Network Effects in Bus Transit: Evidence from Barcelona’s Nova Xarxa

Hugo Badia, Juan Argote-Cabanero, and Carlos F. Daganzo

ITS Working Papers
UCB-ITS-WP-2016-01

ABSTRACT

This paper shows that improving the structure of a bus transit network to facilitate transfers can boost and shape its demand. The idea is illustrated with data from the Nova Xarxa in Barcelona. Deployed in phases, the Nova Xarxa is shown to be attracting more demand than the network it replaces. The paper further shows that this growth is underpinned by transfers -- at the end of 2015, the percentage of trips that involved a transfer was approximately 26%, and it reached a maximum of 57% for line V7. The paper shows these numbers should increase considerably (to 44% and 66%, respectively) once the Nova Xarxa is completed in 2018. This should be compared with the percent of transfers in other existing bus systems, which ranges from 1.3% to 16%.

Keywords: Public transport, Bus system, Bus network design, Transfer-based network, Network effect

INTRODUCTION

This paper presents an empirical analysis of a transfer-based bus network, the *Nova Xarxa* in Barcelona. It attempts to prove two ideas contrary to conventional wisdom: (a) that transit passengers are much less averse to transfers than assumed in current planning practice, and (b) that properly designed transfer-based networks can be very appealing and even attract more demand than their conventional counterparts. To do so, the analysis examines the jumps in demand as new lines and connections were opened in the transfer-friendly *Nova Xarxa*. The observed patterns are found to exhibit a strong network effect, which cannot be explained without a high percentage of transfers. It is also found that the new system attracts considerably more demand than the network it is replacing, attesting to its appeal.

Two bus network design concepts are generally considered by transportation planners: direct-service and transfer-based *(1,2)*. The main difference between the two is how origin and destination pairs are connected. The former encourages direct trips, so most users can complete their travel using a single line. The latter also connects some origin-destination pairs directly, but most are not, so transfers are considered an integral part of the design.

Conventional wisdom dictates that transfers should be minimized since users perceive them negatively. The idea is supported by different studies summarized in *(3)*, which quantify the time penalty equivalent to a bus-to-bus transfer to be between 5 and 50 minutes for the connections in the systems studied. Therefore, many planning efforts have focused on direct-service strategies. In this spirit, some network design models strive to minimize the number of transfers *(4)*, while others constrain their number *(5)*.

In some cases, however, transfer-based networks might be better able to satisfy dispersed mobility patterns. This idea is supported by analytical studies *(6-8)* and, to some extent, by empirical studies that have compared different regions with different network types *(9-12)*. These empirical studies are somewhat limited, however, because they lack longitudinal data. And unlike the work to be presented, they do not focus on the stimulation of demand, transfers or the network effect.

To maximize their appeal, transfer-based networks should have three properties: (i) provide full area coverage with easy transfers and non-circuitous routings; (ii) be easy to understand (e.g. a pure grid); and (iii) operate with high frequency. These features should reduce riders' aversion to transfers and encourage usage; see *(13)* and *(14)*.

The *Nova Xarxa* is unique in that it is the first instance in which a complete direct-service network is being replaced by a transfer-based network that meets the three conditions above. The design is based on plans outlined in *(15)* and the model in *(16)*. The *Nova Xarxa*'s rollout started in 2012, and after several intermediate deployment phases should be completed in 2018. This gradual deployment has created an excellent natural experiment to test the validity of ideas (a) and (b) above with the longitudinal data that it has generated.

The paper describes these tests. It is organized as follows. The second section provides background; it compares Barcelona's pre-existing network with the *Nova Xarxa*. The third section describes the evolution of bus boardings in the *Nova Xarxa* from 2012 to 2015, which unveils a significant network effect. Then, the fourth presents the results of a demand analysis that estimates transfers and establishes the validity of ideas (a) and (b). The fifth section presents some conclusions. The final section, which can be skipped without loss of generality, discusses the technical analysis used in this paper.

BARCELONA'S BUS SYSTEM: THE NETWORK REDESIGN

Barcelona's old urban bus network had 63 direct-service lines with many centripetal routes. The new bus network, the *Nova Xarxa*, will serve the whole city with 28 lines and replace most of the old bus network so that only 20 secondary routes of the old network will be retained. The *Nova Xarxa* will be formed by 8 horizontal lines, 17 vertical and 3 diagonal. The latter will serve three major corridors and be superimposed on a rectangular grid formed by the rest. As of 2015, thirteen of these lines have been opened to the public. Figure 1 shows the 2015 network side by side with the old system. These two maps show that from a user's perspective, the *Nova Xarxa* already exhibits properties (i) and (ii) above, unlike the old system. It has and will continue to have full coverage with non-circuitous routes that are clearly shown on the map.

