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A dynamic cooperation modelling for improving taxi fleet efficiency

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Abstract

In this paper, we propose to study the cooperation behaviour of taxi drivers to optimize a flexible transport service. An agent based model of a theoretical transport system is developed within the Netlogo software. Using simulations, we aim at comparing several optimisation processes for two kinds of associated taxis. The first service is guided by stop attractiveness, and the second service operates using simple communication and cooperation processes between vehicles. The main objective is to comprehend whether or not the cooperation between taxis has an important effect on the global service efficiency. For this study, we simulate the combination of both models to analyse competition *vs* cooperation phenomena in same context and simulations. Some statistical indicators and graphics are defined to quantify the transport service efficiency.
Keywords: flexible transport; ABM; optimization processes; cooperation behaviour; efficiency comparison;

1 Introduction

1.1 Flexible transport

A flexible transport is a public or private transportation service, whose time tables and routes can vary according to immediate client needs. [1] Flexibility depends on the kind of service operating: a regular line activated with at least a single client up to a fleet of responsive taxis which build their routes on the fly, according to spontaneous reservations. A flexible transport must be able to adapt itself to different needs of mobility, different types of spatial network configurations, operating under different technological and financial constraints from clients and carriers. There exist indeed several types of flexible transport.

In Africa, flexible transports are often informal (self-organizing and non corporate) and unsophisticated [2]. This kind of services are observed in the city of Dakar, for example, where corporate (public) transport is insufficient and inadequate, compared to the mobility needs [3,4]. For this work, we modelled two types of taxi services whose behaviour is inspired from illegal taxis (called "clandos") that we studied in Dakar. These informal taxis operate on the major city lanes and in the suburban areas. [5]. Those are collective services, operating without formal rules and communication means. The overall optimisation, when the case arises, emerges due to selfish behaviour from driver knowledge (called "coxeurs") [6].

For the last ten years, flexible transport has grown up in France with many different types of services such as Dynamic Responsive Transports (DRT). Since DRTs are considered to be firstly born in Africa under the term of bush taxis, several new dynamic and adapted services are developing in France or in Europe. They are based on flexibility, on communication and information technologies [7,8].

1.2 Context

In these types of self-organizing transport, it is rather difficult to determine how useful is the adaptability of the service compared to an efficient optimisation kernel (centralized service) that would perform on fixed periods after subsequent demand storage. Moreover, we do not know in what range some factors may influence the service efficiency: (i) individual taxi practice and experience, *i.e.* the way drivers respond to demand (anticipation, adaptation to real time information received), (ii) spatial and temporal structures (networks and flows in time) that help in grouping passengers and (iii) mobility system that allows to globally optimize the fleet and the routes. This research tackles these issues, especially the aspects (i & ii).

1.3 Objective

We propose to compare two types of optimisation processes applied by theoretical taxi services. Our objective is to evaluate what could be the contribution of a more or less sophisticated cooperation behaviour between taxis to improve the efficiency of flexible transport systems.

1.4 Agent Based Modelling (ABM)

We use the multi-agent paradigm [9,10] to model and simulate flexible transport systems. The Agent Based Model (ABM) approach has been accepted for the development and testing of Intelligent Transport Systems (ITS) [11] and the simulation of mobility systems [12]. In the latter, a complex Multi-Agent System is used to simulate, in detail, a large-scale mobility model (for example, at the level of a small country like Switzerland.). Whereas these research works focus on individual mobility, ABM allow us to focus more on vehicle optimization processes. In our case we design and compare different taxi driver behaviours to reflect on optimisation of transport systems. The simulations presented in this paper are fully theoretical. However, taxi drivers

behaviours are modelled after observation of real systems operating in Dakar. We studied them during a recent journey, thanks to a scientific cooperation between the university of Avignon and the Ecole Supérieure Polytechnique of Dakar. The objective of this paper is to focus on the interactions between vehicles and clients moving on their spatial support.

We use a methodology proposed in precedent works [13]. First, we design agents behaviour and the global model using the Unified Modelling Language. Then, several algorithms implement these behaviours and the model is simulated in the Netlogo environment. At the end of the simulation, we collect all the data and we export simulation pictures and movies to help in statistically and visually analyse the operating model.

