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Economic Externalities of the Panama Metro Network

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Abstract

This research analyses some economic externalities generated by the Panama Metro Network. Vehicle congestions in cities produce annual losses of millions of dollars, affecting productivity sensitively. The social benefits of mass transit systems have a positive impact on the dynamics of metropolitan areas. This paper presents results related to the savings in travel times and their economic benefits, under various projected scenarios. These scenarios are compared with actual data of passenger mobilization of the Panama Metro Network. This paper is divided in 6 section. The first section corresponds to the introduction. The second section contained the general description of the Panama Metro network, both line 1 and line 2. The third section is about general methodology. The fourth section is presented the results and its discussion. The final section corresponds to the conclusion and future work.
KEY WORDS: *Panama metro, subway, externalities*

1. Introduction

According to Walrand [1], economists defined externalities as the impact on others of some actions when prices do not reflect that impact. In the transportation sector, Van Lier et al., [2] indicated that externalities arise when transport-consumers/producers impose additional costs to the society without having to bear these costs themselves or without having to transfer or pay compensations. Also, externalities are situations in which one agent can be directly affected by the production or consumption decisions of another. Commuter rail and metro stations can have positive effects. Rail and metro systems are characterized by high-performing [3] and environmentally friendly features [4-6] that make them a crucial factor for driving modal split towards public transport modes, thus reducing private car use and related externalities (such as air and noise pollution, traffic congestion and accidents) [7-9]. Profillidis et al., [10] presented a review of the environmental effects and externalities of the transport sector and the concerns in sustainable transport planning and a study about quantification in monetary units and possible effects of eventual internalization of these external costs. Guijarro [11], on the other hand, empirically examined the impact of the negative externalities associated with road traffic for the city of Madrid, Spain. Stetjuha[12], discussed the theoretical foundations of externalities and the peculiarities of their manifestation in transport. Berbey-Alvarez et al., [13-14], presented previous works about the externalities of Panama metro network.

2. General Description of the Panama Metro Network

Currently, the Panama Metro Network has 2 railway lines. Both railway lines 1 and 2 of the Panama Metro have a double track with a gauge of 1,435 mm and right-hand traffic [15]. The track is configured as a railway line fixed directly on the viaduct. UIC54 type rails (54 Kg / m) will be used on the main road and in the Yards and Workshops [16]. The Panamá Metro line 1 (PML1) is a metropolitan subway with subterranean and elevated track sections operated with a catenary-guided transport system. It began its operations on April 6, 2014 [17]. Currently, the line has a length of 16 km, connecting the northern area of Panama City at the San Isidro station with the southern section of the City, to the Albrook station (Fig. 1). This final station connects with the National Bus Terminal of Albrook that serves the overall country and the city. This station is, in addition, quite close to the local airport, Marcos A. Gelabert. At present, the headway is 3:20 minutes between 6:00 am – 8:00 am (i. e.18 train/ hour), and it is 4:30 minutes (i.e. 14 trains/hour) in off-peak hours [17]. The headway is the time distance between two successive trains on the railway track [18]. The PLM 1 dwelling time corresponds to a range between 20 to 30 seconds. The operating speed at the PML1 is 32 km / h. The maximum speed of the metro rolling stock is 80 km / h [15-17]. At the southern bound, in the Albrook zone, the Panama Metro line 1 has a facility for storage and maintenance of the metro rolling stock with a surface of 10 hectares. Also, the Operations Control Center (OCC) [18] is located at this facility. The metro rolling stock fleet includes trains with 3 and 5 electric coaches with multiple units, with a maximum capacity of 800 and 1000 passengers/train respectively [15-17]

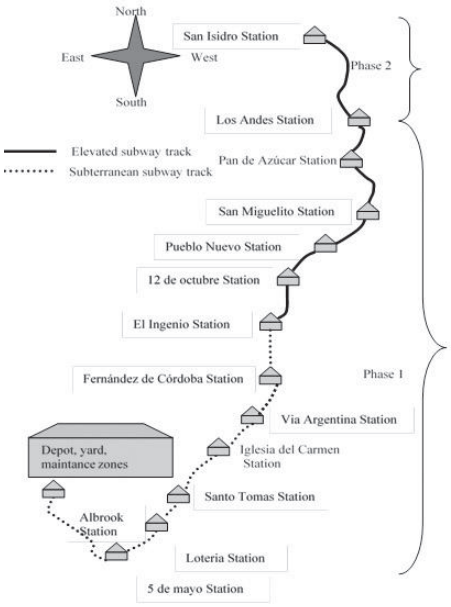

Fig. 1 Scheme of Panama Metro Line 1 (Phase 1 and Phase 2)