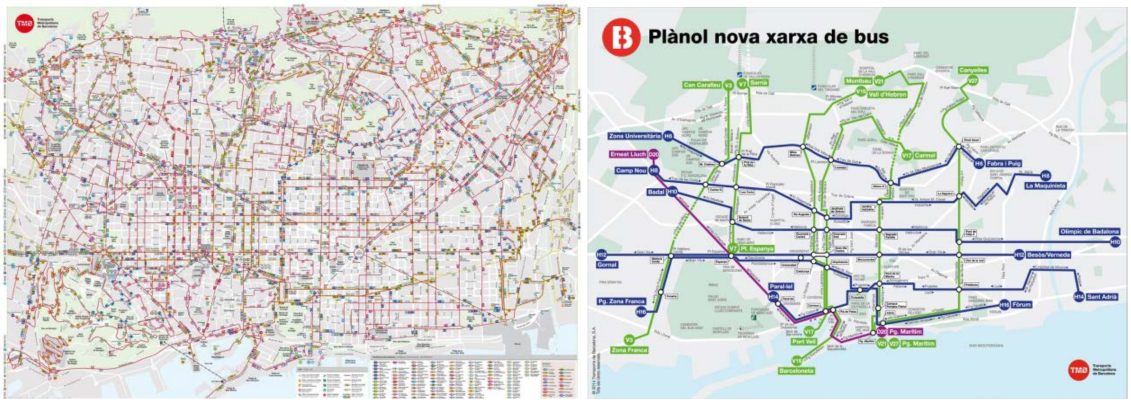


FIGURE 1 Maps of the old bus network and the Nova Xarxa in 2015. (Source: *(17)*)

Property (ii), understandability, is further reinforced by navigational aids on the street and in the buses. Figure 2 shows the diagrams that are provided at transfer locations. These diagrams include: the lines that serve the transfer point, their directions, the station locations, and the recommended walking paths for connecting passengers.

FIGURE 2 Transfer point information examples. (Source: *(17)*)

Now consider property (iii), high frequency. The *Nova Xarxa* will eventually be served by 573 buses with an average headway of 6.18 min, similar across all lines. Contrast this with the old bus network which was served by 761 buses with an average headway of 12.30 min. Thus, the *Nova Xarxa* will use fewer buses but deliver nearly twice the service frequency of the old network.

Gradual implementation process until 2015

Barcelona's old bus network was in full operation until September 2012, when the first instalment of the Nova Xarxa was opened to the public. At that time redundant lines of the old network were eliminated. By December 2015, two more portions of the Nova Xarxa had been opened, and two more sets of old redundant lines had been eliminated. Table 1 summarizes the characteristics of the new lines, and lists the old lines they replaced.

As Table 1 shows, the new lines are being operated with slightly longer headways than those planned for the final phase. This occurs because the agency has to devote bus resources to populate many old lines that cannot be removed because they serve O-D pairs not yet covered by the new network. Since there will be few of these O-D's in the final phase, the idea is to increase the frequency of the new routes to their final targets at that time, when few old lines will have to be retained and populated. As of December 2015, 235 vehicles served the 13 new lines implemented to date.

TABLE 1 Implemented *Nova Xarxa* lines: key features and removed old lines

Phase (Date open)	Bus line	Current headway (min)	Design headway (min)	Bidirectional Length (km)	Old bus line (removed)
1 (10/1/12)	H6	6.0	5.0	9.7	L74
	H12	6.0	3.0	11.4	L56
	D20	6.0	4.0	9.2	L57*[c], L157*[c]
	V7	7.0	7.0	5.1	L30
	V21*[a]	7.0	6.0	8.2 (9.5)*[a]	L10
	Total			**84.1**	
2 (11/18/13)	H8	6.5	5.0	13.0	L15
	H10	6.5	3.0	13.2	L43, L44
	H16*[b]	7.5	5.0	Ph. 2: 4.0 - Ph. 3: 12.2*[b]	Ph. 2: L14*[c], L36*[c], L41*[c] - Ph. 3: L9
	V3*[a]	7.0	5.0	7.5 (8.7)*[a]	L72
	V17	7.0	6.0	8.8	L28, L19*[c], L40*[c]
	Partial			98.1	
	Total			**182.2**	
3 (9/15/14)	H14	8.0	8.0	8.1	L141
	V15	6.5	4.0	8.7	L17, L16
	V27	8.0	8.0	11.1	L71
	Partial			61.3	
	Total			**243.5**	

*[a] These lines cross a tunnel where there are no stops. For this reason, the tunnel length is removed. The total bus line length is displayed in parenthesis.

*[b] This line was implemented in Phase 2 but was extended in Phase 3, for this reason, two lengths are displayed.

*[c] These lines were shortened to avoid overlap with the new lines, but not totally removed.

