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The impact of bus rapid transit design choices on ridership and occupancy: Dutch recipes for success

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ABSTRACT

In designing a bus rapid transit (BRT) system, various design choices are made. This article introduces a fuzzy-set Qualitative Comparative Analysis (fsQCA) approach to examine the effectiveness of combinations of BRT characteristics (design choices) and their impact on *ridership* and *occupancy*. Robust factors for *ridership* in most configurations are, in line with expectations, offering a high frequency and easily accessible vehicles. Branding as a special tire is in some contexts like services around airports or campuses, not part of effective configurations in terms of ridership. However, success in generating higher average trip *occupancy* levels is achieved with coaches that are branded as a higher level of service. These regional services that fill in gaps in rail, combine long stop spacings with a shorter headway during morning peak hours. Based on enhanced bus services with a wide variety of BRT characteristics (n = 141), the followed method can be considered as a first step. To obtain more specific results, it is recommendable to narrow down the focus to bus services that have more characteristics in common. This study underlines once more that gaining ridership with enhanced bus services, is more than just offering a service in high frequencies.

1. Introduction

Bus Rapid Transit (BRT) is known for its versatility. Besides relatively low costs and rapid implementation, its high performance and impact makes these enhanced bus systems a valued mode of public transport (Wright, 2003). All over the world, these enhanced bus systems are implemented and have been expanding rapidly (Hidalgo and Gutiérrez, 2013). Fitting various goals, budgets, and contexts, BRT systems have been emerging in a wide variety of appearances (Hidalgo and Graftieaux, 2008). However, due to their success, some BRT role models face capacity challenges in overcrowding and infrastructure (Hidalgo and Graftieaux, 2008, Li and Hensher, 2013). In addition, BRT also holds risks of safety and service failures (Akbulut et al., 2022): Road safety risks associated with bus drivers (Useche et al., 2017; Gómez-Ortiz et al., 2018; Gómez-Ortiz et al., 2018), a security perception and fear of crime (Soto et al., 2022) and harassment (Nasrin and Chowdhury, 2024) among passengers.

Consequently, BRT can be found in various configurations. In this paper a configuration is regarded as a combination of various bus design choices aiming at performance levels and policy goals. The current variety in these BRT configurations has developed since the first plans in Chicago in the 1930 s (Levinson et al., 2002). Implementation of priority measures for bus and the creation of exclusive lanes gained traction in the 1960 s. Around 1973 a more comprehensive idea of BRT was developed and rolled out in Curitiba, Brazil (Maeso-González and Pérez-Cerón, 2013). Dedicated bus lanes were implemented on major arteries in the city, with elevated bus platforms to increase ease and speed of access and egress. These design features aimed at an overall higher speed of operation at lower costs. After lacking instant success, features were adjusted to attract more passengers, for example by adding new routes and introducing bi-articulated vehicles. Other configurations followed in the Americas (Wright, 2014). Though Brazilian cities that implemented dedicated busways afterwards, were not able to copy the favourable Curitiba outcome, possibly because not all the Curitiba features were implemented (Li, 2014). The specific configurations that were chosen seemed to matter. Further worldwide attention was attracted by the results achieved with a high-end BRT system in Bogotá, Colombia. BRT systems seemed to be able to offer favourable outcomes like travel time saving, high-capacity transport, and emission reduction (Deng and Nelson, 2011, Nikitas and Karlsson, 2015).

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Due to high investments and network constraints, not all design choices are feasible in every context. Therefore, a spectrum of configurations can be seen between fully implemented, and forms with less featured BRT. These do generally include on-street right-of-way in order to reduce travel time and to ensure regularity (Larwin et al., 2007). However, they often lack the heavy infrastructural elements, because of insufficient available space, unwanted urban barrier effects, and available rail-based alternatives. One form of these less featured, enhanced bus services have been labelled as Buses with a High Level of Service (Rabuel, 2009, López-Lambas and Valdés, 2013). This BHLS resembles North American variants that offer commuters services between scattered residential areas and busy downtown locations (Heddebaut et al., 2010). Another form of higher end configurations is known as Branded Bus Services (BBS). These bus services are upgraded and labelled with a distinct visual identity to attract passengers (Hensher et al., 2020). A third form to name is Transitway (Duduta et al., 2012). This infrastructural oriented form enables to offer high speed bus services in high frequencies (Spieler, 2021). Key here is a branded infrastructure consisting of busways (grade separated bus-only roadways) and reserved lanes (Levinson et al, 2002).

A worldwide effort to establish common definitions and a more uniformly approach to ensure favourable outcomes, has resulted in a *BRT Standard*. This standard is a universal scoring system that labels best practices for BRT (Power, 2019). In this standard, higher-end configurations use a separate right-of-way and use of safe and wide, weather protected bus platforms, rather than curb side stops. High scoring systems are sometimes regarded as the Full BRT concept, whereas lower quality configurations, using intersection priority and mixed traffic lanes, are at times considered as BRT-Lite (Cervero, 2013).

In designing a BRT system, various decisions can be made concerning running ways, stations, rolling stock, intelligent transport systems, ticketing, branding, and timetable characteristics. Most research is not looking at the combinatory effect of the (different elements of) configurations on the main policy goals. Understanding this combinatory effect of configurations is helpful to understand which configuration eases congestion and which reduces emissions, with high ridership generally seen as a robust measure of effectiveness.

This paper aims to contribute insights on the effectiveness of BRT design element combinations and aims to move towards a more fit-for-purpose oriented understanding BRT types. This can assist policymakers in considering combinatory design options and policy objectives. This paper relates combinatory design options and effects, but to limit complexity does not include costs or revenues. From scientific perspective, this combinatory perspective on design configurations is novel for BRT and public transport in general. The approach developed for this paper can be applied to international data and/or extended with data that includes costs and revenues.

Therefore, this paper follows a method to evaluate the effectiveness of combinatory BRT characteristics to gain ridership. The effectiveness is evaluated along two dimensions:

1. after adjusting for population density, what configurations do seem to be effective in terms of the number of boardings per route kilometre? And,
2. what configurations are effective in gaining ridership in terms of higher average trip occupancies?

