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Abstract

This paper is derived from project VERT (evaluation of the bicycle as a feeder mode to rail outside urban areas). It focuses on economic analysis implemented in several modeled scenarios, making it possible to compare bike and ride solutions with park and ride solutions, and to draw a cost-benefit analysis. It is applied in a case study in Amboise, comparing scenarios for developing the bicycle as a feeder mode to train, built from observations of present situation, software development to map catchment areas of bicycles and pedelecs, and computing the cost-benefit balance of bike and ride.

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Keywords: Bicycle public transport integration; Bicycle in exurban areas; Economic appraisal; Prospective

1. Introduction

1.1. Objectives

To loosen car dependency, service to exurban areas can rely on the bicycle and public transport integration (BPTI) to achieve time-efficient, environment-friendly and cost-saving trip chains. This topic is scarcely investigated in France in spite of the increasingly important stakes. The potential development of such a combination depends on a set of factors (technical and regulatory aspects, users' constraints and expected benefits, political will), which this paper aims to explore.

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1.2. Study approach

A pluridisciplinary approach focused on a case study is fruitful. Costs and benefits for the community are compared when organizing an attractive bike-and-ride (B+R) service instead of a park-and-ride (P+R) service. This economic analysis is the focus of this paper. It relies on the benchmarking of best French and foreign practices, not reported in this paper. The research also included a sociological approach (qualitative interviews with stakeholders) and an international review. The analysis is applied to a French exurban territory (Val d'Amboise), where regional train is used to reach several employment clusters (including Tours), but where bicycle use for transport is presently low, in particular by lack of decidedly proactive policies putting into effect a global vision for public space adaptation and motorized travel containment. The implementation of intermodal travel with regional train is analyzed in the study according to several scenarios, one of which heavily relies on the bicycle for station access.

1.3. Scope of this paper

This paper focuses on the economic evaluation. The next section will present the methodology used for this evaluation. Then, the cost-benefit balance for each user shifted from P+R to B+R will be modeled. The following section will describe the present situation in the case study. Then, the data and models used in this case study will be presented. The major section will then explain the hypotheses made for the different scenarios. The last section will provide the results of the evaluation in the case study.

Under certain conditions, the findings could be applied to many exurban territories with similar situations.

2. Methodology of economic evaluation

This section presents the approach and the retained hypotheses to estimate the benefit for a traveler shifting in feeder mode to the station from the car parked at the station (P+R) to the bicycle parked at the station in designated facilities (B+R).

The different cost or benefit items belong to three categories:

- Parking facilities: land, equipment investment and operation
- Feeder travel: travel expenses and time spent traveling
- Environment outcome: accidents, air pollution, health and climate change.

The main reference source is the Quinet report (CGSP 2013).

The main limits are:

- Some impacts are not taken into account (urban development, de-congestion, noise reduction), which probably underestimates shift benefits
- Considered stations are located in exurban areas outside the Île-de-France region and P+R is an enclosed lot and B+R only includes secured facilities.

All values are in 2014 Euros unless specified otherwise. Conversion was made following INSEE price index. Negative costs represent benefits.

2.1. Parking facilities

2.1.1. Land rent

Land rent equals surface area in square meters multiplied by unit land rent per m².

Parking surface area equals 1.5 m² per bicycle and 25 m² per car (Héran 2003).

Annual land rent per m² is estimated at 5 € given a land value of 84 € per m² (SOeS 2014).

Therefore, the annual land rent per space is 7.50 € per bicycle and 125 € per car.

2.1.2. Investment

Investment annual depreciation for parking facilities equals investment cost divided by the facility life span. Investment costs were estimated after literature review and authors' survey not reported in this paper at 1,400 € per bike locker and 7,400 € per car space. Life span was estimated at 20 years (Weidmann et al. 2012: 15 years, Héran 2003: 30 years). Annuity is then 70 € per bike and 370 € per car.

2.1.3. Operation

The literature review gives annual operation costs representing 2-3% of investment costs. Retaining the upper bound, annuity is then 42 € per bike and 222 € per car.

2.2. Feeder travel

2.2.1. Travel expenses

Travel expenses equal traveled distance multiplied by unit cost per kilometer.

Table 1 displays the computation of these expenses for the car.

Table 1. Transport expenses for the car used as a feeder mode to train

	All travel	Of which feeder legs	Comment
Daily mileage (km) (1)		6.4*	* Source: ENTD 2008 (last national travel survey in France)
Working days per year (2)		180	Legal standard is 218; reduced to take into account part time and students standard
Annual mileage (km) (3)	12,692*	1,152	(1) x (2)
Marginal expenses (M€ 2011)	48,214**	4,387	Proportional to mileage
Other expenses (M€ 2011)	88,350**	43,557	Proportional to days
Total expenses (M€ 2011) (4)	136,546**	47,944	**Source: INSEE, household consumption, see Beauvais 2013
Car fleet (million) (5)	31.425*	31.425*	
Expenses per year per car (€ 2011) (6)	4,346	1,526	(4) / (5)
Expenses per car-km in 2011 (€)	0.34	1.32	(6) / (3)
Expenses per car-km in 2014 (€)	0.35	1.37	After price index
Annual expenses per car in 2014 (€)		1,577	

Feeder distance by bicycle is shorter than that by car by about 20% as bicycles avoid some detours. So a motorist shifting to cycling would travel only 922 km per year. Cyclists' travel expenses were estimated after Papon (2002) for a regular cyclist cycling 2,000 km per year. Depreciation cost is very low: 0.01 €. Operation costs (maintenance, clothing, equipment) is higher: 0.13 € per km. So, total cost is 0.14 € per km. Finally, for the bicycle, annual expenses represent 128 € per year.

2.2.2. Travel time

Travel time includes ride time and terminal access/egress time. The former equals distance divided by average speed. The latter means time needed for parking search and maneuver, and walking time from parking location to train platform or vice versa.

For the car the assumption is an average speed of 27 km/h (average speed for commuting trips by car, ENTD 2008). Annual distance 1,152 km requires 43 hours. Access/egress time is assumed at 6 minutes per day, i.e. 18 hours per year. Total feeder travel time equals 61 hours.

For the bicycle the assumption is an average speed of 14 km/h (source: Fub French bicycle advocacy organization). Annual distance 922 km requires 66 hours. Terminal access/egress time is assumed at 2 minutes per day (as bicycle parking facilities should be located closer to the platform than car parking), i.e. 6 hours per year. Total feeder travel time equals 72 hours.