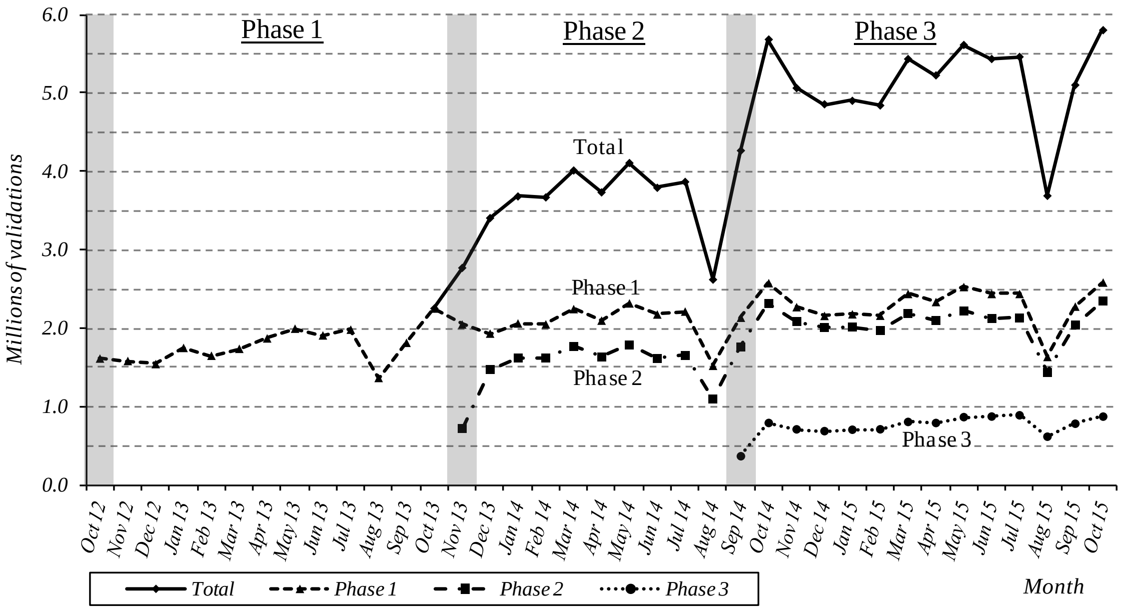
RAW DATA INTERPRETATION: THE NUMBER OF BUS BOARDINGS AND THE NETWORK EFFECT

To see how the network configuration influences travel we tracked the number of ticket validations per month for every line as the network was expanded. In both the old and the new systems, users validate their tickets upon boarding every bus, including transfers. Therefore, validations slightly overstate the number of trips taken by paying customers, since some trips involve more than one boarding. Data collection started in October 2012 when the first lines were opened to the public, and ended in October 2015.

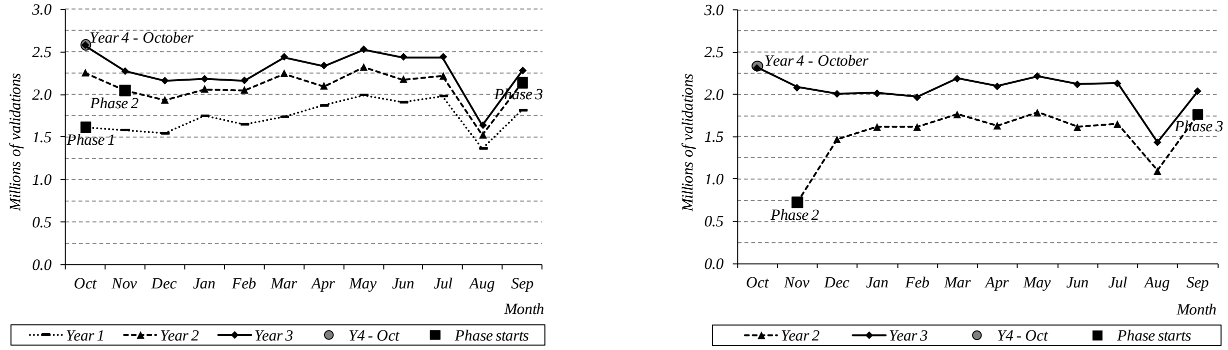
The solid line of Figure 3(a) shows that the total number of validations in the *Nova Xarxa* consistently increased when new lines were opened. This is not surprising since the service was being expanded. A bit more surprising, however, is the fact that if we group the lines by the phase in which they were implemented (see the dotted and dashed lines labelled "Phase 1", "Phase 2" or "Phase 3") one can see how after each transition, the validations on each set of lines increased to a new baseline level. The actual changes can be more clearly seen in Figures 3(b) and 3(c), which superimpose the yearly profiles of these validations. [The 4th year is incomplete. It belongs to Phase 3 and consists of a single month (October), which is marked in the figures by a thick dot. As one might expect, the dot coincides in both cases with the corresponding point for the previous October, which is also in Phase 3.]