In addition, this paper reflects on the followed method to detect effective and less effective bus configurations with BRT characteristics in a typical European context with a dense population. Is this method suitable to apply to enhanced bus services in other parts of the world?

The remainder of this paper is structured as follows. The next section elaborates on a configurational viewpoint and optional design elements that are expected to affect ridership levels. Then follows a section that details on the methodology. After that respectively the results are presented and discussed. This paper ends with conclusions and policy recommendations.

2. Configurational viewpoint and BRT characteristics

For this paper, configurations are perceived as the result of various design decisions. These decisions make up the identity of the enhanced bus service. The number of existing different enhanced bus configurations is significant. To reduce complexity for existing configurations with BRT characteristics, a classification may serve. A classification can be used to identify differences and similarities, and to describe configurations (Bailey, 1994). To classify configurations, several approaches can be followed. The first grouping strategy that my serve is the empirical approach of taxonomy (Bailey, 1994, Miller, 1996). Based on shared characteristics different species can be labelled. Systematic classifications for BRT are scarce. Spieler (2022) groups higher quality bus services into ten different species. The second form of classification follows a conceptual approach and leads to a typology. Based on certain distinctions of conceptual importance, various types can be distinguished. A long-distance bus service imposes different requirements to attract passengers (e.g. less stopping during ride and offering more seating comfort) than a busy city service with high demands (Borsje et al., 2023).

BRT configurations are not static and consist of interrelated elements, that are chosen within a certain context. Within the context of achieving results, the phenomenon 'BRT creep' needs to be mentioned: due to a lack of funding or political will, the quality of service can be stripped down leading to worse performances (see also Racehorse et al., 2015). This raises the question, what changes are desirable or not? To answer this question, configurations must not be assessed without taking in account their outcome performances. This outcome-oriented approach puts focus on the configuration as a quality. This configurational (quality) approach is a third option to classify (Miller, 1996).

The configurational approach is based on combinations of characteristics in regard to achieving certain outcomes. This perspective is compatible with the focus of this paper: finding effective combinations of BRT characteristics in gaining ridership. Based on a literature review, the following BRT factors are expected to contribute to ridership levels:

a. Branding practice: branding BRT as a special tire can shape the identity programs. It can improve the public perception of bus transit and increase the overall demand (Henke, 2007, Hess & Bitterman, 2008),
b. Vehicle Accessibility/ Capacity: easily accessible, high-capacity vehicles attract more passengers than regular vehicles (Currie and Delbosc, 2010, Baltes, 2003, Hidalgo and Guitérrez, 2013),
c. Operation hours (service span): offering more operation hours tends to favour ridership, instead of offering less hours (FitzRoy and Smith, 1998),
d. Stop Spacing: matters for efficiency and effectiveness (Li and Bertini, 2009); a lower average distance between stops should lead to a higher ridership (Hensher and Li, 2012),
e. Number of stops: more stops on a route attract more passengers than less stops (Hensher and Golob, 2008),
f. Frequency: higher frequencies are favourable for gaining ridership, rather than lower frequencies (Currie and Wallis, 2008, Currie and Delbosc, 2010),
g. Operational Speed: more rapid transport attracts more passengers than less rapid transport (Currie and Delbosc, 2014, Ko et al., 2019),
h. Peak Headway: a lower average time interval (in minutes) during peak hours contributes to higher ridership levels (Hensher and Golob, 2008),
i. Reliability: more reliable services attract more passengers than less reliable services (Currie and Wallis, 2008, Ko et al., 2019),
j. Urban density: population and employment density favours ridership success (Babalik-Sutcliffe, 2002),

k. Implementation of Intelligent Transport System measures: leads to a more reliable service and hence more passengers (Cascajo and Monzon, 2014)
l. Pre-board fare collection/verification: contributes to the speed of the service (Hensher et al., 2014). The combination of integrated fare collection and real-time information systems can boost ridership (Ko et al., 2019).

In all, many factors seem to matter for gaining ridership. This list with factors is input for the evaluation of the effectiveness of combinatory BRT characteristics in gaining ridership.

3. Methods

This section describes the conceptual choices and followed steps to determine which combinatory BRT characteristics are successful.

3.1. Methodology: fsQCA

Traditional quantitative research (e.g. regression analyses) has resulted in pinpointing key drivers for generating ridership. However, so far understanding interaction effects of variables has not been the main question (see Currie and Delbosc, 2010, Hensher et al., 2014).

A Qualitative Comparative Analysis (QCA) is a technique that allows a combination of case- and variable-based comparisons to an outcome of interest. A QCA makes it possible to assess complex correlations, involving different combinations of conditions capable of generating the same outcome (Ragin, 2008). Like quantitative research, a QCA also facilitates the analysis of larger numbers of cases in a systematic way. The technique is based on Boolean algebra and has hence distinct capabilities compared with multiple regression analysis (Thiem et al., 2015; Vis, 2012). While regression can assess the net effect on an outcome, the QCA explores combinations of conditions. This latter method can lead to equifinality: multiple causal paths to the same outcome are possible (Kenworthy and Hicks, 2008). This study focuses on combinations of bus design and performance factors (the conditions) in relation to revealed ridership figures (outcome). These conditions are causally linked to outcomes in terms of necessity or sufficiency, by themselves or in a combination of conditions. A QCA key benefit is that combinations that lead to the outcome of interest are linked to individual cases. This enables the researcher to look at the wider context of these cases, including a more qualitative assessment, and thus allow for a better understanding of the complexities beyond the available quantitative data. Methodological advances of this technique also gave a rebirth to the, as outlined earlier, configurational approach (Miller, 2018).

For this study, enhanced bus services are scored in terms of conditions and a certain outcome. Applied thresholds define whether a case belongs to a certain membership or not. A so-called truth table is created that contains all gathered empirical evidence for all cases. Each case (row) in the data set is linked to its outcome. A QCA can be based on crisp data (i.e. all values are either 0 or 1) or on fuzzy data (i.e. values are 0, 1 or values in between 0 and 1). A fuzzy set QCA (fsQCA) considers only values below and above 0.5. This study followed several consequently taken steps.