This travel time is valued with a value of time of 8.50 € per hour (after CGSP 2013, p.147).

2.3. Health and environment impacts

2.3.1. Accidents

Accident cost equals annual mileage multiplied by kilometric accident cost. The latter relies on accident statistics and values for life loss and injuries (table 2).

Table 2. Accident costs in France in 2011 (data ONISR 2014, CGSP 2013, ENTD 2008)

	Cyclists	Car users	Unit cost (€2014)	Value for cyclists (M€)	Value for motorists (M€)
Fatalities	141	2,065	3,254,402	458.9	6,720.30
Injured hospitalized	1,418	12,136	488,160	692.2	5,924.30
Light injuries	2,882	22,837	65,088	187.6	1,486.40
Total value				1,338.70	14,131.00
Vehicle-kilometers traveled (billion)	9.7	398.8			
Unit cost (€/km)	0.138	0.035			

2.3.2. Health

Health benefit (for cyclists) equals annual mileage multiplied by kilometric health benefit. Though it is rigourously in decreasing returns with the level of exercise, the linear approximation is acceptable, as in France 57% of adults do not meet international recommendations for the level of exercise (INPES, 2008), and feeder travel time is below 20 min per trip (200 min per week) in our hypotheses (see below §6.3.2), which does not reach WHO 300 min per week necessary for "additional health benefits"[1]. Unit benefit is estimated at 0.484 € per km (CIDUV 2013), and total benefit equals 446 € per year.

2.3.3. Air pollution

Pollution cost equals annual mileage multiplied by kilometric pollution cost, estimated at 0.014 € per km for the car after CGSP (2013), taking into account GDP growth, emission reduction and price index (nil for the bicycle).

2.3.4. Climate change

Climate cost equals annual mileage multiplied by kilometric climate cost, estimated after CGSP (2013) for CO2 value (42.32 € per gram) and ECF (2011) for life cycle CO2 unit emissions (252 g per km for the car, 21 g per km for the bicycle), at 0.011 € per km for the car and 0.001 € per km for the bicycle.

3. Modeling of the cost-benefit balance per shifted traveler

First, the unit benefit per traveler shifting from P+R to B+R is computed on the basis of the methodology exposed in the previous section. Second, the determinants of the total benefit will

[1] http://www.who.int/dietphysicalactivity/factsheet_adults/en/ visited 2016.02.12

be analyzed, in particular whether scale economy may occur with the number of shifted travelers.

3.1. Computation of unit benefit

The unit benefit is the difference between the cost for the car user and that for the cyclist (table 3). The cost for the car user is that for the car in the previous section divided by the occupancy rate (number of travelers in the car).

Despite small benefits for the car in few components because it is safer and faster, the overall benefit is for the bicycle, as parking facilities and travel are cheaper, and cycling provides a positive health effect.

Table 3: Unit benefit for user shifting from P+R to B+R, by cost component

	Per car (enclosed parking)	Occupancy rate	Per car user (enclosed parking)	Per bicycle (secured parking)	Difference per traveler (+ if bicycle cheaper)	Column percentage
Land rent (€/year)	125	1.1	114	8	106	
Investment annuity (€/year)	370	1.1	336	70	266	
Operation annuity (€/year)	222	1.1	202	42	160	
Total parking facilities (€/year)	717	1.1	652	120	532	26%
Travel expenses per year (€/year)	1,577	1.1	1,433	128	1,305	
Travel time cost (€/year)	516	1.1	469	611	-142	
Total feeder travel cost (€/year)	2,093	1.1	1,902	739	1,163	56%
Accident annual cost (€/year)	41	1.1	37	126	-89	
Health annual benefit (€/year)	0	1.1	0	-446	446	
Pollution annual cost (€/year)	17	1.1	15	0	15	
Climate change annual cost (€/year)	12	1.1	11	1	10	
Total impacts (€/year)	70	1.1	63	-319	382	18%
Grand total			2,617	538	2,077	100%

To test the robustness of that result, sensitivity analyses with respect to some of the hypotheses were conducted:

- If parking space cost 6,000 € (instead of 7,400), then the benefit would be 1,977 €/year.
- If the car distance between home and station were 4 km (instead of 3.2), then the benefit would be 2,085 €/year.
- If car speed were 20 km/h (instead of 27), then the benefit would be 2,194 €/year.
- If the value of time were 15 €/hour (instead of 8.50), then the benefit would be 2,038 €/year.
- If health benefits for cyclists were 20% lower, then the benefit would be 1,988 €/year.
- If accident risks for cyclists were 50% higher, then the benefit would be 2,016 €.

The conclusion is not questioned: the unit benefit is about 2,000 €/year.

3.2. Analysis of cost determinants

The cost determinants will be separated between those of fixed costs (parking facilities) and those of variable costs (feeder travel and impacts).

3.2.1. Determinants of fixed costs

Parking facilities must be paid and maintained even if not used. Previously the implicit assumption was that all spaces were used once and only once a day on average. The price for a parking facility (for cars or bikes) may depend on the following: capacity, sophistication, provider competitiveness and location. For example, the bike parking price may vary from 1 to 4 from a sheltered stand to a locker. For the car the price gap may be 6- or 7-fold with an underground structure. Scale effect may play a role in controlled parking facilities due to the cost for moving gates and payment machines. But for bike stands or lockers the marginal price is close to the average price.

3.2.2. Determinants of variable costs

For feeder travel, environment impacts, and total the fixed and marginal benefits as a function of distance can be derived from the previous sections:

Annual benefit per shifted user in feeder travel = (- 111.85 x Distance) + 1,521.6 (1)

Annual benefit per shifted user in environment impacts= 119.60 x Distance (2)

Annual benefit per shifted user in feeder travel and impacts = (7.75 x Distance) + 1,521.6 (3)

Where Distance is the distance by car between home and station.

Overall the negative effect of distance because the bicycle is slower is compensated by the positive effect of distance because the bicycle is healthier.

3.2.3. Total socioeconomic benefit estimation model

Total annual benefit equals the unit gain per shifted traveler multiplied by the number of shifted travelers. The former can be computed with this formula:

Annual gain per shifted traveler = (7.75 x Distance) + 2,054 (4)

The latter depends on the following: A the market size for all commuting modes, B the train market share as a main commuting mode, C the share of the bicycle as a feeder mode, and D the share of bicycle parking (B+R) in all travelers coming to the station by bicycle, with the formula:

Number of shifted travelers = ((A x B)/2) x (p1 – p0) (5)

Where p0 = C x D before implementing B+R policy and p1 = C x D after that.

