# Optimal downsizing of the bus network in Lyon during the COVID-19 pandemic

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## 1 INTRODUCTION

The COVID-19 pandemic has impacted drastically the transportation networks in general, and the transit demand in particular. The demand has changed both quantitatively, since the total number of network users has decreased, and qualitatively, as some people feel more secure in private rather than public transport (see Tirachini & Cats (2020), Di Renzo *et al.* (2020) and SNCF Réseau (2021)). In this extreme case, network redesign techniques are not flexible enough to rapidly cope with such possible changes of the demand, and transit timetabling or scheduling can be adapted only to small variations of the demand. Consequently, the transportation networks are not capable of following such dynamic variations of offer and demand, and need to be resized dynamically in order to match the new lower demand while offering a guarantee of service quality. When such a modification of the demand occurs, what can transport operators do in order to make the supply match the demand? We propose a novel approach that joins topological modifications of the network (see Guihaire & Hao (2008) and Ukkusuri & Patil (2009)) to the flexibility of re-planning techniques (see D'Acierno *et al.* (2014)). Transit network design is a very widely studied research field, as widely discussed in the work of Barra *et al.* (2007) and the seminal work of Newell (1979)

Our approach considers a urban area (segmented in multiple zones) with a public bus transportation network that traverses the latter. We assume that the reduced demand is known. Our objective is to identify a sub-network (in terms of bus stops) of the original bus transport network that guarantees that: (i) the size (in term of bus stops) of the sub-network is reduced by a known preset factor $p_{elim}$; (ii) the access time between all urban zones and their closest node of the sub-network is not increased by more than a known preset factor $k$; (iii) for all possible pairs of origin/destination, the traveling time on the sub-network is not increased by more than a known preset factor $\alpha$. We highlight that the previous constraints operate in two opposite

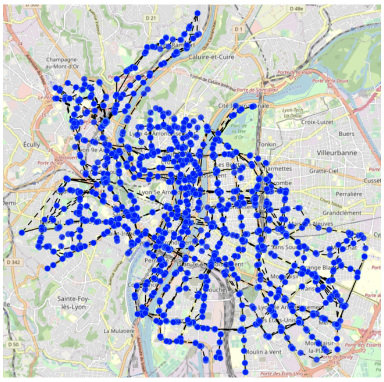

Figure 1 – *Map of Lyon's urban area*

| Notation | Description |
|---|---|
| $V$ | Set of bus nodes available in the analyzed urban area |
| $n_t = \|V\|$ | Number of bus nodes |
| $SP(v_1, v_2)$ | Traveling time of the shortest path between $v_1 \in V$ and $v_2 \in V$ |
| $U$ | Set of urban zone's centroids |
| $n_u = \|U\|$ | Number of urban zones |
| $d(u, v)$ | Access time between $u \in U$ and $v \in V$ |
| $d_{acc}(u)$ | Minimum access time from $u \in U$ to the public transport network |
| $acc(u)$ | Closest bus stop from $u \in U$ |
| $OD(u_1, u_2)$ | Demand from $u_1 \in U$ to $u_2 \in U$ |
| $p_{elim}$ | Minimum ratio of bus node to exclude |
| $\alpha$ | Admissible increase factor of the delay |
| $k(u)$ | Admissible increase factor of the the access time of $u \in U$ |
| $V_{sol} \subseteq V$ | Subset of $V$ which represents a solution |

ways. On the one hand, the size of the network shall be reduced. On the other hand, both the access time and travel time over the reduced network shall not deteriorate significantly.

Therefore, a sub-network is considered to be optimal if it induces a minimal global delay, weighted by the reduced demand. Finding such an optimal sub-network is the problem we are interested in. In this paper, we propose a general MILP (Mixed Integer Linear Program) solving the problem above, that we apply on the real case of Lyon's urban area (France) with the public bus network (see Figure 1).

## 2 MIXED-INTEGER LINEAR FORMULATION

We divide the urban area of Lyon into 1,464 zones that approximately contain the same number of inhabitants. We assume that we know the access time between the centroids of each urban zone and its closest node of the bus network. We also assume that we know the modified reduced demand that we model as an origin/destination matrix as well as the traveling time of the shortest path between any origin and any destination on the bus network. The possible origins and destinations of the demand are the centroids of the urban zones of $U$. Let us introduce some notations before defining the MILP.

For the topology of the network, we use the data of the transit network of Lyon (TCL) (see Dinsic (2021)). This database contains 1144 geographic positions of all the bus stops. The road segments and intersections are retrieved from Open Street Map, which is a collaborative project that maps the topology of the roads all around the world. The cost $c$ of the edges corresponds to the length of these roads. Consequently, the matrix $SP$ of the shortest paths between all pairs of bus stops is computed from these real distances. For the urban zones, we have taken the IRIS zones defined by the French institute of statistics and economic studies (INSEE). We divide the IRIS zones into smaller ones, and compute the centroids of these zones. The access time $d$ between the bus nodes and the centroids of the urban zones is the haversine distance between the corresponding geographic points.

Let us define, for all $u \in V$ and all $k \in {\mathbb{R}_+}^{n_u}$, $D_u^k = \{v \in V | d(u,v) \leq k(u) d_{acc}(u)\}$. We also define $M$ as an upper bound on the $d(u,v)$.