3.2. Case Selection, Unit of analysis and outcome of interest

To find out, which combinations of BRT characteristics given a specific context, are successful in gaining ridership, and which are not, it is necessary to determine the units of analysis. For this study, the chosen units of analysis are Dutch bus systems with BRT characteristics. In the Netherlands, public transport has been organised by means of concessions which are tendered out. All Dutch concessions (OV in Nederland Wiki, n.d.) have been analysed to compile a list of active systems with BRT characteristics. To compile this list of systems active in January 2017, three criteria were used: (1) systems need to be branded as a system of a higher level of service, and/or make use of (2) segregated or dedicated lanes, and/or are operated with (3) distinguishing '*higher level of service*' vehicles. After consultation of experts and all responsible authorities, in total 141 systems met the one or more described characteristics.

The outcome of interest is ridership. Ridership is generally measured in numbers of boardings and alightings in a certain period (comp. Hensher et al., 2014, Stewart et al., 2017). To determine ridership success, two outcome variables are used: annual Boardings per Route Kilometre per Capita (BPRC) and Passenger Kilometres per Vehicle Kilometre ratio (PKVK).

The first outcome of interest (i.e. BPRC) is based on what Currie and Delbosc (2010) call the annual Boardings per Route Kilometre (BPR). The number of boardings is divided by route length, because longer route lengths can attract more boardings than short route lengths. However, another major influence of urbanised areas on ridership and service supply (Taylor and Fink, 2003) is addressed. To control for population size effects, the boardings per route kilometre are divided by the total number of people living in a 500 m radius of all the bus stops along every bus route. So, the first outcome variable used is the BPRC: the annual Boardings per Route Kilometre *per Capita*. The necessary data to calculate this was provided by transport authorities (annual boardings) and by open data used for travel information (i.e. route length, stop locations, numbers of people living in a 500-metre radius of each stop location).

The second outcome variable (i.e. PKVK) is based on Currie and Delbosc (2010) as well. In their quantitative analysis to determine the key drivers for BRT ridership, they use the Passengers per Vehicle Kilometre ratio (PVK). Dividing by vehicle kilometres is done to control for service level. The ratio they use however, does not deal with the travelled distance by passengers. Short rides are treated equally as long-distance rides. To incorporate the travelled distance, the quotient of the passenger kilometres and vehicles kilometres has been used. All these data were provided by transport authorities.

3.3. Selection of conditions

The included conditions are based on international literature review of major drivers of ridership. Most of the factors found by prior research, are used for this analysis (see section 2, a through j); two (k and l) were excluded. Factors as Implementation of Intelligent Transport System measures (factor k) and pre-board fare collection/ verification (factor l) are applicable for regular PT as well in the Netherlands and therefore not selected. So, only BRT-factors that are distinctive in the Dutch context are included in the study. Although factors like car ownership (Babalik-Sutcliffe, 2002) and employment rate might have regional influence, their importance seem inferior to residential density and hence not selected in this study. If desired, these factors still can be used afterwards to interpret outcomes. This also applies to the factor direct connection to Central Business Districts (see Babalik-Sutcliffe and Can Cengiz, 2015).

3.4. Data collection and calibration

Data on annual boardings, passenger kilometres, service hours and kilometres are supplied by PT authorities and in some cases provided by operators. These data are based on a national information profile that prescribes the information that operators need to provide on their operations (i.e. MIPOV2008). These data originate from two nationally operating systems. One system concerns electronic ticketing data for public transport. These data are a result of check-in and check-out transactions in vehicles or stations. The other national system deals with real-time travel information. Part of this system are timetables, stop locations (x, y coordinates), real-time vehicle positions and so forth. Source data on bus stop locations, service schedules and actual performance in November 2017, are provided by the national data warehouse for real time travel information (NDOV, n.d.). This month only data concerns over 10 million records with information on planning and service performance. Route length was distracted from open data (openOV.nl). The number of inhabitants living in a radius of 500 m around all Dutch bus stops were provided by the province of Gelderland. Additional information on branding practices and vehicle types was retrieved from an online source (OV in Nederland Wiki, n.d.).

The collected data was analysed to find maximum, minimum, median and mean scores (see appendix A). These statistics were used to determine the impact of certain thresholds. In this calibration procedure, thresholds for each condition and outcome were chosen in order to analyse the empirical manifestation of possible configurations. No theories have been found that could be used to pinpoint certain thresholds. Therefore, the data are used to set the threshold levels. This is also in line with the broadly set definition of BRT for this study. The thresholds used are directly interpretable. Conversion thresholds are set to transfer raw scores into membership scores (Table 1).

Branding Practice –A single brand name applied to various bus services (family branding) is applied seven times (Bravo, Breng, Connexxion, doorZeeland, Syntus Utrecht, Twents, VoorU). The branding of the higher level of service is similar to the regular buses in that area. Endorsed branding – using a sub-brand to an overarching parent brand – was only found for one formula. The vehicle type and look and feel of this brand (Breng direct) resembles the main brand to such an extent, that a threshold of 0.4 is used. In case vehicle had a higher quality appearance, a level of 0.6 should have been appropriate. In 2017 all other cases concern nine individual brandings as a special tier or service (i.e. Rnet, Qliner, Qlink, Maxx, Volans, Brabantliner, Limburgliner, Valleilijn, Veluwelijn).

Vehicle Access – Coaches (high floor), double-decker and regional buses are valued as 0. (Bi) articulated buses are considered as the easiest access vehicles (1). Regular low floor types (0,9) and low entry with a partial low floor (0,8) are regarded as a less easy to access.

Operation Hours – Lines with less than 60 service hours a week are valued as '0'; lines operating more than 140 h a week are valued with '1'. The threshold 60 is chosen to filter out systems that offer trips during less than 12 operation hours on a workday (12 * 5). To address the systems that are in operation more than 20 h an average day, the upper threshold is set on 120 operation hours.

Stop Spacing – Calculated by dividing the route length by the number of stops leads to a certain stop space. The shortest stop spaces (average of 500 m or less) are valued by '0'; the longest distances (> 2,5 km) by '1'.