From there the resulting equation is derived:

Total annual benefit = ((A x B)/2) x (p1-p0) x ((7.75 x Distance) +2,054) (6)

4. Reconstitution of present situation in Amboise case study

We now move to the case study of Amboise station (on the river Loire, near Tours). The study area is the catchment area of this station.

4.1. Total commuting market

The market size for all modes is obtained by estimating the number of travelers for all purposes for each origin-destination pair (both ways), then by summing. The specific TMTM model is used, using INSEE census data giving the number of commuters between commune i and commune j (table 4), and using equations derived from the processing of ENTD 2008 that give the annual number of regular trips to work and education in function of the number of commuters and trip frequency, then the annual number of trips for all purposes in function of the annual number of regular trips, trip length, and a typology of relations. The distinction of the direction of travel is made to separate “residents” who live in the study area and work elsewhere from "non-residents" who live elsewhere and work in the study area. The annual data are further distributed to get the market size for a basic working day.

The study area includes in a first step three communes entirely: Amboise, Pocé-sur-Cisse and Nazelle-Négron, then is adjusted in a second step to the attraction area of the station that also includes part of four other communes less than 7km from Amboise station: Chargé, Limeray, Saint-Ouen-Les-Vignes and Saint-Règle (see below section 5.3).

Table 4: Commuters to and from Amboise (2010, census data)

	Residents	Non-Residents	All
Home to work	1,404	1,215	2,619
Home to education	541	549	1,090
Both	1,945	1,764	3,709

Model TMTM turns 3,709 commuters into 5,554,000 trips for all modes all purposes per year, with a change coefficient assumed to be the same for residents and non-residents (figure 1).

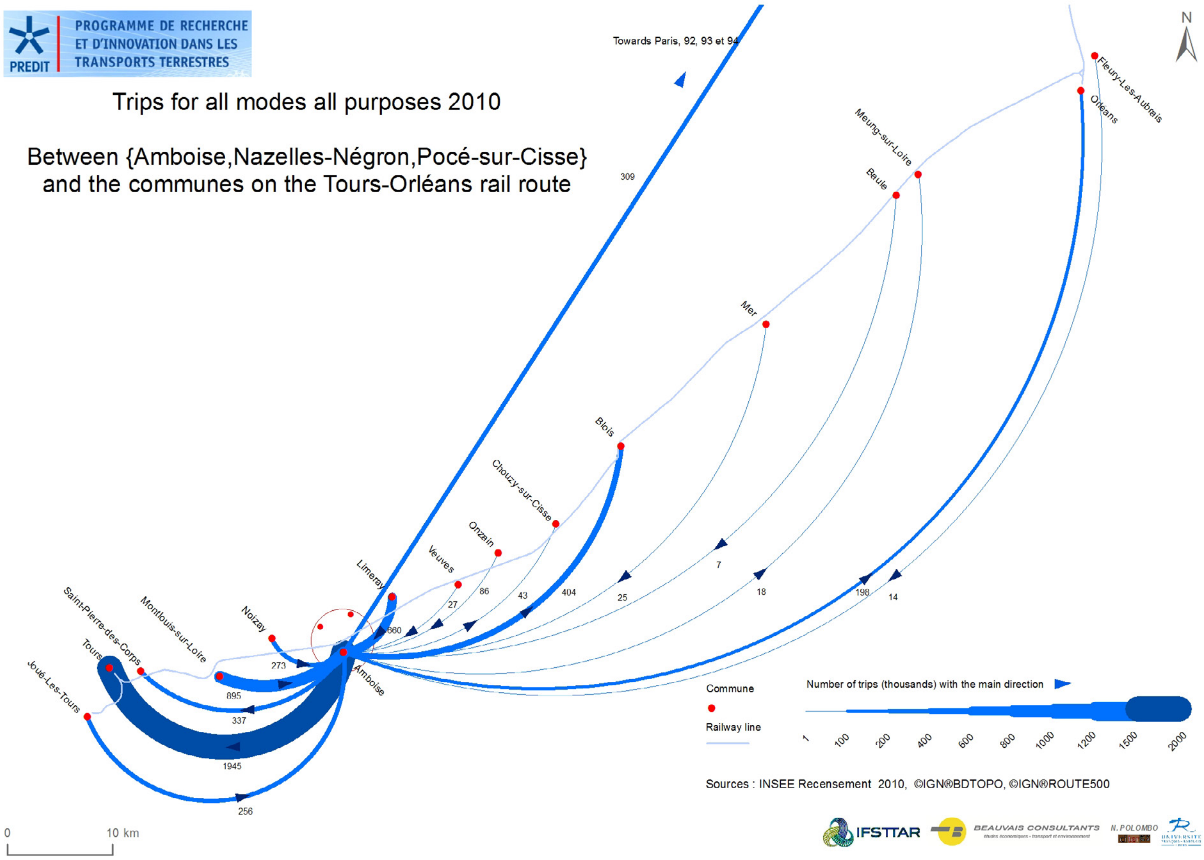

Fig. 1: Access modal share model in the catchment area of Amboise station, current situation

Knowing the distribution of the train patronage by day (Beauvais 1999), this distribution is assumed to be valid for all modes. The number of trips per basic working day is deduced: 19,400 of which 10,200 for residents and 9,200 for non-residents in 2010 (when commuting data was applicable). The evolution until 2014 is supposed to follow that of the population (0.43% per year). The last correction to fit with the final perimeter (attraction area of the station) is also based on the ratio of populations, which corresponds to a coefficient 1.21. Finally the corrections yield a total of 23,915 trips, of which 12,541 for residents and 11,374 for non-residents, in 2014 for the final perimeter.

4.2. Station attendance

The data on the number of passengers at Amboise station were provided by the regional council (Direction des transports), after SNCF Aristote dataset. They include all trains for 2012 and 2013, and are based on ticket sales. They record 465,740 trips in 2012 and 473,370 in 2013. The trend was assumed to be true until 2014 (+1.6%), and the conversion to basic working day values was assumed to be the same as above.

It yields 1,682 trips per basic working day.

To distribute those trips between residents and non-residents we rely on our own surveys (table 5) on October 14-15, 2014, assuming access in the morning and egress in the evening were made by residents. Residents make 77% of the station attendance (table 8). So the 1,682 trips estimated or a basic working day split into 1,302 trips for residents (or 651 travelers) and 380 for non-residents (or 190 travelers).