2 Methodology

2.1 Structure of the model

As we can see on figure 1 and 2, we modelled two types of agents: the clients and the taxis. There are also two types of taxis (blue and yellow taxis) which differ in the way they move and communicate with each others. For each type, agents have the same behaviour. Their knowledge about the territory and the system functioning is very limited. They move on a virtual territory made up of a continuous land (pedestrians) and a road network (vehicles). The graph is non planar, non complete, and non directed. Stops and markets are nodes of the edges. The markets are the places of interest where the clients want to go. This territory contains 50 stops including 3 markets which are randomly generated.

Along the network, taxis continuously move from stops to stops and pick up clients to drop them at a targeted market. Clients are randomly and regularly generated in a constant quantity (200 clients every 500 iterations). Once generated, these pedestrians walk to the most attractive and the closest stop. Then they wait at a stop to catch a taxi to go to a market. They are considered to be served when they reach the market (fig. 3). In our example, each service involves from three to six taxis applying the same moving rules on the space and the network. Each taxi can carry a maximum of ten clients. Some details are provided in the figures 2 and 3. They describe the model structure and the agent activity.

Figure 1. Structure of the virtual territory: 3 blue and 3 yellow taxis operating at the same time on the same territory.

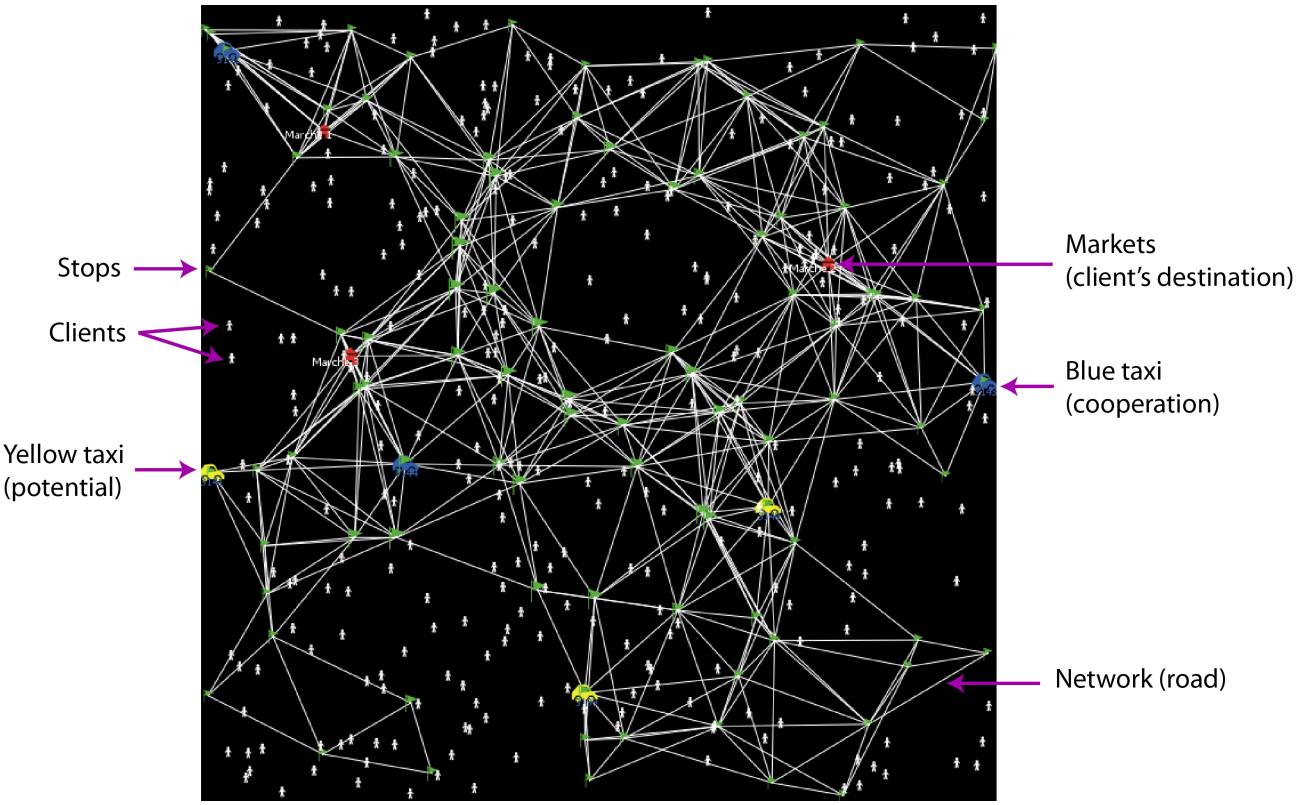

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Figure 2. Diagram of classes.