Number of Stops – Lines with most scheduled stops (>40) score '1' and with few (<5) score '0'. The systems in this analysis serve an average of 22 scheduled stops. To mark the more extreme scores, the lower threshold is set at 5 stops, and the upper threshold at 40 stops.

Average Frequency – By dividing the number of scheduled departures by the number of service hours, the average frequency is calculated. Nine or more departures per hour are considered as high average frequencies.

Operational Speed – The quotient of service kilometres and service hours is the base for speed (included planned dwelling time). Highest speeds are rated as '1', lowest as '0'. This without regard of rural or urban services.

Peak Headway – Lines with a departure interval of 6 min or less between 7.00 and 9.00 am on working days are rated with '1'; an interval of more than 15 min is rated with '0'.

Reliability – Vehicles arriving three minutes or more late at its final destination, are considered unreliable. Best performing lines (<10 % late) scored '1'; the worst (>25 %) '0'.

Given the number of the previously described nine design and performance parameters, 196,608 different configurations are possible to construct (=3*4*4*4*4*4*4*4*4).

For both outcomes of interest, thresholds are determined as well:

BPRC – Annual Boardings per Route Kilometre per Capita: worst outcome (<0.05) scored '0'; the best (>1) scored '1'. Intermediate outcomes are scored: 0.2 (0.05—0.2), 0.4 (0.2—0.4), 0.6 (0.4—0.75), and 0.8 (0.75 – 1). These thresholds were chosen to divide the data set into substantial groups. A BRPC that equals to '1' means that when taking in account the population density, the bus system has a relatively high number of boardings.

PKVK – Distance travelled by passengers divided by the distance made by vehicles: worst scoring outcome (less than 6) scored '0'; the best (more than 15) scored '1'. Intermediate outcomes are scored: 0,2 (6—7,5), 0,4 (7,5—9), 0,6 (9–10), and 0,8 (10–15). These thresholds

Table 1
System performance elements and conversion thresholds.

Design/ performance	Reference	Conversion thresholds			
Branding Practice	(Henke (2007), Hess and Bitterman (2008, 2016)	Family = 0	Endorsed = 0,4		Special Tier = 1
Vehicle Access	Currie and Delbosc (2010), Currie and Delbosc (2014)	Hi floor = 0	Low entry = 0,8	Low floor = 0,9	(bi) articulated = 1
Operation Hours (week)	FitzRoy and Smith (1998), Currie and Delbosc (2010)	< 60 = 0	60–120 = 0,33	120–140 = 0,67	≥ 140 = 1
Stop Spacing (km)	Hensher and Li (2012), Hensher et al. (2014), Currie and Delbosc (2014)	≤ 0.5 = 0	0.5–1.5 = 0.33	1.5–2.5 = 0.67	≥ 2.5 = 1
Number of stops	Hensher and Golob (2008)	≤ 5 = 0	5–20 = 0.33	20–40 = 0.67	≥ 40 = 1
Frequency (average)	Hensher et al. (2014), Currie and Wallis (2008), Mackett and Babalik-Sutcliffe (2003), Hensher and Li (2012)	≤ 3p/h = 0	6 – 3p/h = 0.33	9—6p/h = 0.67	≥ 9p/h = 1
OperationalSpeed (average)	Currie and Delbosc (2014), Imam and Tarawneh (2012)	< 30 km/h = 0	30 – 40 km/h = 0.33	40 – 50 km/h = 0.67	>50 km/h = 1
Peak Headway (mins 7–9 AM)	Hensher and Golob (2008)	≥15 = 0	10 – 15 = 0.33	6—10 = 0.67	≤ 6 min = 1
Reliability (arrival > 3 mins late)	Mackett and Babalik-Sutcliffe (2003), Davison and Knowles (2006), Redman et al. (2013)	>25 % = 0	15–25 % = 0.33	10–15 % = 0.67	< 10 % = 1

were chosen to divide the data set into substantial groups.

4. Results

This section addresses what combinatory characteristics coincide with the outcomes of interest. While each design and performance characteristic may have its own impact on ridership, some characteristics are more important than others. Basically, there are two types of possible relationships between a characteristic and the outcome of interest (Ragin, 1987). A characteristic can be necessary (condition is always present) to produce the outcome, or a characteristic can be sufficient to obtain the outcome: when the condition is present, the outcome is present. The results of both types of relationship are reported.

4.1. Analyses of necessity

The first analysis explores the strength of necessity relationship between the individual conditions (characteristics) and the outcomes of interest. The strength of necessity is reflected in the inclusion score. This value is the proportion of the cases where a single condition and the targeted outcome both occur. If the inclusion score is 0.9 or higher, it means that in 90 % or more of all cases, the targeted outcome occurs with the presence of a certain condition. Based on a commonly accepted norm of > 0.9, none of the included conditions are powerful enough to explain the BPRC or the PKVK on its own (see Table 2). So, none of the conditions turn out to be necessary for producing both outcomes.

The highest inclusion scores for a necessary condition and a BPRC = 1 are 0.888 (*frequency*) and 0.859 (*operation hours*). This means that 88.8 % and 85.9 % of the cases with the most annual boardings per route kilometre per capita, offer a high frequency (nine or more departures per hour in a direction) and 140 or more operation hours a week, respectively. The highest scores for a necessary condition and a PKVK = 1 are 0.797 (*number of stops)* and 0.791 (*stop spacing*). So, almost 80 % of the BRT configurations with the highest average of boardings per vehicle kilometre, offer no more than 40 stops and a large stop spacing (at least 2.5 km).

Since no single values of the conditions are individually necessary, there is no need to test for trivialness (Dusa, 2019: 115). However, for the sake of completeness the other two presented parameters are elucidated. The lower the Relevance of Necessity (RoN) score, the more trivial a condition; a higher RoN means a higher relevance. A decent score of relevance is > 0.6 (Dusa, 2018). So, Frequency and Operation Hours, should not be regarded as trivial (RoN > 0,6). The relevance of the conditions is also indicated by the measure for empirical relevance (covN), the given "raw coverage" for necessity. Meaning how often a certain condition (C = 1) is present in the outcome = 1. The general accepted norm for covN is > 0.5. Based on the findings, Frequency and Operation Hours should be regarded as relevant.