Fig. 2 Panama Metro Network (Line 1+ Line 2)

Panama metro line 2 (PML2) has an extension of 21 km and 16 elevated railway stations. Its routes towards the northeast of Panama City. PML2 began its operations on April 25, 2019. Current, it connects the eastern area of Panama City, beginning at the Nuevo Tocumen station, to the northeast, to the San Miguelito station (Fig. 2). Currently, the headway is 3 minutes (peak hours). PML 2 is a metropolitan subway with elevated track sections operated with a catenary-guided transport system [16]. At the east bound, in the Nuevo Tocumen zone, the Panama Metro line 2 has a facility for storage and maintenance of the metro rolling stock, with a surface of 12 hectares. The rolling stock fleet has 21 trains with 5 electric multiple units' coaches with a maximum capacity of 1200 passengers/train. As in PML1, top speed of the trains is of 80km/h [15-17]. The trains are fed through a rigid catenary system in 1500 volts in direct current [17]. Currently, the PLM 2 dwelling time corresponds to a range of 20 to 30 seconds [19]. The minimum stop time at the stations is 20 seconds. PLML2 was originally designed to move near 16 thousand passengers' hours in both directions but it can move over 40 thousand passengers soon. The maximum slope is of 35 mm/m [15], with a top commercial speed of 35km/h.

3. Methodology

Based on other example of modeling [8, 20-21] the methodology for this research analyzes 2 operational scenarios of public transport in Panama City defined by studies of the Panama Metro [23] (Table 1)

Table 1

Operational scenarios of public transport in Panama City [22, 23]

Scenario	Description
C	PML1 in operation. Line 1 starts from San Isidro, which translates into a 16 km length and 17 stations. Restructuring of the Metrobus system. This configuration is maintained until the year 2035.
D	Both lines 1 and 2 of the Panama metro in operation. Same as scenario C but in 2020 Metro Line 2 is added: La Doña - San Miguelito (green line of the master network). This line was designed with an approximate distance of 19 km and with 12 stations, eight of which were considered in the San Miguelito - Pedregal section. An initial capacity of 12,000 passengers per hour was considered. This configuration is maintained until the year 2035.

For both scenarios, the monetary value of time has been used as a function of the corresponding annual minimum wage in Panama. To establish a preliminary conservative calculation of the economic savings of time for users of line 1 of the Panama metro, we have the following:

$$\left.\begin{aligned} Ah_{econo_{salarymin}} &= \left(Tvsm - Tvcm\right)\left(Salary\_min\right)\left(DAP\right); \\ Ah_{econo_{stratum}} &= \left(Tvsm - Tvcm\right)\left(Salary\_prom_{estracto}\right)\left(DAPE\right), \end{aligned}\right\} \quad (1)$$

where *Tvsm* – road trip time (Shared vehicle platform); *Tvcm* – Metro total travel time in line 1. The original travel time of line 1 of the Panama Metro corresponded to 23 minutes. With the additional extension from the Andes Station to the San Isidro Station, the time increased to 26 minutes [23]; Salary_min – Minimum hourly wage in Panama ($3.48/hour).

Calculations considering a monthly salary of $613 (22 working days/month, 8 hours/day); Salary_prom_stratum – Average salary per hour, or per minute according to the social; DAP – Yearly demand for line 1 of the Panama Metro; DAPE – Estimated yearly demand by stratum for line 1 of the Panama metro.

4. Results and its Discussion

4.1. Externality of the Line with Scenarios C and D and Minimum Wage

The real demand for line 1 of the Panama metro has been increasing since its inauguration on April 6, 2014 except for 2020 (Table 2). In 2014, annual travel demand was 57.54 million trips per year, in the following year 2015 the annual travel demand increased by 68.97 million, giving a percentage increase over the previous year of 16.58% (Table 2). From there, the annual travel demand evidenced successive percentage increases in the order of 12.47% (2016), 3.34% (2017), 6.34% (2018) and 19.53% (2019). The increase of 19.53% in 2019 was due to the star of operations of PML2 since this line connects with PML1. In the case of 2020, the reason for the drop in demand has been the necessary application of quarantine periods and urban mobility restrictions in Panama City as measures indicated by the Ministry of Health of Panama for reducing infections during the Covid-19 pandemic. Fig. 3 shows the comparison between the real annual demand for trips on PML1 [23-27] 2020, with the European travel standard, which indicates that the construction of a travel line is justifies when the real demand exceeds 25 million trips per year [24, 28]. The total number of trips PML1 from its inauguration on April 6, 2015 to 2020 has been 519.72 million trips (Fig. 3 and Table 2).