Let us consider the mathematical program $(P)$, with the decision variables $x$ and $d_{acc}^x(u)$. The decision variables $x$ represent the characteristic vector of a sub-network $V_{sol}$: $x(v) = 1$ if $v \in V_{sol}$ and $x(v) = 0$ otherwise. For each $u \in U$, $d_{acc}^x(u)$ represents the access time from $u$ to the closest node of $V$ that remains in the subnetwork: $d_{acc}^x(u) = \min_{v' \in v, x(v')=1} d_(u,v)$.

$$
\begin{array}{llcll}
min & \sum_{(u_1,u_2)\in U} OD(u_1,u_2)(d_{acc}^x(u_1) + d_{acc}^x(u_2)) & & & \\
s.t. & \sum_{v \in D_u^k} x(v) & \geq & 1 & \forall u \in U \quad (1) \\
 & d_{acc}^x(u) & = & \min_{v \in D_u^k} d(u,v) + (1 - x(v))M & \forall u \in U \quad (2) \\
 & d_{acc}^x(u_1) + d_{acc}^x(u_2) + SP(acc(u_1), acc(u_2)) & \leq & \alpha(d_{acc}(u_1) + d_{acc}(u_2) + SP(acc(u_1), acc(u_2))) & \forall (u_1,u_2) \in U^2 \quad (3) \\
 & \sum_{v \in V} x(v) & \leq & (1 - p_{elim}) n_t & \quad (4) \\
 & x & \in & {\mathbb{Z}_+}^{n_t} & \\
 & d_{acc}^x & \in & {\mathbb{R}_+}^{n_u} &
\end{array}
$$

First of all, one can prove that $(P)$ can be written as a MILP, because the minimum function in constraints (2) can be linearized. We give the following interpretation of constraints. Constraint (1) ensures that from any urban zone $u$, the access time to the closest node of the sub-network does not exceed $k(u)$, *i.e.* there is at least one node in the bus network at distance lower than $k(u)d_{acc}(u)$. Indeed, from $u \in U$, $D_u^k$ are the bus stops that are accessible in an acceptable time w.r.t the pre-defined requirements. Constraint (2) defines $d_{acc}^x(u)$ as the new access time from $u$ to its closest node of the sub-network. These decision variables are entirely defined by $x$ since we have equality constraints. Constraint (3) ensures that any itinerary's travel time does not increase more than by a factor $\alpha$. Constraint (4) ensures that the elimination ratio of bus nodes is at least $p_{elim}$. Finally, we conclude that the optimal solution of $(P)$ are the optimal sub-networks according to our criteria defined in the first section.

# 3 CASE STUDY IN LYON'S URBAN AREA

We choose the parameter's values as follows: $\alpha = 2$, meaning that for each trip, the traveling time one the reduced network can not exceed twice the original one. For all $u \in U$, $k(u) = 2$, meaning that for each urban zone, the access time to the network cannot exceed twice the original one. In our application, $p_{elim}$ takes values between 0.1 and 0.6, meaning that we ensure to delete between 10% and 60% of the bus stops.

This choice of parameters is a reasonable one for our real case-study, since the increase of access time is acceptable for most people (especially for the lower access times). Note that if the increase of access time or travel time is reduced, then some high values of $p_{elim}$ would make the problem unfeasible.

We use the optimization software CPLEX to solve the MILP on the real instances described above. We represent the solution in Figure 2 by representing the deleted bus stops in red while the remaining ones stay in blue.

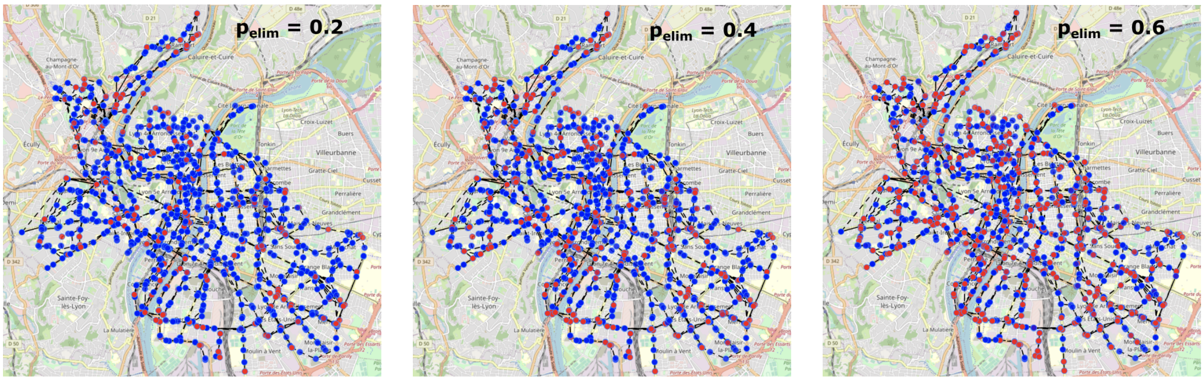


Figure 2 – *Map of remaining open stops in blue, and deleted stops in red for different values of* $p_{elim}$.

The optimal sub-networks we found with different values of $p_{elim}$ can act as an interesting raw material for further optimizations with other criteria. It can be useful, for instance, to decrease the number of lines in the network. One can decide of a threshold $t$, and close all the lines for which the percentage of remaining open stops is lower than $t$. This would provide the network designers with a decision tool that can help them evaluate which lines to keep open and which ones to close. One can also completely redesign the lines from the optimal sub-network. In both cases, the goal is to end up with a number of lines lower than before, inducing a lower operational cost without significantly degrading the level of service.

The optimal sub-network in terms of bus stops can also be useful to change the service frequency on the most impacted lines. If a bus line has many stops closed, then the frequency on this line can be increased in order to match the increasing demand on the remaining open stops.

As a final remark, note that the evaluation of the delay are here static, but we are currently working on a dynamic way to evaluate a solution, taking into account the dynamic traffic conditions. We would be pleased to present these updated results during the conference.

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