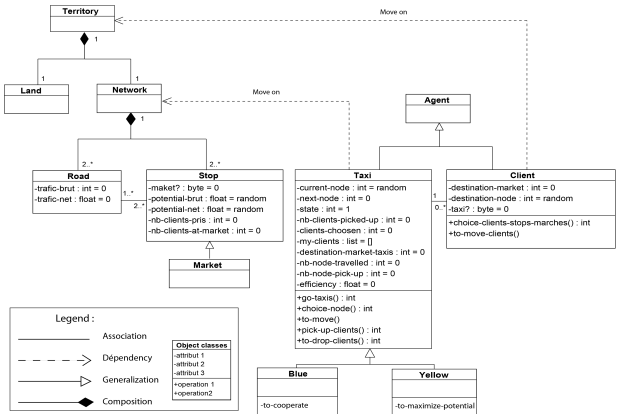
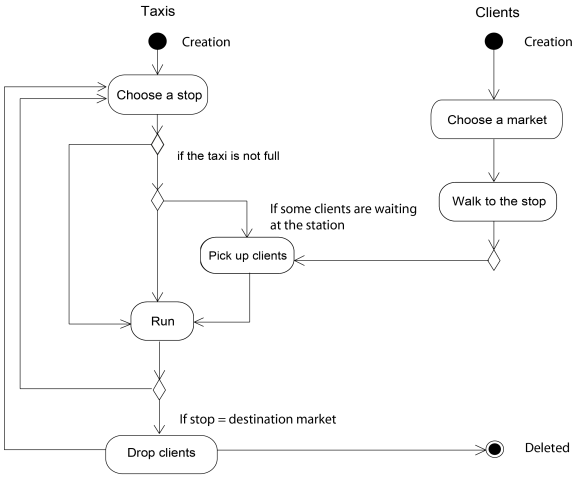


Figure 3. Activity diagram of agents.



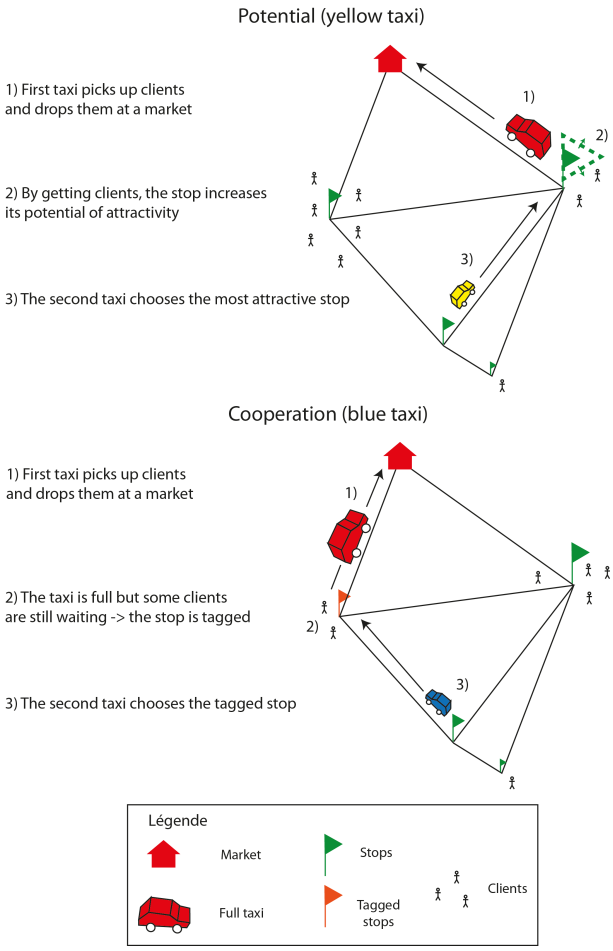
2.2 Optimization processes

The main objective of the model is to evaluate and to compare the ability of two types of taxi services to respond to spontaneous demand of mobility (fig. 4). Contrary to other works in Intelligent Transportation Systems [14] there is neither an explicit communication between vehicles, nor a centralized optimization system. Stops become the interface of communication between agents of a particular type, and between them and their clients.

We simulated two types of taxi driver behaviours in parallel:

- The first one (yellow taxis) operates using a potential of attractiveness. Three taxis target the most attractive stops, without any cooperation. The stop attractiveness is proportional to the number of agents having reached it. These taxis can be considered as reagents.
- In the second one (blue taxis), three taxis transmit some information about clients location to other taxis by tagging stops with waiting clients. Each taxi randomly moves on the network, prioritizing those stops that are tagged. Thus, blue taxis are cognitive agents.