Table 2

Summary of the biannual comparative increase in number of trips and percentage

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
Real anual demand of line 1-RADL1 (in million)	57.54	68.97	78.80	81.52	87.04	108.17	37.69	519.72
Annual increase in trips (in millons)	-------	11.43	9.83	2.72	5.52	21.13	-70.48	---
Percentage of annual increase in trips (%)	-------	16.58	12.47	3.34	6.34	19.53	-187.01	---

Table 3 shows the real annual demand data used in this research based on operating statistics for line PML1. The real annual demand for line 1 compared to the standard of 25 million trips has been exceeded with a surplus of 230% (2014), 276% (2015), 315% (2016), 326% (2017), 348% (2018), 433% (2019) and 151% (2020).

Table 3

Percentage comparison of the real annual demand of line 1 and European standard

Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
European standard for annual travel [29, 30]	25	25	25	25	25	25	25
Real annual demand of line 1 [30]	57.54	68.97	78.80	81.52	87.04	108.17	37.69
Percentage over European Standard	230	276	315	326	348	433	151

Table 4 shows the results of the calculation of the socio-economic externality PML1 for the 2014-2020 periods. To quantify the saving or socio-economic externality, two specific scenarios were selected that were attached to the operational reality of public transport in Panama City. Two scenarios were selected: C and D (Table 1), and minimum wage data for Panama City.

Table 4

Preliminary quantification of the economic externality of Panama metro line 1 2014-2020

Scenarios[30]	C	C	C	C	C	D	D	Totals
Parameters and calculations	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Travel time highway (minutes)[23]	80	69	70	71	71	71	67.61	---
Travel time subway(minutes)[23]	23	23	26	26	26	26	26	---
Saved travel time	57	46	44	45	45	45	41.61	---
Minimun salary/hour	3.48	3.48	3.77	3.77	4.16	4.16	4.30	---
Annual real demand (in millions)	57.54	68.97	78.80	81.52	87.04	108.17	37.69	519.72
Real economic value of externalities (in millions of US$)	190.21	184.01	217.86	230.50	271.56	337.48	112.31	1543.93
GDP in current prices (in millions of US$)	49,922	54,092	57,908	62,219	65,128	66,801	---	---
% Real externalities over GDP (GDP)	0.38	0.34	0.38	0.37	0.42	0.51	---	2.39

As seen in Table 4, the economic externalities based on the real annual demand of line 1 of the Panama metro have been increasing from 2014 to 2019, except for 2020, due to the fall of the passenger demand as explained above. For 2014, the estimate value of the socio-economic externalities corresponds to 190.21 million US dollars. As seen, the successive estimates of economic externalities correspond to 184.01 (2015), 217.86 (2016), 230.50 (2017), 271.56 (2018), 337.48 (2019) and 112.31 (2020). After 7 years of operation, the sums of the annual socio-economic externalities of line 1 of the Panama metro add up to a total of 1543.93 million US dollars.

4.2. Externality of Line 1 of the Panama Metro with Scenarios C and D, Percentage of Social Stratum and Income by Social-Economical Stratum

Marinho et al., [33] presents the distribution in percentage and income by social stratum in Panama as shown in Table 5. This information was used in the calculation of the socio-economic externalities in this project. Table 6 shows the low-income US$ month during the period 2014-2019.

Table 5

Percentage distribution and income by social-economical stratum in Panama [33]

Panama	%	Income range US$ month
High	22.2	Greater than 2,565
Middle	47.6	Between 1,089 and 2,565
Low	30.3	Less than 1,089

Table 6

Low Income US$ month during the period 2014-2019

Income	**2014**	**2015**	**2017**	**2018**	**2019**
Income US$ Month	574.6	663.1	744.1	741.6	769
Income US$ hours	3.19	3.68	4.13	4.12	4.27
Income	2014	2015	2017	2018	2019

Table 7 presents the economic externalities by social stratum in PML1 for the period 2014-2020. For the preliminary calculations based on the minimum wage, with the operating scenarios shown in Table1. As seen in Table 7, for the PML1, the stratum that generates the greatest economic externality the is the one with middle income. For example, for the year 2014, the economic externality generated by the middle-income stratum was 253 million US dollars. For the estimates of the economic externalities for the years 2014-2020 are also shown in Table 3. For example, for the year 2014, the total economic externality generated was 479 million US dollars. The total economical externalities generated were 471 (2015), 518 (2016), 553(2017), 590 (2018), 737 (2019), 238(2020) respectively. As seen, the ratio, in percentage, of the economic externalities over GDP for each of the years are 0.96% (2014) 0.87% (2015), 0.89% (2016), 0.89% (2017), 0.91% (2018), 1.10% (2019) respectively. The total of the estimates of the economic externalities of the three social stratums corresponds to US $ 3586 million during the period 2014-2020.

