rep. Institut Jožef Stefan, Delovno poročilo DP-14427 (in Slovene), Ljubljana, Slovenija.

[4] David Bole, Matej Gabrovec, Janez Nared, and Nika Razpotnik Visković. 2012. Integrated planning of public passenger transport between the city and the region: the case of ljubljana. *Acta geographica Slovenica*, 52, 1, 141–163.

[5] Malcolm Egan and Michal Jakob. 2016. Market mechanism design for profitable on-demand transport services. *Transportation Research Part B: Methodological*, 89, 178–195. DOI: https://doi.org/10.1016/j.trb.2016.04.020.

[6] Cveto Gregorc and David Krivec. 2012. Networking of public passenger transport modes, a step towards sustainable mobility in ljubljana urban region. *Procedia-Social and Behavioral Sciences*, 48, 3009–3017.

[7] Simon Koblar and Luka Mladenovič. 2020. Calculating the speed of city bus trips: the case of ljubljana, slovenia. *Urbani izziv*, 31, 1, 112–122.

[8] Wengen Li, Jiannong Cao, Jihong Guan, Shuigeng Zhou, Guanqing Liang, Winnie K. Y. So, and Michal Szczecinski. 2019. A general framework for unmet demand prediction in on-demand transport services. *IEEE Transactions on Intelligent Transportation Systems*, 20, 8, 2820–2830.

[9] Statistical Office RS. 2023. Statistical yearbook of RS. accessed on 23.8.2023. (2023). https://www.stat.si/Pages/en/goals/goal-12.-ensure-sustainable-consumption-and-production-patterns/12.5-average-co2-emissions-per-km-from-new-passenger-cars.

[10] SmartMOVE. 2022–24. Smart mobility measures for sustainable mobility in slovenia. project financed by iceland, liechtenstein and norway funds from the eea financial mechanism and the norwegian financial mechanism. (2022–24). https://kt.ijs.si/project/smartmove/.

[11] Amirmahdi Tafreshian, Neda Masoud, and Yafeng Yin. 2020. Frontiers in service science: ride matching for peer-to-peer ride sharing: a review and future directions. *Service Science*, 12, 2-3, 44–60. DOI: 10.1287/serv.2020.0258.

[12] Jernej Tiran, Luka Mladenovič, and Simon Koblar. 2015. Accessibility to public transport using the ptal method: the case of ljubljana. *Geodetski Vestnik*, 59, 4, 723–735.

[13] G. Titos, H. Lyamani, L. Drinovec, F.J. Olmo, G. Močnik, and L. Alados-Arboledas. 2015. Evaluation of the impact of transportation changes on air quality. *Atmospheric Environment*, 114, 19–31.

[14] Steve Wright, John D. Nelson, and Caitlin D Cottrill. 2020. Maas for the suburban market: incorporating carpooling in the mix. *Transportation Research Part A: Policy and Practice*, 131, 206–218.

Zbornik 26. mednarodne multikonference

INFORMACIJSKA DRUŽBA – IS 2023

Zvezek A

Proceedings of the 26th International Multiconference

INFORMATION SOCIETY – IS 2023

Volume A

Slovenska konferenca o umetni inteligenci
Slovenian Conference on Artificial Intelligence

Uredniki / Editors

Mitja Luštrek, Matjaž Gams, Rok Piltaver

http://is.ijs.si

12. oktober 2023 / 12 October 2023
Ljubljana, Slovenia