Figure 4: Two optimization processes



2.3 Variables and indicators

To analyse the model results, we chose four indicators. Each indicator is collected for all taxis and is aggregated for both types of taxis. Here are the indicators:

- The *averaged relative gain* (fig. 5) of taxis is the number of clients picked up divided by the travelled distance.
- The *pick up rate* (fig. 6) is the number of stations where at least one client has been picked up by a vehicle, divided by the total number of covered stations (%).
- The *averaged occupation rate* (fig. 7) in the taxis is depicted by the distribution of the number of passengers in the vehicles, processed for all iterations.
- The *servicing rate* (fig. 8, 9, 10) is the ratio between clients who arrived at the market and the total number of clients generated during the simulation (a high value indicates a good service efficiency).

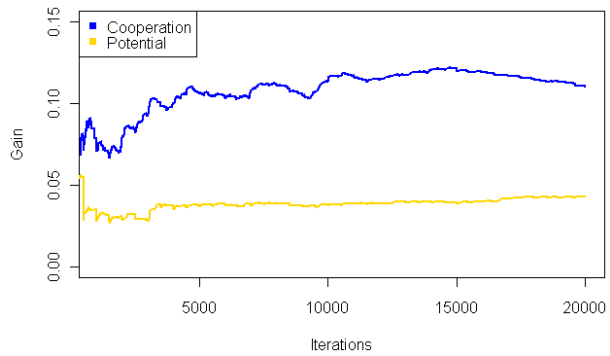
The third section presents a comparison of these two behaviours, according to several relevant variables and indicators.

3 Results

3.1 Local analyses: yellow *vs* blue taxi efficiency

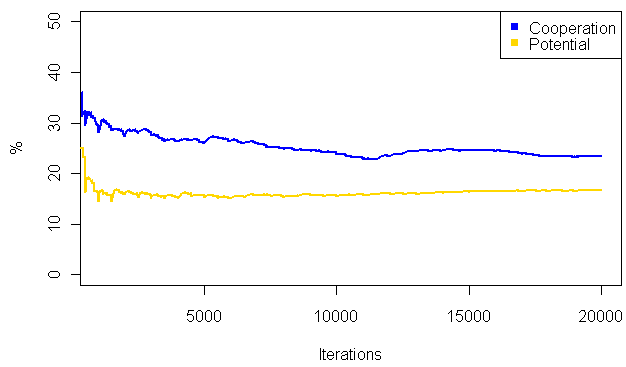
First, the figure 5 shows that blue taxis picked up much more clients than yellow taxis for an equal travelled distance, thanks to cooperation ability. We can notice a significant difference between averaged gains for all the simulations, even if the cooperation indicator seems less stable than in the case of taxis guided by potential attractiveness, due to randomness. This result shows a better space exploration despite a certain demand incertitude and a non negligible frequency for vehicles travelling to empty stops.

Figure 5. Averaged relative gain of taxis.



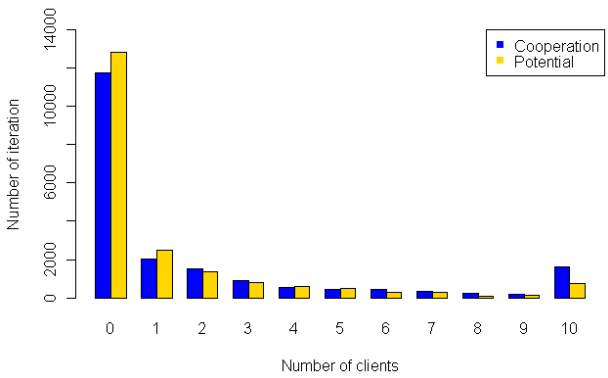
As we can see on the figure 6, the pick up rate of blue taxis smoothly decreases along the simulation. We explain it by the capacity of clients to target the most attractive and the nearest stops. Clients, who are sensitive to sites attractiveness, spontaneously group at the best located stops, often close to the markets, waiting for taxis. So, the randomized behaviour due to cooperating taxis is slightly less efficient at the end of the simulation. However, the indicator shows that cooperating taxis served more stops where clients are waiting than taxis attracted by potential. The outcome of such a cooperation based on a simple message assigned to the stations allows a 'clever' behaviour from the taxis, that improves the taxi efficiency.