The observed jumps in validations from one phase to the next strongly suggest that the implementation of new bus lines leads to an increase in the boardings of pre-existing lines, most likely due to the new connections and the possibility to link more origin-destination pairs with a single transfer. In other words, the jumps likely are a manifestation of the network effect that arises when high-frequency lines provide extended coverage to an entire region.

The evidence is fairly conclusive. The jumps in the curves of Figure 3 are unlikely due to seasonal effects since the curves show similar profiles in different years and their jumps are quite pronounced. In particular, note that the number of boardings for the lines of Phase 1 grew by about 31.7% as Phases 2 and 3 were completed.



(a) Time series of monthly validations in the Nova Xarxa



(b) Validation profiles for lines opened in Phase 1 **(c) Validation profiles for lines opened in Phase 2**

FIGURE 3 Total monthly validations for groups of implemented lines

Furthermore, this notable growth in boardings for specific lines cannot be attributed to an improving economy or any another factor that could stimulate the demand for transportation. During the study period, Barcelona’s overall transit ridership (including Metro, light rail and all bus services) and private vehicle demand levels remained approximately unchanged. This is shown by the solid line of Figure 4, which tracks the number of overall transit trips from 2011 until 2014. The line decreases by 2.1% in a very narrow band. The pattern is almost identical for private vehicle trips. This is shown by the dashed line, which decreases by 3.2% between 2011 and 2014. These declining numbers indicate that the boarding increases seen in the *Nova Xarxa* were not the result of a benign economic climate or an overall increase in the city's demand for mobility.

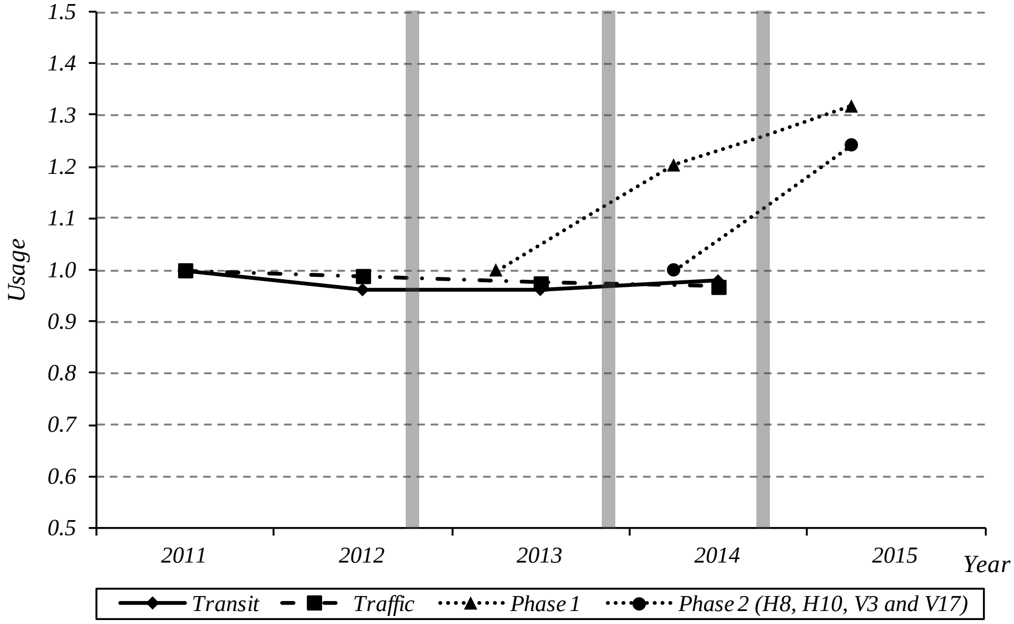


Figure 4. Usages of various transport modes from 2011 to 2015: initial usages are set to 1. (Source for transit and traffic data: (*18)-(21)*)

Further supporting the presence of network effects is that positive jumps in boardings were consistently observed for all lines and all phases. In particular, as shown by the dotted line marked with triangles in Figure 4, the aggregate boardings on Phase 1 lines increased 20.3% from Phase 1 to Phase 2 and by another 9.5% from Phase 2 to Phase 3. The growth in boardings by the lines deployed in Phase 2 is best captured by ignoring line H16 because this line was not held fixed (line H16 was extended so substantially in Phase 3 that its validations quadrupled). The fixed lines that remained grew by 24.2% from Phase 2 to Phase 3, as depicted by the dotted line marked with circles in Figure 4.

