Post-corona shared mobility

Modelling and controlling virus spread processes in shared mobility networks.

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1 Achievements

Figure 1: Brigth (?) future of ride-pooling (source: DALL-E ChatGPT)

The *Post-Corona Shared Mobility* project was a significant step on a path towards better understanding, control, design and operations of ride-pooling services. This path originated with a unique method *ExMAS* [KC20] published at TU Delft (during ERC-funded Critical MaaS project of prof. O.Cats), which was a cornerstone for this project. Indeed, building on *ExMAS* we developed a **stream of methods, experiments and findings pushing forward the strategic analysis of ride-pooling services** (both in the pandemic and regular times). This body of research is now followed-up with the Horizon Europe project *SUM* (`www.sum-project.eu`) and practically implemented for demand-responsive bus feeder services in Kraków and Jerusalem.

2 Results

In particular, thanks to this project we:

1. know how viruses spread via the ride-pooling contact networks and how to control them [KCS21]
2. understood the true potential of ride-pooling on a big dataset of 1.5 million trips in NYC and report the system properties and performance [Shu+24]
3. introduced the network structures of shareability graphs, formalized them and correlated their properties with ride-pooling system performance [BK23]
4. proposed the novel method to efficiently pool more than 14 travellers into attractive hyper-pooled rides [KC24]
5. extended the ride-polling analyses towards travellers heterogeneity and incorporated user-specific and latent to the operator behavioural traits (penalty for sharing and value of time) into system assessment [BK24].
6. demonstrated how we can balance two opposing objectives of ride-pooling: virus spreading and efficiency with graph neural networks [Pro+24]

7. understood temporal dynamics of two-sided markets (like ride-pooling systems) and their growth patterns [GK24]
8. reviewed and synthesized the post-pandemic market of ride-pooling services [SK22]
9. formalized and simulated computational complexity of ride-pooling problems [AK22]
10. understood the drivers dynamics and their strategies towards serving ride-pooling [AGK24]
11. introduced drivers behavioural traits into the two-sided mobility markets and simulated its impact on the system performance [GAK23]

3 Achieved and not-achieved objectives

We have reached the objectives stated in the research plan as follows:

WP1 *forecast demand for post-corona shared mobility (data-driven travel behaviour modelling)*

In [SK22] we provide an overview of the postpandemic ride-pooling market based on the analysis of three components: a) literature review, b) empirical pooling availability survey and c) travellers' behaviour studies. We conclude that the core elements of the ride-pooling business model were not affected by the pandemic. It remains a promising option for all the parties involved, with a great potential to become attractive for travellers, drivers, TNC platforms and policymakers. The travel behaviour changes due to the pandemic seem not to be long-lasting, our virus awareness is no anymore the key concern and our willingness to share and reduce fares seem to be high again. Yet, whether ride-pooling will get another chance to grow remains open. The number of launches of ride-pooling start-ups is unprecedented, yet the financial perspectives are unclear.

To better **forecast demand for shared mobility,** in [Shu+24], we use 1.5 million NYC taxi trips (sampled over a six-month period) and experiment to understand how well they could be served with pooled services. We use an offline utility-driven ride-pooling algorithm and observe the pooling potential with six performance indicators: mileage reductions, travellers' utility gains, share of pooled rides, occupancy, detours, and potential fleet reduction. We report distributions and temporal profiles of about 35 thousand experiments covering weekdays, weekends, evenings, mornings, and nights. We report complex spatial patterns, with gains concentrated in the core of the network and costs concentrated on the peripheries. The greatest potential shifts from the North in the morning to the Central and South in the afternoon. Offering pooled rides at the fare 32% lower than private ride-hailing seems to be sufficient to attract pooling yet dynamically adjusting it to the demand level and spatial pattern may be efficient. The patterns observed in NYC were replicated on smaller datasets in Chicago and Washington, DC, the occupancy grows with the demand with similar trends.

WP2 *model virus spreading on shared mobility networks (epidemic simulations with stochastic, time-evolving contact networks)*

In [KCS21] we combine epidemiological and behavioural shareability models to examine spreading among ride-pooling travellers, with an application for Amsterdam. Findings are at first sight devastating, with only few initially infected travellers needed to spread the virus to hundreds of ride-pooling users. Without intervention, ride-pooling system may substantially contribute to virus spreading.

Despite being the algorithmic backbone to the ride-pooling problems, the shareability graphs have not been explicitly analysed yet. In In [BK23], we formalise them, study their properties and analyse relations between topological properties and expected ride-pooling performance. We introduce and formalise two representations at the two crucial stages of pooling analysis. On the NYC dataset, we run two simulations with the link generation formulas. One is when we increase discount offered to the travellers for shared rides (our control variable) and observe the phase transition. In the second, we replicate the non-deterministic behaviour of travellers in ride-pooling. This way, we generate probabilistic, weighted networks. We observed a strong correlation between the topological

properties of ride-pooling networks and the system performance. Introduced class of networks paves the road to applying the network science methods to a variety of ride-pooling problems, like virus spreading, optimal pricing or stability analysis.