Table 2
Analysis of necessary conditions.

	Conditions	Outcome BPRC inclN	RoN	covN	Outcome PKVK inclN	RoN	covN
BR	Branding Practice	0.648	0.396	0.334	0.719	0.432	0.428
VE	Vehicle Access	0.767	0.611	0.494	0.620	0.595	0.461
OH	Operation Hours	0.859	0.634	0.549	0.753	0.638	0.556
SS	Stop Spacing	0.653	0.659	0.473	0.791	0.751	0.662
AS	Amount of Stops (Access)	0.674	0.652	0.478	0.797	0.738	0.652
FG	Frequency	0.888	0.826	0.729	0.714	0.799	0.676
SP	Operational Speed	0.338	0.765	0.369	0.504	0.849	0.636
FH	Peak Headway	0.600	0.922	0.778	0.489	0.907	0.731
RE	Reliability on Arrival	0.540	0.845	0.608	0.454	0.840	0.591

4.2. Analysis of sufficiency: Number of boardings

For the flow of the paper, details on the analyses of sufficiency are reported in Appendix B. This paragraph continues with the recipes that either support or negate the outcome (i.e. being effective in terms of the number boardings per route kilometre per capita). To better understand the recipes and their contexts, this paragraph also reports the individual bus services following effective recipes.

In total 16 of the 141 analysed enhanced bus systems are covered in seven different effective configurations, that lead or coincide with relatively more annual boardings. At the other side of the spectrum, 33 enhanced bus systems are covered in four different configurations that lead to or coincide with relatively few annual boardings. All (in-) effective configurations are visualised in a dipswitch diagram (see Fig. 1 and box text for interpetation). The configurations of the remaining 91 systems in this so-called conservative solution, are regarded as unconvincing and are therefore not visualised (see Appendix B for details).

The number of effective configurations (bS1-bS7) can be reduced to three (basic) recipes. This because some individual bus services (boxed together in figure 2) are member of more than one configuration. All three (basic) recipes (including their variants) have two characteristics in common: they offer a *high average frequency* of service, and they deploy easily *accessible (bi) articulate vehicles*.

The first successful basic recipe distinguishes itself from the other two, by offering weekly less than 140 operation hours. Three out of the four recipe variants offer: a short spacing, are not branded as a higher level of service, are less reliable, and offer a short peak headway during morning rush hour. Further analysis of these configurations learns that all unbranded bus systems are serving educational institutes and science parks (see Table 3). These bus systems, used by students with student fares, offer service hours in accordance with the opening hours of the institutes. With a few exceptions, these bus systems do not offer a weekend service. Exceptions in branding strategy are the systems branded as *Rnet* and the endorsed branded system as *Breng direct*. The latter operates seven days a week and the first one six days with a Saturday service.

The second successful basic recipe offers a (more) reliable service on arrival and is branded as a higher level of service. One of the two variants offers a short peak headway and the other a short stop spacing. These configurations use (bi-) articulated low-floor buses and are operated for many hours week. Most of the regional bus services that follow this basic strategy provide transportation from and to railway stations in Amsterdam. Two local bus services in Almere serve a hospital and connect railway stations (see Table 3).

The third successful recipe applies to a single formula: an express bus service that connects the Eindhoven railway station to Eindhoven airport. It has a long stop spacing, is not branded as a higher level of service, offers no short peak headway, and is less reliable at arrival.

The four configurations on the right-hand side of the conditions (bN4-bN1) are negating with many annual boardings, meaning they are related to less effective performance on annual boardings. All four configurations are carried out with less accessible, longer distance, regional buses. Configuration bN4 illustrates, that offering a high average frequency is not a guarantee for success in terms of many annual boardings.

4.3. Analysis of sufficiency: Average trip occupancies

Four configurations (oS1-oS4) are effective in gaining the highest average passengers per vehicle kilometre. The least successful configurations are covered with five recipes (oN5-oN1). The number of configurations can be reduced to two effective (basic) recipes and two ineffective basic recipes (see Fig. 2). These configurations cover respectively 6 and 16 unique enhanced bus systems; the remaining 119 cases are unconvincing (Appendix B).

All successful configurations in this conservative model solution,

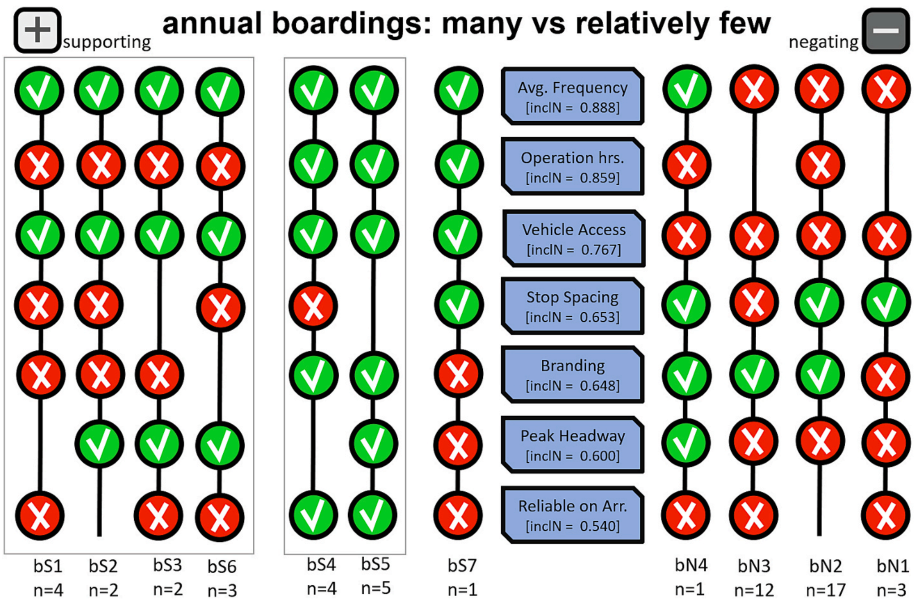

Fig. 1. Effective (supporting) and less effective recipes in number of boardings per route kilometre per capita, and their present (✓) or absent (X) ingredients.