Table 5: Amboise station access and egress passenger counting

Day	Period	Access		Egress		Total
Tuesday 14 October 2014	Morning	576			121	
	Evening		155	334		
Wednesday 15 October 2014	Morning	358			120	
	Evening		101	436		
Total residents		934		770		1,704
Total non-residents			256		241	497

4.3. Train market share

Dividing the trips by rail by the trips all modes (table 6), we get a resulting higher rail market share for residents than for non-residents.

Table 6: Train market share in Amboise station

	Residents	Non-residents	All
Trips by rail	1,302	380	1,682
Trips all modes	12,541	11,374	23,915
Rail market share	10.40%	3.30%	7.00%

4.4. Feeder modes

Many surveyors were needed to know the feeder mode split, because the station is accessible from the North and from the South, some motorists park out of sight and could be counted as pedestrians, and the number of modes was high to distinguish between parked bikes and boarded bikes for example. This survey was conducted on Tuesday 14 October 2014 between 5:20 and 9:37 (table 7).

Table 7: Feeder mode modal share in access to and egress from Amboise station

	Access		Egress	
	Trips	%	Trips	%
Car users with car parked (P+R)	265	44.7%	16	13.0%
Car users picked up or dropped off	128	21.6%	12	9.8%
Pedestrians	135	22.8%	71	57.7%
Powered two-wheelers	10	1.7%	0	0.0%
Bicycle parked or picked up (B+R)	21	3.5%	0	0.0%
Boarded or unloaded bicycles	20	3.4%	16	13.0%
Taxi	4	0.7%	1	0.8%
Department coach	1	0.2%	2	1.6%
Urban shuttle	9	1.5%	5	4.1%
Total	593	100.0%	123	100.0%

5. Data and applications in Amboise case study

To analyze feeder conditions around Amboise station, several datasets and mapping tools were used. An integrated mapping tool was developed to support feeder mode share modeling within the catchment area. The model, detailed in the next section, works on the principle that access and egress travel time is the first factor for feeder mode choice (Krygsman 2004).

The mapping tool of the catchment area integrates the origins-destinations of the feeder trips, locations and volumes, with realistic estimations of traveled time by bicycle, pedelec and car. A first version of the mapping tool, called Pop200 deals with the access to the station and handles population data, a second one called Emp200 focuses on egress with employment data.

5.1. Population and employment data

INSEE provides comprehensive socioeconomical data on a 200-meter level basis for French municipalities; we used the 2010 data. The 200-meter grid shaping the inhabitants dataset has been set as the spatial reference scale of our mapping tools.

Employment data from SIRENE register (INSEE) were mapped on the 200-meter square grid after geolocation. These data collected on municipality basis concern paid jobs.

5.2. Cartographic descriptions

Road and cycling networks were integrated using the open data geomatics platform OpenStreetMap (OSM). Critical data like road speed limits and cycling paths and lanes were checked on the field and added to the OSM platform when necessary.

Grade information is essential for bicycle travel time. Topographic data come from BD-ALTI from IGN providing variations in terrain elevation with an accuracy of 25 m.

5.3. Route planners

As regards the bikes and pedelecs, OpenStreetPlanner platform was used to compute travel times between Amboise station and the centers of the 200-meter grid elements containing inhabitants or jobs covering the 7 communes. OpenTripPlanner[2] is an open source multimodal planner based on OSM data that provides high quality cycling travel times. The planner has been set for taking grades and road network data into account to select routes and estimate travel times for bikes and for pedelecs, in both access and egress directions. The weights for fitting parameters balancing grade avoidance, safety (cycling infrastructure) and celerity in route planning were tuned experimentally after several trials on the field. They were set to {0.2, 0.6, 0.2} for bikes and {0, 0.6, 0.4} for pedelecs. On-flat speeds were set to 14 km/h and 17 km/h respectively.

Regarding car route planner, the standard OSM solution OSRM[3] was used. Travel times are computed with congestion-free conditions in OSRM, but car feeder travel times are only used to adjust the catchment area: above 10 minutes of car feeder travel time, grid elements are excluded.

An access to applications Pop200 and Emp200 is available at
http://www.comeetie.fr/galerie/vert/isochrone.html and isochrone-emploi.html.

6. Scenario construction in Amboise case study

The last two sections of the paper focus on the access stage in Amboise station case study. Access involves the largest set of solutions for car and bicycle as feeder modes, including P+R and B+R. Bicycle feeder modes are easiest to develop for access than for egress (Hegger 2007, Martens 2007). Besides, the scale and precision of population data in application Pop200 makes close analysis of access in the catchment area available.

6.1. Scenario construction

Our aim is to compare contrasting situations for access conditions to Amboise station in the next future: in line with the current trend on the one hand, resulting from strong proactive policies to support bicycle use for transport and BPTI on the other hand.

The proactive policy measures that would be applied to get high quality conditions for cycling from and towards Amboise station are not detailed here. However, not to mention general measures regarding education, advocating or financial aspects for instance, local action plans are quite well-known among which: good access and egress routes for bicycles, speed calming plan for motorized traffic, quality bike parking facilities with secured options, integrated pricing for bike parking, fees for car parking, and so on (see for instance Martens 2007, Cervero et al. 2013).

Both future contrasting situations must be compared all things being equal, and especially station attendance conditions, see terms A and B in equation (6). Two types of evolution are identified, with low or high increase in Amboise station attendance.

Time horizon was set to 2025, which makes 11 years after field observation and economical quantification in 2014. A decade is long enough to enable local and national policies to show effects, and short enough to assume some continuity in planning and mobility trends.

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[2] See http://www.opentripplanner.org.
[3] See http://project-osrm.org.

We end up with four situations, named A, B, C and D, by crossing scenarios regarding station attendance and scenarios regarding proactive policies for bicycle access conditions. Two comparisons are thus to be done: B with A and D with C.

Table 8: Contrasting scenarios for 2025

	Low increase in station attendance	High increase in station attendance
Business as usual scenario: bike access conditions in line with the current trend	A	C
Proactive policies scenario: high quality bike access conditions	B	D

6.2. Scenarios regarding station attendance

Mobility is assumed to follow population trend. The first scenario continues the trend between 2006 and 2011 population census; it leads to 5% increase between 2014 and 2025. The second scenario relies on Amboise area planning document SCoT and its forecast for population development, which leads to 11% increase for the same time horizon.

Train market share, currently 10.4% for residents, is assumed to be 11.3% in 2025 in trend forecast based on today's national data for train mobility. In the second scenario we assume a doubling of train market share in 2025, which yields 20.8%.