WP3 *propose efficient strategies to trace and control it (service design and management).*

Central to this objective is the *DEEN* method proposed in [Pro+24], where we consider the problem of reducing virus spreading in the system network (graph) while keeping the utility of the whole system at the maximal level. To balance the above two opposite goals, we propose Deep Epidemic Efficiency Network (DEEN), an unsupervised clustering method, which optimises graph efficiency in an epidemic scenario using Graph Convolutional Neural Networks and a novel loss function. Given the desired virus transmission, it constructs a graph partition for which the predefined transmission rate is not exceeded and utility function is maximised. We show that proposed method successfully solves three real-life problems: ride-pooling service in New York City, economic exchange between regions in Poland, and information sharing via peer-to-peer network. In particular, by dividing 150 New York taxi travellers into four groups our method increases epidemic threshold more than twofold at the cost of reducing utility only by 13%.The model can be instrumental in future pandemic outbreaks when we need to balance between maintaining efficiency and preventing the spread of the virus.

In [KCS21], we identify an effective control measure allowing to halt the spreading before the outbreaks (at 50 instead of 800 infections) without sacrificing the efficiency achieved by pooling. Fixed matches among co-travellers disconnect the otherwise dense contact network, encapsulating the virus in small communities and preventing the outbreaks.

Others During the course of the project two PhD students carried a research programme that will form a significant part of their dissertations (**PhD defences planned in 2025** (Michał Bujak, Farnoud Ghasemi). Remainder of their research program will be codnudcted under the *SUM* project which is a follow-up of this programme.

Non Achieved Objectives

COVID19 remark The proposal was written in 2020, during severe lockdowns, without prospects to quit pandemic and forget about it. Luckily, we forgot faster than we though and came-back to business as usual. Fortunately, the original research plan (how can travelling together in ride-pooling services help in pandemic urban mobility), happened to be outdated (at least until the next pandemic) and irrelevant. The COVID-related studies since 2021 were almost unpublishable, with editors' mailboxes clogged with pandemic-related studies wrote by authors often sacrificing quality for timeliness.
Such dynamic changes called for a strategic adaptation of the original research plan, which (in my opinion) was a successful adaptation. We first addressed the core of pandemic challenges related with ride-pooling (like in [KCS21; SK22; Pro+24]) and then developed the general methods and experimental studies (like in [KC24; BK24; GK24]).

On-going works Despite the end of the project, some on-going research is expected to be submitted to journal in the coming months, in particular:

1. Competition paper, where we simulate how MoMaS [GK24] can reproduce dynamics of two competing pooled service providers (which can allow better understand how virus-risky and virus-safe operations of competing providers may affect on risk-averse users) - to be submitted to *SciRep* in Dec 2024.
2. Individual pricing, where operator can shape pricing strategies at single agent-level to improve performance (including virus transmissivity) - submitted to *TR:C (Q1)* in Nov 2024.
3. Reinforcement Learning applied to optimize platform strategy to grow and maximise revenue and market share - presented at **IEEE ITSC** Conference[1], to be published soon.

[1] `https://its.papercept.net/conferences/scripts/abstract.pl?ConfID=87&Number=875`

4 Impact

With 6 papers published in journals, 13 conference proceedings, 3 presentations and 7 public repositories of code we contributed towards the field of ride-pooling.

The results of this project were directly applied in the Horizon Europe project *SUM*. In SUM we use the variety of ride-pooling methods, revolving around [KC20], to provide analytical support to introduce pooled on-demand feeder. We partnered with the City of Kraków on the LajkBus (`https://ztp.krakow.pl/kmk/lajkbus`) on-demand van service allowing travellers with areas poorly served with Public Transport. The service is planned to launch in Skotniki (Kraków) Oct 2024 and the initial assessment was based on our strategic planning, with the assessment methodology proposed in [Shu+24].

We proposed a set of methodological improvements which are generically applicable to any transport systems. Analysts, policymakers, platform-managers and transport modellers may apply them to understand:

(i) how ride-pooling networks may contribute to virus spreading [KCS21],

(ii) what is the potential of introducing hyper-pooled services with high occupoancy [KC24],

(iii) how will the system work if we include heterogeneity of traveller's behaviours [BK24],

(iv) what are the growth trajectories of two-sided platforms and how we can control them with regulations and pricing schemes [GK24],

(v) how to balance between efficiency and reducing virus spreading [Pro+24],

(vi) how to optimize how the drivers react to different strategies applied by platforms (in press),

(vii) drivers react to incentives to serve particular areas [GAK23],

(viii) how the ride-pooling problems scale with size [AK22],

(ix) what is the potential of pooling for big datasets [Shu+24].

The number of citations of our work let us think that the future of ride-pooling services will be impacted by the findings of *Post-Corona Shared Mobility*. If successful (and our results aimed to enhance potential success of ride-pooling) this will contribute to more sustainable urban mobility (less kilometres travellers, greater occupancies, lower emissions and congestion), more accessible transportation (filling white spots of public transport with affordable ride-pooling services) and efficient (requiring less subsidies from taxpayers money).

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