Figure 6. Pick up rate.



Moreover, we can see a peak of occupation rate when the taxi is full (see 10th class, figure 7). This is due to the capacity of taxis to explore areas where some groups of clients are waiting together at tagged stations. This capacity partly explains the averaged gain improvement of blue taxis. Let us also notice the highest peak in the distribution corresponds to vehicles which pick up their first client (about half time or the transport operating).

Figure 7. Occupation rate within taxis.



3.2 Global analyse: comparison of servicing rates

The following figures (8, 9, 10) depict the evolution of the servicing rate for two simulated instances of optimisation. Let us recall the *servicing rate* is the ratio between clients who arrived at the market and the total number of clients generated during the simulation. This indicator allows us to compare two cases of services at a more aggregated level because it concerns the complete fleet of taxis: a first service involves six cooperating taxis, a second service associates three cooperating taxis and three non cognitive taxis only guided by stop attractiveness. This second simulation gathers the two systems we studied previously.

For each of them, we compute 10 simulations given the same network and the same parameters. Only the random demand process changes. Then we draw their servicing rate evolution along 20000 iterations, the thicker central curve (in red) corresponding to the averaged values of the 10 simulations.

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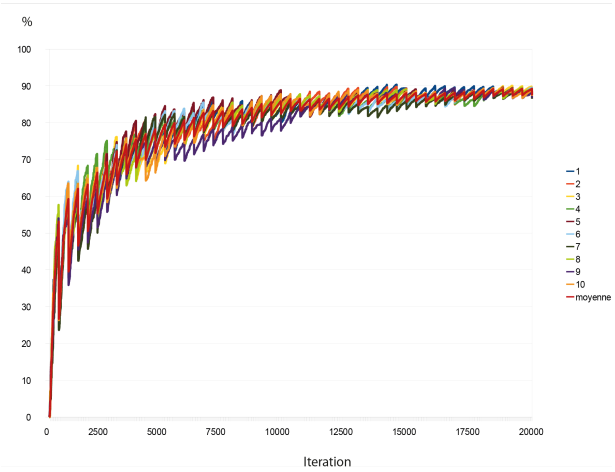
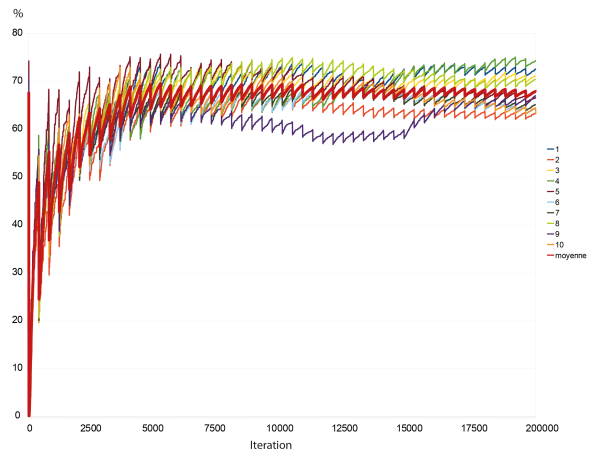
Figure 8: servicing rate evolution for 6 cooperating taxis



On the figure 8, we notice that the curves are very close to each others, moreover closer when the number of iterations increases. Although a non-negligible effect of the demand random process, the servicing rate does not vary much. Let us remark that the absence of tagged stops implies a complete random exploration of space to look for clients, at least at the begin of simulations. However, this state does not last very long: about 88% of the clients succeed in getting to a market at the end of the simulation. For each of them, the servicing rate becomes progressively stable. Some previous works show that this configuration is similar when considering only taxis guided by market attractiveness, whose behaviour strongly structures the territory due to cumulative flows reinforcing spatial attractors. The global servicing rate evolution is rather smoothed when the taxi driver behaviour is homogeneous.