The crossing of low (respectively high) hypothesis for mobility and train market share leads to 1,492 rail trips (respectively 2,886) for residents in 2025. The scenarios regarding station attendance are thus built with factor 1.15 for the low increase hypothesis and factor 2.22 for high increase.

6.3. Scenarios regarding bike access conditions

Given data from the reconstitution of present situation in Amboise (section 6), an access modal share model within the catchment area of Amboise station is designed using application Pop200. Two sets of hypotheses for modal shifts are formulated for both scenarios, leading to different future modal split schemes for 2025.

Access mode choice modeling is based on the following principles:

- Train users are uniformly distributed over the population within the catchment area; only their access mode depends on the remoteness from the station. This assumption is acceptable in short distance catchment area as in this French exurban territory. The ratio between inhabitants and train users is thus considered as unique within the catchment area, and specific for each station attendance scenario.
- The catchment area of the station is made up of embedded ring areas where the access modal share is assumed constant. Train users accessing the station on foot necessarily belong to the closest area called *central zone*. The farthest zone called *external zone* includes motorized feeder mode users only.

6.3.1. Current access modal share model

Table 9: Passengers accessing Amboise station in 2014 (reconstitution), by feeder mode

Access mode	Walking	Parked bike	Boarded bike	Pedelec	Parked Car	Car drop-off	Other motorized	Total
Modal share	22.8%	3.5%	3.4%	0%	44.7%	21.6%	4.0%	100%
Volumes	148	23	22	0	291	141	26	651

Modal passenger volumes for current situation are derived from the number of passengers (table 6) and the observed modal share for the access stage (table 7). Motorized modes except car make a single category: powered two-wheelers, taxis, coaches and buses (table 9).

Knowing the current ratio between inhabitants and train users within the catchment area, application Pop200 is used to estimate the minimum time threshold in terms of bike feeder time that clusters the 193 passengers accessing the station by bike or on foot in the central area. Walking passengers are supposed to live in the direct vicinity of the station; they are mapped into the same central zone.

The maximum travel time accepted by residents in Amboise area for station access by bike turns to be 13 minutes (maximum travel time estimated for both access and egress). The bike-13-minutes isochrone line in the catchment area of Amboise station defines the bounds between central zone (active modes) and external zone (motorized modes only), see figure 2. Central zone includes 34% of the population within the catchment area.

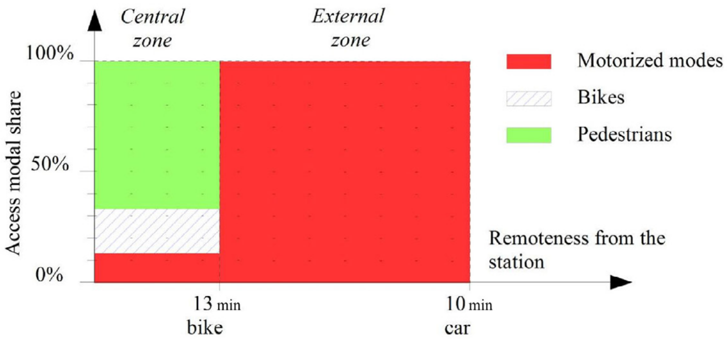

Fig. 2: Access modal share model in the catchment area of Amboise station, current situation

6.3.2. *Modified access modal share models for 2025*

General assumptions regarding cycling behavior and regulation evolutions for the next decade are the following:

- Pedelec: important usage growth, including for commuters and BPTI users. BPTI travelers shifting to pedelec previously used standard bikes or cars. When replacing car, substitution rate is higher for P+R than for car drop-off, since drop-off may be constrained by drivers own trip and is not sensitive to parking fees. Pedelecs are assumed to be all parked because of their weight.
- Boarded bike policy: restricted but not forbidden for non-folding bikes. The current level of non-folding boarded bikes expressed as a percentage of total train attendance is kept as the maximum allowed level in the future.
- Folding bikes: under favorable conditions for BPTI, important usage growth of folding bike (Sherwin and Parkhurst, 2010), stability otherwise.

For the sake of simplicity, *other motorized* modal share is assumed to remain unchanged. Modal shifts between walking and cycling travelers in central area are supposed to balance; walking modal share is thus assumed unchanged.

In *business as usual* scenario, the pedelec diffusion is the only source of change in the access modal share. Pedelec access creates an intermediate area Zi, through car access substitution. The maximum bike and pedelec feeder time remains at its current value, 13 minutes. Zi includes 16% of the population, as estimated by application Pop200.

In *proactive policies* scenario, accepted cycling feeder time increases considering the favorable conditions for cycling towards the station. New access territories are opened for bike and pedelec: Zj and Zk. The threshold in cycling feeder time is set to 20 minutes, the duration of the train trip between Amboise and Tours (Krygsman 2004). Let us mention that the bike route planner computes bike and pedelec travel times on the basis of the current road network whereas the scenario forecasts strong improvements for bikes routes and overall cyclability. For instance a bridge over the river Loire dedicated to bikes and pedestrians has long been asked for by local cyclist advocacy groups and is supposed to be built. Bike and pedelec travel times are thus significantly overestimated in application Pop200 as regards proactive policies scenario. Zj and Zk include 20% and 11% of the population, respectively.

Hypotheses for shifting to bike and pedelec in 2025 scenarios are detailed in table 10.

Table 10: Hypotheses for feeder mode shifting between 2014 and 2025

Type of scenario		Business as usual	Proactive policies for cycling and BPTI
Enlargement of active mode feeder area:		Pedelec diffusion	Pedelec diffusion and acceptability of larger cycling feeder time
Car as feeder mode in central zone		Decline	Disappear
Shifting:	in zones:		
Bike to pedelec	Central	10%	10%
Parked car to bike+pedelec	Zi	20% (all pedelec)	80% (¾ bike ¼ pedelec)
	Zj		80% (½ bike ½ pedelec))
	Zk		60% (all pedelec)
Car drop-off to bike+pedelec	Zi	10% (all pedelec)	40% (all bike)
	Zj		40% (all pedelec)
	Zk		10% (all pedelec)
Folding bikes users among bike feeder passengers		10%	35%