In summary, this section has established that the *Nova Xarxa*'s lines exhibit: (i) boarding volumes that have increased at a higher pace than any of their transit or private vehicle alternatives; and (ii) jumps in these boardings that occur as new lines are deployed. All of the above points to the appeal of the new system and the existence of a positive network effect that arises with the implementation of new lines. Passengers must be taking considerable advantage of transferring opportunities. The next section estimates the number of passenger trips taken (the demand) for each line, and the percent that transfer.

ANALYSIS: TRIPS TAKEN AND THE PERCENT THAT REQUIRE TRANSFERS

Because only ticket validations are observed a model was constructed to break these validations into transfers and initial boardings. Since the latter correspond to trips taken, this breakdown enabled us to assess the growth in travel demand, and in the percent of demand that requires transfers. This section focuses on the results of this model, and only describes its logic qualitatively. A full description is given in the final technical analysis section.

If transit users were to avoid transfers, one would expect demand levels in already deployed lines not to be affected as new lines are implemented. Therefore, it stands to reason that the demand and the percentage of transfers can be teased out from the longitudinally observed growth in validations per line by examining its statistical relationship to the fixed length of the line and the growing length of the connecting lines. As explained in the final section, a parsimonious two-parameter regression model does the job. The model predicts both, the number of monthly passenger trips and the number of monthly passenger trips with a transfer, for each line during each of the network deployment phases.

The model's two parameters are assumed to be different for each line. Therefore, they were separately estimated across them. Only lines opened in Phase 1 were considered because only they contained sufficient longitudinal information to estimate their parameters. Opened in Phase 1, line D20 was excluded because its parameters could not be reliably estimated. D20 is a diagonal line in the periphery that is connected at sharp angles to other lines. As a result, many of its connecting paths are too circuitous to be practical. This feature makes estimation less reliable because it requires assumptions about route choice.

This left lines H6, H12, V7 and V21. For maximum statistical efficiency, all data from Phases 1-3 were used. Only lines opened in Phase 1 were selected because (i) they were longitudinally observed the longest (under three different network configurations); and (ii) their basic demand (without transfers) was easier to isolate without specification error because Phase 1 included the fewest connecting lines. The resulting model was then applied to all the lines and phases, past and future, to predict the demand and the percent that involves transfers.

Table 2 displays the predictions. For each line and implementation phase, the table includes the total monthly demand, the number of transfers, and the corresponding percentage. The values obtained indicate that the number of validations involving transfers increases with successive phases to a considerable fraction of the total. In the third phase, 26% of the trips involve a transfer, and for line V7 the number rises to 57%. These values are expected to increase further as new *Nova Xarxa* lines are deployed in the phases to come. Ultimately, the model predicts that transfers will represent more than 44% of all trips in the final phase and almost 66% for line V7. Thus, it seems apparent that given the right conditions and contrary to conventional wisdom passengers will embrace transfers. In other words, the results strongly support idea (a) of the introduction.

It is also worth noting that transfers seem to be occurring because the network was designed to encourage them. The *Nova Xarxa*'s current 26.3% value already exceeds by a wide margin the transfer percentages of the old bus network, which was about 11% *(22)*. Both the current and forecasted values are also much higher than the percentage of transfers in other urban bus networks that are less transfer friendly: Melbourne 16% *(23)*, or Boston 1.5%, London 13% and New York 3% *(24)*. These numbers are consistent with the idea that a network designed for transfers can attract transfers. They also suggest that such a network could also attract more demand than a direct-service network -- idea (b) of the introduction.

TABLE 2 Trips generated and percent of trips with transfers for each line and in total

	Line	H6	H12	V7	V21	Total
Phase 1	Monthly demand	467,572	407,824	101,765	241,204	1,218,365
	Number of transfers	26,375	50,016	37,018	22,527	135,936
	Percentage transfers	5.6%	12.3%	36.4%	9.3%	11.2%

Phase 2	Monthly demand	499,747	454,308	137,929	268,598	1,360,582
	Number of transfers	58,549	96,500	73,181	49,922	278,153
	Percentage transfers	11.7%	21.2%	53.1%	18.6%	20.4%
Phase 3	Monthly demand	539,051	475,054	150,906	276,433	1,441,444
	Number of transfers	97,854	138,385	86,159	57,757	380,154
	Percentage transfers	18.2%	29.1%	57.1%	20.9%	26.4%
Final phase	Monthly demand	682,823	716,536	189,384	301,701	1,890,445
	Number of transfers	241,626	379.867	124,637	83,025	829,155
	Percentage transfers	35.4%	53.0%	65.9%	27.5%	43.9%

Further analysis confirms this idea. That new demand is stimulated by the new network can be seen by comparing the demand of the new lines versus those that they replaced. To compare apples with apples we verified from the map that the replaced lines had similar or better coverage than the new lines. This is weakly confirmed by the rough similarity in the monthly demands of the new and replaced lines, which are shown on the first two rows of Table 3. The values for line V7 are dissimilar because V7 is considerably shorter than the line it replaced. So, to test idea (b), compare now row 1 with row 3, which displays the current total monthly demand of the new lines in Phase 3. This approximates the extra demand due to the improved connectivity, ease of use and level of service of the transfer-based network. As can be seen from the table, the difference exceeds 20% for lines H6, H12 and V7, and is about 6% for line V21. This strongly supports idea (b) – that a properly designed transfer-based network can induce extra demand.