Reading the dipswitch diagram

The dip-switch diagram visualises the configurations (recipes) found to be (not) effective. The boxes label the design characteristics (ingredients) that either need to be present ('✓' labelled green circle) or absent ('X' labelled red circle), or that particular factor does not play a role in the configuration (circle is absent). The visualisation of the gained results resembles a tri-state DIP-switch unit with several in-line switches that can be put in three positions: 'on' or '+', 'off' or '-', and 'neutral' or '0'. DIP-switch diagram seems to address the visualisation.

The ingredients are presented in order of inclusion scores from high to low. All ingredients are connected by a vertical line to visualise the recipe. If two or more recipes are framed together, then this indicates the existence of a basic recipe with variants of appearance. Basic recipes only exist if they share one or more cases. The recipes to the left of the ingredients support the outcome (i.e. are effective); the reverse applies for the ones to the right (i.e. least effective recipes). So, configuration bS1 stands for an unbranded service, that does not perform well concerning reliability at arrival. For this effective recipe, less than 120 service hours a week is sufficient: no 24-7 hour service is offered. However, when in service, a high average frequency is offered. (Bi) articulated buses are deployed for a service with a short average stop spacing (<1,5 km). Peak headway plays no role for this configuration bS1. Four bus services (n=4) are associated with this configuration.

offer a *short peak headway* (10 min or less) during morning rush hour, and make use of a *limited number of stops*. Recipe oS4 is applied to a bus system that serves a university complex, an academic hospital, and other educational institutes. Operation hours are limited to weekdays. The unbranded service is locally operated in a high frequency (> 6x p/h) with easily accessible articulated buses.

In addition to a short peak headway and limited number of stops, the other effective basic recipe is regionally operated with coaches that are branded as a special tier. All of these intercity bus services (see Table 4) fill in gaps in the rail network. Variants on this basic recipe offer at least two out of the following three design options: (a) seven-day service, a (b) long average stop spacing (>1.5 km) and/or a (c) high average frequency (> 6x p/h). The only bus service (member of oS1) that does not offer a seven-day service, operates (unlike oS4) on Saturday as well (see Table 4). Only one bus service meets all three variants. This Rnet system, operates from a railway station in Haarlem to an Amsterdam campus and a major business centre annex main public transport node in Amsterdam.

Configurations with a poor average trip occupancy, offer many operation hours and are designed with a shorter average stop spacing (<1.5 km). In addition to these characteristics, one ineffective basic configuration makes use of unbranded, easy-access vehicles. Similarly to the effective basic recipe, the other ineffective basic recipe makes use of high-floor vehicles that are branded as a special tier. However, this ineffective basic recipe offers a longer peak headway and a shorter stop spacing.

4.4. Comparing both model results

As reported, three (basic) recipes are associated with a higher number of annual boardings, and two (basic) recipes facilitate a high average trip occupancy. Of all analysed enhanced bus services, only one follows a configuration that is successful in both outcomes of interest. The combination of recipes bS3 and oS4 seems to work both ways: it is successful in dealing with high demand and by offering demand driven service hours, a high average trip occupancy is achieved. No branding as a special tier is needed.

Another implementation of an enhanced bus system shows up twice in the results. However, this system is not very effective on both outcomes of interest. This bus system, operated between Groningen and Drachten (recipe oS1 & bN4), achieves a high average trip occupancy, and is the same time not effective in generating many annual boardings. This result demonstrates that less effective systems in carrying comparatively many passengers, can still be of importance in carrying them efficiently. Again, demand driven service hours are offered, but this time with branded service leading to a high average trip occupancy.

5. Discussion

Two results stand out in this study. First, good vehicle access and a

Table 3
BRT characteristics of effective bus services in gaining high number of boardings.

Recipe	Avg. Freq.	Oper. hrs.	Vehicle Access	Stop Spacing	Branding	Peak Hdwy	Reliab. at Arr.	Veh. rides	Type of Service [route length]	Weekend Service	Service linked to
bS1-3,6	>6p/h	<120 hr	≥ low entry	<1.5 km	Family (U-ov)	≤10	>15 %	1685	local [6.8 km]	No	RS, Hosps, Science Park Utrecht
bS1	>6p/h	<120 hr	≥ low entry	<1.5 km	Endsd (Breng direct)	**>10**	>15 %	770	regional [11.7 km]	Yes	RS Arnhem, Bus station Wageningen
bS1	>6p/h	<120 hr	≥ low entry	<1.5 km	Family (Bravo)	**>10**	>15 %	540	local [6.1 km]	No	RS, Hosp., Colleges, Eindhoven
bS1	>6p/h	<120 hr	≥ low entry	<1.5 km	Family (Bravo)	**>10**	>15 %	624	local [8.1 km]	Sat. only	RS, Hosp., Colleges, Science Park Eindhoven
bS2	>6p/h	<120 hr	≥ low entry	<1.5 km	Family (Bravo)	≤10	**<15 %**	630	local [7.0 km]	No	High Tech Campus Eindhoven
bS3	>6p/h	<120 hr	≥ low entry	**>1.5 km**	Family (Breng)	≤10	>15 %	690	local [7,7 km]	No	RS, Campus Nijmegen
bS6	>6p/h	<120 hr	≥ low entry	<1.5 km	**Special Tier (Qlink)**	≤10	>15 %	1130	local [8.1 km]	No	RS, Campus Groningen
bS6	>6p/h	<120 hr	≥ low entry	<1.5 km	**Special Tier (Rnet)**	≤10	>15 %	826	regional [16.7 km]	Sat. only	RS A'dam, Hospital, Zaandam
sS4	>6p/h	>120 hr	≥ low entry	<1.5 km	Special Tier (Valleilijn)	**>10**	<15 %	872	regional [11.9 km]	Yes	RS, Hospital, Campus Wageningen
sS4	>6p/h	>120 hr	≥ low entry	<1.5 km	Special Tier (Rnet)	**>10**	<15 %	929	regional [11.7 km]	Yes	RS A'dam Central and Landsmeer
bS4-5	>6p/h	>120 hr	≥ low entry	<1.5 km	Special Tier (Maxx)	≤10	<15 %	1459	local [8.8 km]	Yes	RSs, Hosp. Almere
bS4-5	>6p/h	>120 hr	≥ low entry	<1.5 km	Special Tier (Maxx)	≤10	<15 %	1504	local [11.6 km]	Yes	RSs, Hosp. Almere
bS5	>6p/h	>120 hr	≥ low entry	**>1.5 km**	Special Tier (Rnet)	≤10	<15 %	1615	regional [28.4 km]	Yes	RS Hoofddorp, Schiphol Airpt, Campus/Hosp. A'dam
bS5	>6p/h	>120 hr	≥ low entry	**>1.5 km**	Special Tier (Rnet)	≤10	<15 %	960	regional [40.3 km]	Yes	RS Amsterdam Central, bus station Edam, Hoorn RS
bS5	>6p/h	>120 hr	≥ low entry	<1.5 km	Special Tier (Rnet)	≤10	<15 %	997	regional [26.4 km]	Yes	RS Amsterdam Central, Monnickendam, Marken
bS7	>6p/h	<120 hr	≥ articulated	>2.5 km	Family (Bravo)	≥ 15	>15 %	803	local [9.7 km]	Yes	RS Eindhoven to Airport