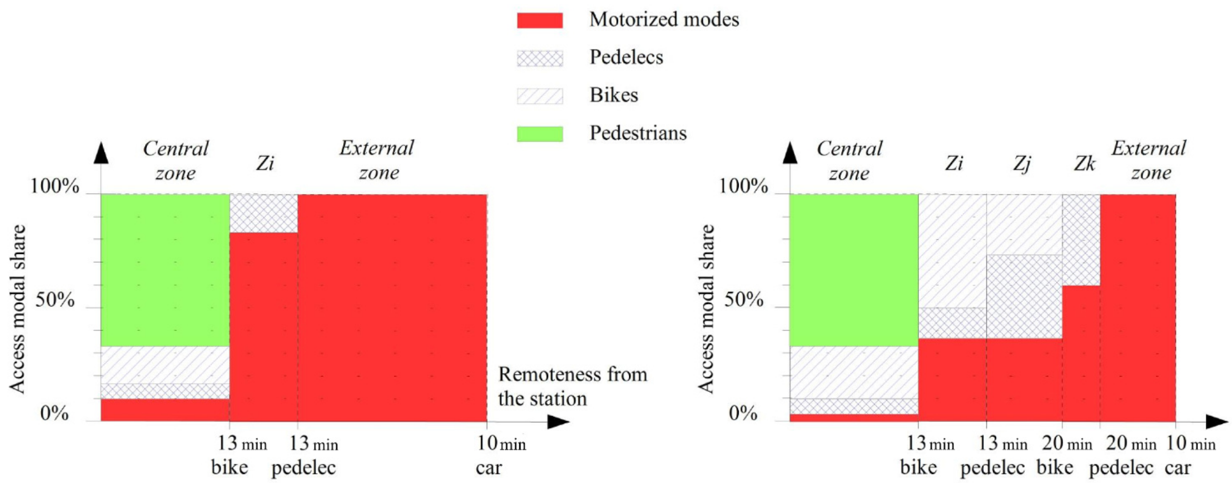

Fig. 3: Access modal share models in 2025 a) business as usual scenario (left) b) proactive policies scenario (right)

In proactive policies scenario, the rates for shifting from parked car to bike and pedelec ensure that the P+R volume remains at its current level in 2025, even in case of high increase in station attendance. However, 80% rate in Zi and Zj can be reduced to 60% with the same effect in P+R volume if a 25% overestimation in bike travel times is assumed because of bikes routes and overall cyclability improvements.

The modal share in the different zones within the catchment area are depicted for both scenarios in figure 3.

6.4. Access modal share and passenger counts in 2025 scenarios

Based on the two sets of hypothesis, access modal share and volumes within the whole catchment area can be computed using application Pop200 (table 11).

Table 11: Access modal share in 2025

	Business as usual scenarios			Proactive policies scenarios		
	Passenger		Modal split	Passenger		Modal split
2025 scenarios	A	C		B	D	
Walking	169	328	22.7%	169	328	22.7%
Bicycle parked	19	39	2.6%	87	171	11.8%
Bicycle boarded	27	51	3.6%	80	156	10.8%
Pedelec parked	29	56	3.9%	114	221	15.3%
Car parked	314	608	42.1%	148	284	19.7%
Car drop-off	157	304	21.1%	118	226	15.7%
Other motorized	31	57	4.0%	30	57	4.0%
Total	746	1,443	100%	746	1,443	100%
Total Bike + Pedelec	75	146	10%	281	548	38%
% parked in Bike + Pedelec			65%			70%
% Pedelec in parked			60%			60%
% Folding Bike in boarded			20%			70%

Business as usual scenario leads to 10% cycling modal share (bike and pedelec) whereas *proactive policies* scenario leads to 38%. 38% cycling modal share represents the potential for cycling access provided good BPTI conditions are fulfilled in Amboise territory. Average bicycle feeder distances remain moderate even in this scenario: 2.6 km for bikes and 3.5 km for pedelecs (5.3 km for cars).

The catchment area with the five embedded feeder zones is mapped in figure 4.