Figure 9: servicing rate evolution for a set of 3 taxis guided by attractiveness and 3 cooperating taxis

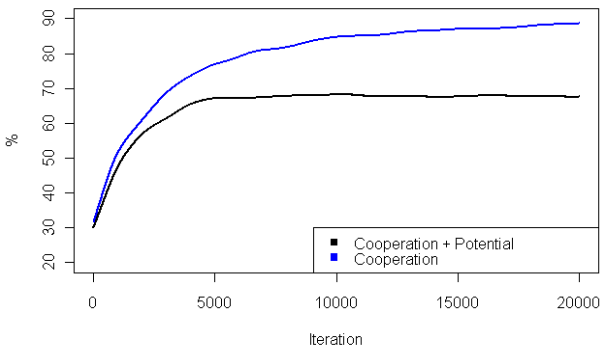


The figure 9 shows a different behaviour in servicing rate values. The variation is significant in a range of 15%. It is paradoxal compared to the previous results which showed converging pick up rates when taxis cooperate. Indeed, it seems that mixing the two different systems somehow destabilizes the global equilibrium with non negligible oscillations, even more marked when the maximum level of servicing rate is reached, at a noticeable value of 78%. However, this rate is lower than the one of a system gathering taxis applying the same behaviour (see for instance the figure 8, with a top value at about 90%).

This is illustrated by the figure 10, that summarizes these two situations in same conditions. The black line represents the servicing rate of the simulations previously analysed, including three blue and three yellow taxis. The blue line represents the servicing rate of a simulation with 6 blue taxis. It seems that cooperating taxis are globally more efficient than two separated services, notably after a long time of operating, where the deviation is more marked. Indeed, while the combined system quickly reaches a maximum, the cooperation system continues to increase.

Contrary to what one might think, we cannot observe a significant complementarity between both optimization processes. Even, there seems to be a weak decrease of the averaged servicing rate, which can probably be explained by the fact the territory is quickly structured by attractors, which draw the taxis and their clients into only a few locations. This new flow skeleton on the network seems then to hamper the cooperating system and induces a significant loss of the global efficiency.

Figure 10. Servicing rate for two different kinds of 10 similar simulations



We can propose a functional explanation to this observation. Indeed, these results highlight the influence of the transport system structure regarding the client spatial repartition and the taxi operating mode(s). To be efficient, the cooperating service must be able to randomly and homogeneously explore the whole territory to serve. In that way, these cooperating taxis can quickly empty the stops where some clients wait, on a very large area (this is confirmed by the figure 7). At the opposite, the taxis which maximize the market and stop attractiveness tend to encourage the grouping of the clients on a very few locations, usually close to the markets. Let us recall that, in this case, both taxis and pedestrians are sensitive to attractiveness. Hence, these stops are rapidly saturated in such a way that only three taxis guided by attractiveness are not enough to fulfil the mission. Many clients wait together at these locations which are unfortunately not often visited by the cooperating taxis, because they are, for most of them, close to each others.

4 Conclusive discussion

The approach proposed in this paper does not pretend to provide a generalized explanation on how cooperation can help in transport optimization. Nevertheless, it sets as a first contribution to comprehend flexible service behaviour in dense urban areas and cities, such as Dakar, where blue taxis supposed to cooperate and regular yellow taxis 'live' together.

Although it is not really surprising to find that cooperation between taxis improves transportation efficiency, these experiments show that the statistical deviations are significant between the two tested services. One lays on place attractiveness and hence introduces the network as a strong spatial support to guide the taxis. The other one bets on the only cooperation to improve the mobility efficiency, letting some kinds of local pheromones on stops, while considering the space structure as more passive. On a global point of view, the better efficiency of cooperating taxis should favour a knowledge sharing in flexible public transportation.

But let us keep in mind the utility function of a taxi is to maximize the individual profit. More distances, more incomes. In some cases, this may be in contradiction with a global efficiency optimisation. Indeed, we used an agent representation to model and study a utility function from the 'local transport authority' point of view. Only considering the cooperating service, this tends to show that a mixture of cooperation, regulation and competition could be potentially useful to improve the global efficiency of such flexible services. This needs to be proved by real operational services comparisons and by processing many simulations on different territories.

On another hand, these experiments open on questions about the complementarity between competing services. One could obviously think that any cooperation between different modes could be of interest. That does not seem to be the case when cooperating and attracted taxis are associated to serve the same territory. It is due to their differentiated impact on the network polarities: through the graph whose node attractiveness is changed, that will strongly influence the client location and subsequently the taxi moving in both systems. In further works, it will be interesting to undertake the analysis of those transport systems sensitivity and relationship. In what way can we make them cooperating, keeping a good balance between contradictory objectives at many levels (taxi, groups of taxis, transport local authority, carrier)? What is the optimal repartition of blue and yellow taxis for such a purpose? Should we use different perimeters for different systems, that partially overlap or only partition the space? Many issues that can be comprehended thanks to a recent three months journey in Dakar, where we questioned the taxi drivers about their practice.

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