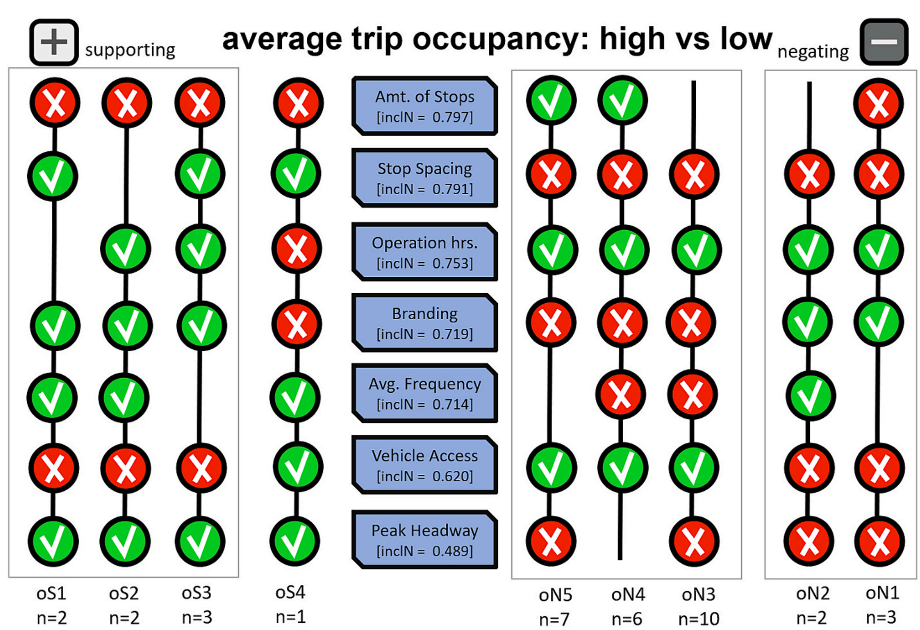

Fig. 2. Effective (supporting) and less effective recipes in gaining high average occupancy levels, and their present (✓) or absent (X) ingredients.

high average frequency are key: these two features are present in all successful configurations that generate many annual boardings. Second, in achieving high average occupancy levels, coach operated regional bus services (with relatively limited ease of access) can outperform the bus operated ones (with easier access). Passengers appear to overall value a branded service that stops less often and that offers a headway of 10 min or less during morning rush hours.

Before discussing these findings, this section addresses some characteristics of the followed method. The underlying analysis is based on a wide variety of 141 bus services. As a consequence of applying general

Table 4
BRT characteristics of bus services effective in higher average trip occupancies.

Recipe	No. of Stops	Stop Spacing	Oper. Hrs..	Branding	Avg. Freq.	Vehicle Access	Peak Hdwy	Veh. rides	Type of Service [route length]	Weekend Service	Service linked to
os1-3	< 20	>1.5 km	>120 hr	Special Tier (Rnet)	>6p/h	high floor	≤10	1041	regional [22.7 km]	yes	RS Haarlem, Campus, RS A`dam Zuid
os1	< 20	>1.5 km	**<120 hr**	Special Tier (Qliner)	>6p/h	high floor	≤10	597	regional [41.3 km]	sat. Only	RS Groningen. P + R, Drachten
os2	< 20	**<1.5 km**	>120 hr	Special Tier (Rnet)	>6p/h	high floor	≤10	1254	regional [14.1 km]	yes	Zoetermeer, P + R, RS Leiden
os3	< 20	>1.5 km	>120 hr	Special Tier (Qliner)	>6p/h	high floor	≤10	798	regional [31.0 km]	yes	RS Groningen, Assen
os3	< 20	>1.5 km	>120 hr	Special Tier (Qliner)	**<6p/h**	high floor	≤10	914	regional [26.2 km]	yes	RS Alphen a/d Rijn, H'dorp, Schiphol Airpt
os4	< 20	>1.5 km	<120 hr	Family (Breng)	>6p/h	articulated	≤10	690	local [7,7 km]	No	RS Nijmegen Campus, Hospital

conversion thresholds and including multiple characteristics, the followed method has led to somewhat diffuse or undifferentiated results. Nevertheless, the comparison of this broad spectrum of enhanced bus services appears to provide relevant insights. The advantage of the applied method is that the underlying, original bus services are labelled, and that one can refer back to their context after the analysis is carried out. This distinctiveness enables the researcher to better understand why a configuration might be effective in achieving the outcome of interest.

Contrary to general perspective on easy-access bus configurations, high floor bus systems seem to be more effective in creating high average trip occupancy levels. Short headways (10 min or less) and long stop spacing during morning rush hour are key. These effective, comfort oriented, regional systems are branded as a special service. This service-formula seems to appeal to commuters, who need or want to be in office at a certain time. This is in line with the findings that on-board comfort is valued by certain user segments (Borsje et al., 2013) and more general to regional travellers and in case of longer travel times (Hansson et al., 2019). The obvious longer afternoon rush hours, enable operators to spread their trips over a longer time frame than in the morning hours and utilize the offered seats more efficiently. However, this finding needs additional study, to figure out whether more characteristics are part of this recipe for success. This is significant, because a higher average trip occupancy, is an important feature for making public transport more affordable.