TABLE 3 Monthly demand for the new lines and the old lines they replaced

Line	H6	H12	V7	V21
Equivalent monthly demand of replaced old lines	446,856 (L74)	381,897 (L56)	122,086 (L30)	261,093 (L10)
NX monthly base demand (0-transfer)	441,197	357,808	64,748	218,676
NX total monthly demand (Phase 3)	539,051	475,054	150,906	276,433

CONCLUSIONS

Analysis of the *Nova Xarxa* shows that a well-designed transfer-based network can attract new users, and that these users will not be averse to transferring. The acceptance of transfers by transit users not only means that more trips can be completed using a network but that an agency can operate more effectively by consolidating service in well-connected, high-frequency corridors.

In the case of Barcelona, the case study reveals that the new lines are already serving more demand than the pre-existing lines they replaced. Furthermore, the current levels have been reached after a gradual increase concurrent with the expansion of the network. This increase contrasts with a slight declining trend for all transportation modes. This strongly suggests that the growth in demand is due to network effects of the new design and not to other economic, social, or urban factors.

The results also show that the new network is drastically reshaping the demand. While conventional bus networks in big cities exhibit transfer percentages ranging from 1.5% to 16%, the *Nova Xarxa* current percentage is 26% -- and this value is projected to rise to 44% when the number of lines is expanded from 13 to 28 at the project's completion in 2018. These considerable numbers support the notion that transit users will transfer if given an attractive chance.

In view of these findings we recommend that transfers be systematically considered as an integral part of bus network design, much as when considering subway systems. The case study in this paper shows that, properly designed, transfer-based bus networks can capture much demand and be an effective mobility solution for many cities.

TECHNICAL ANALYSIS

This section can be skipped without loss of generality.

Demand Model

A regression model is proposed. It assumes that the number of validations in a line, V_k, arises from two demand types: (i) direct trips, where origin-destination pairs can be served without a transfer and therefore must lie in the influence area of line k; and (ii) one-transfer trips for origin-destination pairs requiring transfers. To simplify the analysis, we assume that the generation rates for trips of type (i) and (ii) are uniform in space for each line, although they can vary across lines. Except where indicated, the model shall assume that the influence areas of the various lines, where trips are generated, do not overlap.

Although a detailed analysis would take into consideration the station-to-station O-D demands and a route assignment, this can be avoided here because Barcelona's network closely resembles a homogeneous rectangular grid. To see how this helps, assume for the moment that the grid is perfect with no overlaps and similar frequencies everywhere where people choose the shortest path. Furthermore, since the stop spacing is practically constant, ignore the stops and assume that people walk to/from the closest line. Also let's (reasonably) assume that each line has a catchment area of uniform width where the trip generation rates for direct trips and 1-transfer trips are uniform. These rates are assumed to be proportional to the number of destinations in the respective catchment areas. It is then possible to express the trip generation rate of each type as a function of the length of the line and the combined length of the lines that have a direct connection with it.

To do this, let V_k be the number of boarding validations for line k in some specific month, l_k be the line's length, and $l_{1,k}$ the combined length of the lines that connect with it at the time of observation. With the assumptions above, the number of validations should increase linearly with both lk and $l_{1,k}$. Thus, the proposed regression model is:

$$V_k = \beta_{0,k} l_k^2 + \beta_{1,k} l_k l_{1,k} \qquad (1)$$

The first term of (1) represents the number of trips generated with destinations along the line, and therefore no transfers. This is the direct demand. The second term represents the number of boardings with origin (or destination) on line k and destination (or origin) on the connecting lines. Note that only one half of these validations are outbound trips from line *k*. Thus, the formulas for total transfers, X_k, and total demand, D_k, generated by line k are:

$$X_k = 1/2 \beta_{1,k} l_k l_{1,k} \qquad (2a)$$

$$D_k = \beta_{0,k} l_k^2 + 1/2 \beta_{1,k} l_k l_{1,k} \qquad (2b)$$

So far we have assumed that we have a grid with a well-defined routing for each O-D pair. However, Barcelona is not a perfect grid, and there are a few locations where two lines overlap. This requires a modification of (1) because in the region of overlap some people can choose either of the two lines, and this provides a routing option that splits the demand. The modification should consider the length of overlap and take into account the overlapping lines' frequency ratio in order to reflect such demand split.