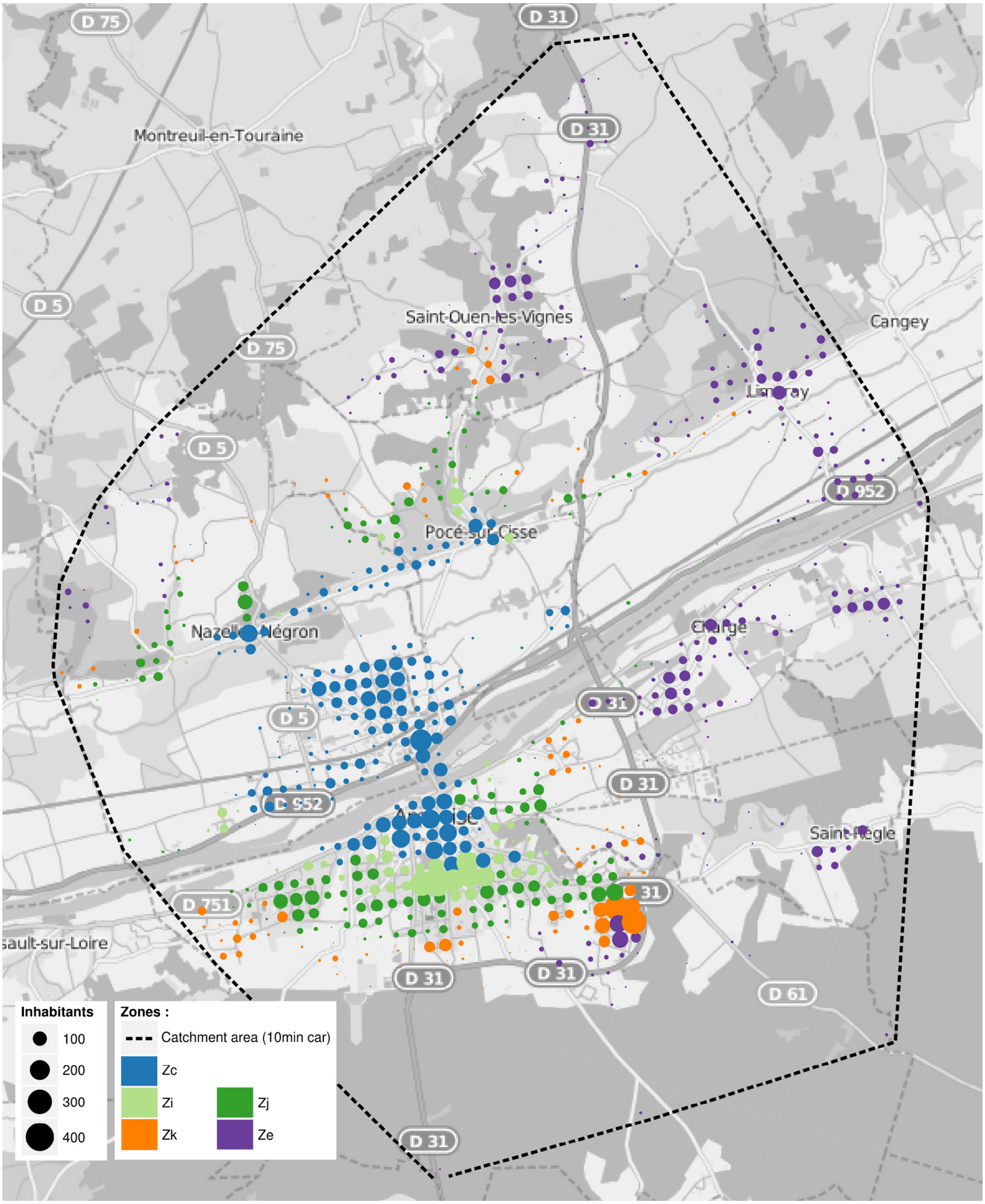

Fig. 4: Feeder zones in Amboise area

7. Socioeconomic balance in Amboise case study

The project expected benefit relates to the difference between situations with and without project, as exposed in section 2. The total benefit of shifting travelers from the car to the bicycle is the benefit per traveler multiplied by the number of shifted travelers, as in section 3.

7.1. Method

General hypotheses are exposed in section 2. Amboise case study specific hypotheses are:

- Cost for non-guarded car parking facility: 7,156 € per space (694,131 € for 97 spaces).
- Cost for bike parking: 400 € per bike (sheltered stands), 1,801 € per bike (secured space, after project actual cost), 1,101 € per bike (average, with proportion of secured space: 50%).
- Land rent: 5.22 €/year/m² (after average land price 87 €/m² surveyed from seloger.com).
- Pedelec cost: 0.27/km (depreciation cost: 0.14 €/km after purchase cost: 1,053 €, life span 4.5 year and annual mileage 1,889 km, operation cost: 0.13 €/km, 6t 2015 p.8-9). Pedelec health benefit reduction (compared to standard bikes): 32% (Grossoleil 2014, p.75). Pedelec CO2 emissions: 22 g/km.
- Drop-off and pick-up car cost: 0.354 €/km (much lower than P+R because of fixed costs as the car may be used for other purposes during the day). A return trip is attributed to the passenger and not only the trip where s/he is present. No terminal access time is considered.
- Average speeds: 14 km/h for standard bikes, 17 km/h for pedelecs and 25 km/h for cars (lower than in section 2 as Amboise bridge is often congested).
- Average car feeder trip distance 4.3 km (computed with application Pop200 for current situation, higher than that in section 2 (3.2 km)). Average bicycle feeder trip distance 2.0 km (instead of 2.6 km). Resulting distance for shifted travelers is given in table 12.

Table 12: Feeder travelers shifted from the car to the bike, between scenarios with the same level of station attendance

	Scenario B compared with scenario A (Moderate station attendance)			Scenario D compared with scenario C (High station attendance)		
	Number of shifted travelers	Car feeder distance (m)	Bike feeder distance (m)	Number of shifted travelers	Car feeder distance (m)	Bike feeder distance (m)
P+R to parked bike	52	3,027	2,857	101	3,017	2,848
P+R to boarded bike	47	3,027	2,858	92	3,023	2,854
P+R to parked pedelec	68	4,062	3,860	131	4,066	3,864
Drop-off to parked bike	11	2,598	2,456	23	2,607	2,468
Drop-off to boarded bike	11	2,598	2,456	21	2,588	2,444
Drop-off to parked pedelec	17	3,974	3,716	34	3,925	3,669
Total	206			402		
Mean		3,401	3,216		3,391	3,207

7.2. Results

Table 13: Benefit per shifted feeder traveler by shift type, between scenarios with the same level of station attendance, in Amboise case study.

	Scenario B compared with scenario A (Moderate station attendance)			Scenario D compared with scenario C (High station attendance)		
	Car user cost	Bike cost	Shift benefit	Car user cost	Bike cost	Shift benefit
P+R to parked bike	2,556	570	1,985	2,550	569	1,981
P+R to boarded bike	2,556	418	2,137	2,553	418	2,135
P+R to parked pedelec	3,185	1,011	2,175	3,188	1,012	2,176
Drop-off to parked bike	1,295	524	771	1,300	512	788
Drop-off to boarded bike	1,295	360	935	1,290	358	932
Drop-off to parked pedelec	1,981	981	1,000	1,957	971	986

The benefit per shifted traveler (table 13) is circa 2,000 € per year from a P+R user, and below 1,000 € per year from a drop-off user. The difference is explained by a lower depreciation cost for the car used for drop-off, which can be used during the day for other purposes. Differences between bike modes are small.

Total annual benefit is 387 k€/year in case of a moderate Amboise station attendance, 753 k€, in case of a high station attendance (table 14).

Table 14: Total annual benefit by shift type and benefit component for shifting feeder mode in Amboise station from the car to the bicycle

	Scenario B compared with scenario A (Moderate station attendance)		Scenario D compared with scenario C (High station attendance)	
	kEuros/year	Percentage	kEuros/year	Percentage
P+R to parked bike	103	27%	200	27%
P+R to boarded bike	100	26%	196	26%
P+R to parked pedelec	148	38%	285	38%
Drop-off to parked bike	9	2%	18	2%
Drop-off to boarded bike	10	3%	20	3%
Drop-off to parked pedelec	17	4%	34	4%
Total, of which	387	100%	753	100%
Parking facilities	77		150	
Feeder travel expenses	253		492	
Feeder travel time	-25		-48	
Accidents	-23		-45	
Health	97		189	
Pollution	5		10	
Climate change	3		5	

A sensitivity analysis to fuel prices was conducted. In case of a doubling of fuel price, the total annual benefit of shifting feeder travelers from the car to the bicycle would increase by 7%.

8. Conclusion and discussion

The whole research included more than the economic evaluation reported in this paper, in particular an international review, a sociological approach, and the evaluation of cyclability conditions.

8.1. International review of bike public transport integration

After document analyses, field visits, and interviews with experts, very varied configurations of bike public transport integration are evidenced, which sheds light on the high complexity of investigating such a travel behavior lying at the crossroads of three large thematic domains: the bicycle and cycling facilities, comprehensively considered public transport, and intermodal strategies and equipments. This complexity is all the highest as the situation is analyzed in different countries, with different contexts within each country, and as evolutions over time are taken into account to foster foresight thinking.