This study suggests that to be successful in carrying many passengers, it is in certain contexts not necessary to brand an enhanced bus system as a special tier of service. The effectiveness of unbranded systems with a lower reliability in this study, can be explained by user segments. The unbranded services in this study that coincide with many annual boardings are linked to universities, science parks and academic hospitals. Many students traveling to a campus are captive frequent passengers. These experienced passengers do not need a branded service to find their way to their destination. Following a branding strategy aimed at attracting new or more passengers might lead to (additional) capacity challenges in overcrowding and/or in infrastructure in case of an increased frequency of service. Other effective services in this study (not linked to educational institutes) are branded or sub-branded ('endorsed') as a special tier to attracting commuters. The choice whether to brand or not to brand vehicles as a higher level of service is not a matter of efficient vehicle capacity utilisation only. Interchanging branded vehicles for regular services does not contribute to effective marketing and communication. At the same time: the degree of vehicle interchangeability affects the fleet size and costs.

Only one enhanced bus service is effective in generating many annual boardings and achieving a high average occupancy. The effectiveness on both dimensions can be explained by the applied, demand driven service schedule in a circle route, adjusted to the opening hours of a university. Other configurations successful in generating many boardings gain a lower average trip occupancy. This is attributable to supply driven service schedules that are troubled by asymmetric passenger transport. Since many passengers travel mainly in one direction during rush hour, as a result, the vehicles need to return less crowded or even empty, to pick up new passengers for the rush hour direction. As a consequence, the average trip occupancy is lowered. Offering a wider span of service might not contribute to a high average trip occupancy as well.

The applied method in this study is a novel in the field of public transport. The approach seems to be an addition to existing methods to compare various enhanced bus services (e.g. Hensher et al., 2020, Mavi et al., 2018). Presumed ridership encouraging shorter average stop spacing turned out to be an element in the configurations with many boardings. However, the contrary is found with systems with high average occupancies. Possibly the Dutch situation where a lot of passengers are using bicycles in combination with public transport (Shelat et al. 2018) can explain why a higher spacing does not have such a big effect. For future application, one might consider narrowing down the selection of cases. When analysing a less diverse set of bus services, that share characteristics (e.g. coach operated commuter services only) one can emphasise certain aspects in more detail and compare results internationally.

The applied configurational quality approach is distinctive to more quantitative forms of analysis that focus on predictive values of individual variables. This research underscores the importance of offering a high frequency and/or a short headway as ingredients for a BRT configuration to gain ridership. However, additional characteristics seem to matter to gain many boardings or high average trip occupancies. High frequencies require larger fleets and more bus drivers which lead to higher costs. More insights on the dilemma of a less service hours and/or lower frequencies and deploying vehicles with more capacity is one of the issues that need to be addressed in future research. Another issue that requires further study is coping with growing demand: at what point do ridership increases become a threat to service quality, passenger comfort, and system performance? And to what extent is dynamic vehicle reassignment (Farahmand et al., 2024) an option to address both capacity issues?

6. Conclusion and policy recommendations

Clearly, the ridership success of enhanced bus services with BRT characteristics, is highly dependent on the context in which its offered and the configuration of the design factors of that service. This study underlines once again that BRT is a highly diverse set of services, with many design factors to be considered. The approach taken keeps that contexts into perspective, while carrying out a systematic analysis of the key factors explaining success in 141 different bus lines in the Netherlands.

In addition, this study indicates that looking at the factors separately and outside their context misses a key element, the effect of the configuration, in this case on boardings and occupancy. Two factors prove robust in most configurations: high frequencies and short peak headways. However, it shows that when frequencies are high, but reliability is low, this still can lead to success rates in ridership. To consider a certain configuration, the return on investment of the service needs to be included. Offering high frequencies are costly and related to the additional revenues of expected higher ridership rates should be taken into account. Additional analysis on finetuning the configurational choices is needed. Obviously, one of the performance factors, occupancy, has a threshold: too high occupancy and associated boardings and alightings (AlHadidi and Rakha, 2019), is not providing a quality service. In this research the authors could not filter this out. The double evaluation of both ridership and occupancy was used to get to more robust outcomes.

Depending on the policy or managerial objective, other additional elements in the configurations are effective. For example, if the goal is to generate many boardings, a high frequency and easy-access vehicles seem to be essential elements in the configuration. The need for applying branding strategies to generate many boardings has not been established in this study. However, if a high average trip occupancy is desired on connections with sufficient potential, a branded, special service appears to be effective in combination with a larger stop spacing and a short headway in the morning peak hours. Offering many operation hours and applying a short stop spacing, do not seem to result in a high average trip occupancy.

This research shows that policy makers should create room for designers of BRT systems to tweak the system to local and temporal requirements. Funding schemes for BRT projects should allow that flexibility to create effectiveness. This flexibility also includes a stepwise implementation of BRT features (Asimeng and Jauregui-Fung, 2025). The research also shows what recipes are promising and what interactions occur between different design variables, although it was obviously based on a select number of cases.

This all has implications for policy makers and system designers. Policy makers have to be careful in terms of financing specific forms of BRT. Standardising might be attractive for researchers and policy makers. The conceptual differences, capacity, comfort, network reliability, and budget allocation might be helpful in standardising and making design differences. It clarifies what to include in the analysis or in the funding scheme. However, for the purpose of creating results, a broader definition and tweaking the eventual service to the needs of the environment is key. This means a dilemma for the aforementioned researchers and policy makers, creating clarity for themselves or creating room for results with flexible public transport.

The results from this study underline the fact that successful BRT is more than just offering a rapid bus service in high frequency: successful BRT comes in different configurations and are dependent by the context. And the definition of effectiveness is depending on the policy or managerial objective that needs to be achieved.

CRediT authorship contribution statement

René Borsje: Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Suzanne Hiemstra-van Mastrigt:** Writing – review & editing, Supervision. **Wijnand Veeneman:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2025.101703.

Data availability

Data will be made available on request.

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