On account of the overlap, the new model introduces two additional definitions of line lengths: the length of the overlap region, lo,k; and the combined length of all lines that connect with this region, $l_{1,o,k}$. It is also necessary to introduce ηo,k as the fraction of buses flowing on the overlapping region that are not on line *k*; i.e., the ratio of the overlapping line frequency and the total frequency. This ratio is an approximation for the fraction of the demand that is syphoned away by the overlapping line. In terms of headways, with H_k representing the headway of line k and $H_{o,k}$ the headway of the overlapping line, the expression is:

$$\eta_{o,k} = (1/H_{o,k})/(1/H_k + 1/H_{o,k}) \qquad (3)$$

With this notation, the specification for the demand of a line *k* that experiences and overlap of length $l_{o,k}$ is:

$$V_k = \beta_{0,k}(l_k^2 - l_{o,k}^2\eta_{o,k}) + \beta_{1,k}(l_k l_{1,k} - l_{o,k} l_{1,o,k}\eta_{o,k}) \quad (4)$$

$$X_k = 1/2\beta_{1,k}(l_k l_{1,k} - l_{o,k} l_{1,o,k}\eta_{o,k}) \quad (5a)$$

$$D_k = \beta_{0,k}(l_k^2 - l_{o,k}^2\eta_{o,k}) + 1/2\beta_{1,k}(l_k l_{1,k} - l_{o,k} l_{1,o,k}\eta_{o,k}) \quad (5b)$$

The least squares regression method was then used to fit Equation (4) to the data from each line and in this way obtain four sets of β-estimates. Part (a) of Table 4 summarizes these data for lines H6, V7 and V21. These lines do not exhibit significant overlaps and therefore, $l_{o,k} \equiv 0$. The table also includes the dependent variables V_k. Part (b) of the table summarizes the data for line H12, which overlaps significantly with line H16. Therefore, the table includes its $l_{o,k}$, $l_{1,o,k}$ and $\eta_{o,k}$ values on separate rows.

TABLE 4 Estimation data

(a) Lines H6, V7 and V21: $l_{o,k} \equiv 0$

Line:		H6	V7	V21
l_k (km):		9.70	5.11	8.18
$l_{1,k}$ (km)	Phase 1	13.28	26.87	24.90
	Phase 2	29.48	53.12	55.18
	Phase 3	49.27	62.54	63.84
	Final phase	121.66	90.47	91.77
V_k (val./month)	Phase 1	493,396	139,880	263,862
	Phase 2	559,272	205,859	316,317
	Phase 3	636,431	240,423	335,337

(b) Line H12

Line:	H12	l_k (km):	11.38	
Phase:	1	2	3	Final
$l_{1,k}$ (km):	17.42	33.61	53.73	139.14
$l_{o,k}$ (km):	-	-	4.17	4.17
$l_{1,o,k}$ (km):	-	-	34.31	42.40
$\eta_{o,k}$:	-	-	0.44	0.44
V_k (val./month):	450,804	563,196	605,949	-

Results

The following table summarizes the results obtained for each line.

TABLE 5 Results for lines H6, V7, V21 and H12

Line H6	R^2	Adjusted R^2	Std. error	F	Significance
	0.996	0.995	38,561	2586	0.000
Explanatory variable coefficient		Std. error	Significance	Conf. Int. 70%	VIF
$\beta_{0,H6}$	4689.1	193.4	0.000	4483.8 - 4894.4	5.35
$\beta_{1,H6}$	409.5	55.1	0.000	351.0 - 468.0	5.35
Line V7	R^2	Adjusted R^2	Std. error	F	Significance
	0.994	0.994	16,024	1865	0.000
Explanatory variable coefficient		Std. error	Significance	Conf. Int. 70%	VIF

$\beta_{0,V7}$	2479.6	414.5	0.000	2039.6 - 2919.5	10.91
$\beta_{1,V7}$	539.2	42.5	0.000	494.1 - 584.2	10.91
Line V21	R^2	Adjusted R^2	Std. error	F	Significance
	0.990	0.989	32,961	1039	0.000
Explanatory variable coefficient		Std. error	Significance	Conf. Int. 70%	VIF
$\beta_{0,V21}$	3268.1	306.3	0.000	2943.0 - 3593.3	9.26
$\beta_{1,V21}$	221.2	49.3	0.000	168.9 - 273.6	9.26
Line H12	R^2	Adjusted R^2	Std. error	F	Significance
	0.999	0.998	26,914	4900	0.000
Explanatory variable coefficient		Std. error	Significance	Conf. Int. 70%	VIF
$\beta_{0,H12}$	2762.9	114.6	0.000	2641.2 - 2884.5	7.00
$B_{1,H12}$	504.6	36.2	0.000	466.2 - 543.0	7.00

The parameter values were entered in (5) to predict the monthly number of passenger trips (and passenger trips with transfers) generated by each line in the four phases of the project, using the explanatory variables in Tables 4 and 5. Tables 2 and 3 of the fourth section contain the results.