It is in this intricate context that stands the search for cost data, which are needed for our economic approach. Costs narrowly interact with other aspects such as stakeholders' play. A key fact consists in a significant comparison work of B+R costs versus P+R costs made in 2012 by Weidmann et al. from ETH in Zurich. Data from other sources were gathered, while pointing out uncertainty factors.

Elements that are likely to foster foresight vision are the outcome of international cases, considered not in a static way but in a dynamic way, which is here illustrated with two examples: the evolution of parking devices opens perspectives for lowering the secured/unsecured ratio within bicycle parking supply when compared with the present French situation; the emergence or implementation of diversified solutions for vehicle technology (pedelecs), as well as cyclability outside urban areas, may alleviate obstacles to the massive development of the use of the bicycle as a feeder mode.

8.2. Economic methodology and model

Taking stock of those analyses, a method for estimating the expected benefit when one traveler bikes to the station instead of using the car was elaborated. The investment and operating costs of parking facilities, feeder ride monetary and time spending, accident risks, health benefits of exercise, air pollution generated by cars, and carbon emissions attributable to car rides, were taken into account. Thus, the socioeconomic benefit was estimated at circa 2,000 € per year and per passenger (pax) shifted from the car to the bicycle.

Then, in a second step, a model was built to estimate the annual benefit in function of the number of shifted pax from the car to the bicycle. The total annual benefit depends on the volume of trips for all transport modes, on the train market share, on the proportion of bicycle users on feeder trip legs before implementing measures to trigger modal shift, on the new proportion of bicycle users on feeder trip legs after implementing these measures, and last on the distance between the traveler's home and the station.

8.3. Case study choice and sociological approach

To implement this model, and more widely to examine the issues raised by BPTI on a concrete case, an application field was chosen according to different criteria, including attractiveness for bicycle feeding behavior. Thus, Amboise station was preferred to other sites for its better potential and for its location within bicycle reach of the town centre.

Besides economic approach, a sociological part was developed to show the implication of different stakeholders in the process, who were interviewed in the Amboise case. The central role for planning and strategy is the region's and the train operator's responsibility. Other communities (department, intercommunalities and municipalities) share the intervention domains (public transport supply, parking, bicycle routes). Users only play a minor role.

8.4. Case study economic evaluation

The reconstitution of the present situation for implementing the economic model relies on several stages: 1. Computation of the total trip market for Amboise, after INSEE data and our TMTM model, scoring at about 5.5 millions trips per year, in large part to Tours, but not only. 2. Among these trips, estimation of Amboise station attendance, with SNCF data backed by our own counting, totaling 1,302 trips of residents per basic working day accessing a train in Amboise, and 380 trips of non-residents egressing a train in Amboise, which represent respective market shares of 10.4% and 3.3%. 3. Observation of present feeder modes to the station, 7% for bicycle in access (residents), half of which concerning boarded bikes, and 13% for bicycle in egress (non-residents, who are four times fewer as residents).

To analyze feeder conditions to and from Amboise station, different datasets and tools were used. INSEE population data, in a 200-meter grid, and job data, road network and topographic data, and two route planners including one for bicycles made it possible to develop Pop200 and Emp200 software that respectively map population and jobs that are accessible from Amboise station within a certain time cycling by taking into account streets likely to be actually used.

Then, contrasted scenarios for access to the station were built: a proactive scenario favoring the bicycle compared to a business as usual scenario. Both scenarios are crossed with two configurations depending on the growth of Amboise station attendance, so that the rail market share in 2025 may hit respectively 11.3% or 20.8%. The business as usual scenario only takes into account the diffusion of pedelecs, opening a wider territory to bicycle access (zone Zi), estimated with application Pop200. The proactive scenario makes it possible to increase the range of standard bikes (zone Zj), and a fortiori that of pedelecs (zone Zk). In each zone, hypotheses for shifting to bikes or pedelecs from P+R or car drop-off were made, as well as hypotheses on the share of on-board bicycles and folding bike use. This enables the modal share of bicycle and pedelecs as access modes to raise from 10% in the business as usual scenario to 38% in the proactive scenario, with average bicycle feeder range increasing from 2.0 to 2.6 km, and that of pedelecs from 2.5 to 3.5 km. The Pop200 application made it possible to accurately map concerned populations. Similar analyses were made for egress from the station (travelers alighting in Amboise station to go to work there) with application Emp200: the main business areas become reachable by bike or pedelec from Amboise station under the proactive scenario hypotheses.

The feasibility of scenarios was supported by the detailed analysis of parking in Amboise station, and that of cyclability conditions of some feeder routes connecting with the best and fastest path the station to the main population settlements (residents) or to the main working places (non-residents). It showed that car parking in Amboise station could be contained, and bicycle parking in Amboise station and cycling conditions could be improved.

Finally, the economic model applied to the hypotheses made in the Amboise case delivered a unit benefit in the order of 2,000 € per year and per shifted pax from P+R to bicycle, and in the order of 1,000 € per year and per shifted pax from car drop-off to bicycle, with a similar benefit for standard bikes and pedelecs. This results in a total annual benefit for applying the proactive scenario instead of the business as usual scenario of 390,000 to 750,000 €, according to the station attendance evolution configurations. This very positive balance makes the point for all involved governments to commit in favor of bicycle use to access the station.

8.5. Implications

There is room for considerable progress of BPTI in France, even in middle size territories such as Val d'Amboise, located at the brink of exurban and rural areas.

Our economic results for benefits of the B+R solution compared to the P+R solution show the dominating share of parking facilities, feeder expenses and health benefits. Those are points to argue for developing BPTI with local governments (reducing car parking costs by stations), as well as users (avoiding to dedicate a car to park at the station, avoiding the need of a second car, improving one's health). By comparison, time losses, or accident risks are low. Time losses can be reduced, or bicycle range increased, by choosing pedelecs, that also bring significant health benefits.

Implementing BPTI should follow a pragmatic approach, by developing supply as demand rises, both in capacity and secure solutions. There must be an equilibrium, which may evolve, between secured and basic parking. All bicycle parking facilities should at least include bike stands; all device not enabling to bind and support the bicycle frame must be banned. For more sophisticated and secured technical solutions, accurate studies are necessary to choose the most appropriate solution: different types of secured enclosed precincts, or in some cases bike stations or lockers. The cost of bicycle parking in station varies according to the share of those facilities in the whole supply.

Finally, all stakeholders should work together to meet the BPTI development common goal, so as to provide high benefits for the community as identified.

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