ACKNOWLEDGMENTS

H. Badia was funded by an FPU grant, reference number AP2010-4544, from the Spanish Ministry of Education. The authors would also like to thank Transports de Barcelona for providing access to the relevant dataset and their valuable feedback. Lewis Lehe provided valuable comments.

REFERENCES

1. Vuchic, V. *Urban Transit: Operations, Planning and Economics*. John Wiley and Sons, New Jersey, 2005.
2. Dodson, J., P. Mees, J. Stone, and M. Bruke. The principles of public transport network planning: a review of the emerging literature with select examples. *Urban Research Program*, Issues Paper 15, 2011.
3. Currie, G. The demand performance of bus rapid transit. *Journal of Public Transportation*, Vol. 8 No. 1, 2005, pp. 41-55.
4. Zhao, F. Large-scale transit network optimization by minimizing user cost and transfers. *Journal of Public Transportation*, Vol. 9, No. 2, 2006, pp. 107-129
5. Baaj, M., and H. Mahmassami. Hybrid route generation heuristic algorithm for the design of transit networks. *Transportation Research Part C*, Vol. 3, No. 1, 1995, pp. 31–50.
6. Thompson, G.L. Planning considerations for alternative transit route structures. *Journal of American Institute of Planners*, Vol. 43, No. 2, 1977, pp. 158-168.
7. Daganzo, C.F. The break-bulk role of terminals in many-to-many logistic networks. *Operations Research*, Vol. 35 No. 4, 1987, pp. 543-555.
8. Badia, H., M. Estrada, and F. Robusté. Bus network structure and mobility pattern: A monocentric analytical approach on a grid street layout. *Transportation Research Part B*, Vol. 93A, 2016, pp. 37-56.
9. Schimek, P. Understanding Differences in Public Transit: Comparison of Boston and Toronto. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1604* (1), Transportation Research Board of the National Academies, Washington, D.C., 1997, pp. 9-17.
10. Thompson, G.L., and T.G. Matoff. Keeping up with Joneses: planning for transit in decentralizing regions. *Journal of the American Planning Association*, Vol. 69, No. 3, 2003, pp. 296-312.
11. Brown, J.R., and G. L. Thompson. Examining the Influence of Multidestination Service Orientation on Transit Service Productivity: A Multivariate Analysis. *Transportation*, Vol. 35, No. 2, 2008, pp. 237-252.
12. Brown, J.R., and G. L. Thompson. Should Transit Serve the CBD or a Diverse Array of Destinations? A Case Study Comparison of Two Transit Systems. *Journal of Public Transportation*, Vol. 15, No. 1, 2012, pp. 1-18.
13. Mees, P. *A very public solution: transport in the dispersed city*. Melbourne University Press, Melbourne, 2000.
14. Nielsen, G., J.D. Nelson, , C. Mulley, G. Tegner, G. Lind, and T. Lange. Public transport - Planning the networks. *HiTrans Best Practice Guide*, Vol. 2, Stavanger, Norway, 2005.
15. Estrada, M., M. Roca-Riu, H. Badia, F. Robusté, and C.F. Daganzo. Design and implementation of efficient transit networks: Procedure, case study and validity test. *Transportation Research Part A*, Vol. 45, No. 9, 2011, pp. 935-950.
16. Daganzo, C.F. Structure of competitive transit networks. *Transportation Research Part B*, Vol. 44, No. 4, 2010, pp. 434–446.
17. Transport Metropolitans de Barcelona - TMB. http://www.tmb.cat/
18. Ajuntament de Barcelona - Direcció de Serveis de Mobilitat. *Dades bàsiques de mobilitat 2014*. Barcelona, 2015. (In Catalan)

19. Ajuntament de Barcelona - Direcció de Serveis de Mobilitat. *Dades bàsiques de mobilitat 2013*. Barcelona, 2014. (In Catalan)
20. Ajuntament de Barcelona - Direcció de Serveis de Mobilitat. *Dades bàsiques de mobilitat 2012*. Barcelona, 2013. (In Catalan)
21. Ajuntament de Barcelona - Direcció de Serveis de Mobilitat. *Dades bàsiques de mobilitat 2011*. Barcelona, 2012. (In Catalan)
22. Transports de Barcelona. *Private communication*, 2016.
23. Currie, G., and C. Loader. Bus netwrok planning for transfers and the network effect in Melbourne, Australia. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2145*, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 8-17.
24. Guo, Z. *Transfers and path choice in urban public transport systems*. PhD dissertation, Massachusetts Institute of Technology, 2008.