Table 7

Quantification of the economic externality by socioeconomic stratum of line 1 of the Panama metro 2014-2020

Scenarios [28]	2014C	2015C	2016C	2017C	2018C	2019D	2020D	Totals
Saved travel time (minutes)	57	46	44	45	45	45	41.61	
Real annual total demand	57.54	68.97	78.8	81.52	87.04	108.17	37.69	519.72
High-income real demand (22.2%)[23]	12.77	15.31	17.49	18.10	19.32	24.01	8.37	115.38
Middle-income real demand (47.6%)[23]	27.39	32.83	37.51	38.80	41.43	51.49	17.94	247.38
Low-income real demand (30.3%)[23]	17.43	20.90	23.88	24.70	26.37	32.77	11.42	157.47
Externality salary/hour-high-income (14.25)-EHI	173	167	183	193	207	257	83	1,262
Externality salary/hour- middle-income (9.73)-EMI	253	245	268	283	302	376	121	1,848
Externality salary/hour-low-income -ELI	53	59	67	77	81	105	34	476
Externality total in million US$ dollars)	479	471	518	553	590	737	238	3,586
GDP in million US$ dollars (current prices)	49,922	54,092	57,908	62,219	65,128	66,801	---	
Real externality over GDP (current prices)	0.96	0.87	0.89	0.89	0.91	1.10	---	5.62

From the strata division of the population, approximately 33% of the externality value corresponds to the high-income segment, 48% to the middle-income segment, and 19% to the low-income segment. This structure is due to the weighing factor coming from the higher salary of the middle-income segment although the estimated annual travel demand of the low statement is higher. Thus, the equivalent externality high-income stratus will be greater compared to the low-income segment, even though the latter has a greater number of estimated trips throughout the entire 2014-2020 period, as can be seen in Table 7 with an estimated total of trips of the low-income segment of 157.47 million, of 247.38 million for the middle-income segment, and of 115.38 million trips for the high-income segment. (see table 7). The total of the estimated externalities of all the socioeconomic segments corresponds to US $ 3586 million and the sum of the percentage ratio of these externalities to the GDP of Panama within the 2014-2020 period corresponds to 5.62% of the GDP.

4.3. Preliminary Socio-Economic Externalities of Line 2 of the Panama Metro

Line 2 of the Panama Metro started operations on April 25, 2019. Prior to this, it was operational during World Youth Journey and the visit of Pope Francisco. From January 22 to 27, 2019, PML2 transported 579, 933 passengers. Due to the Covid-19 pandemic, the expected mobility figures for the year 2020 have been strongly affected, being so that already in the month of May, the authorities of the Panama Metro announced that since the social distancing measures were implemented, demand from travelers fell to a minimum of 9% compared to the usual number of users [29]. The authors consider that this situation is a transitory, and once the Pandemic is over, Line 2 will transport the expected passenger volumes.

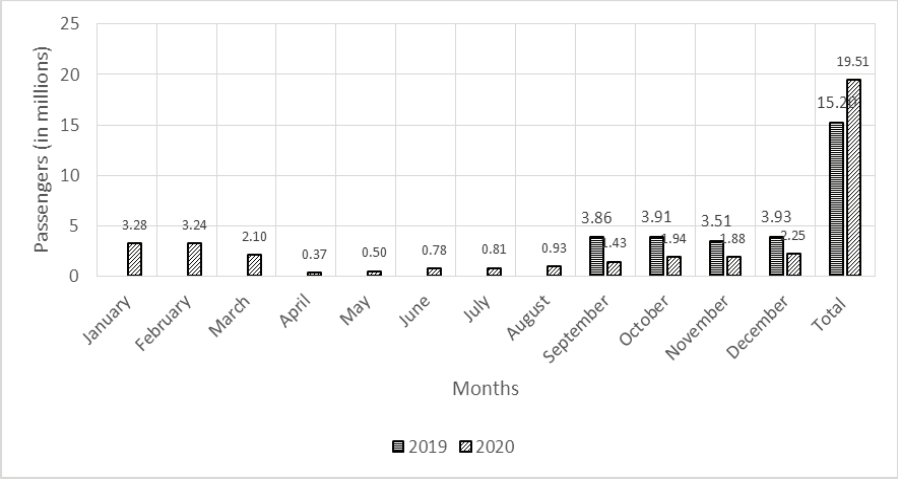

Fig. 4 Real monthly travel demand of the line 2 of the Panama metro

Fig. 4 shows the historic data for travel demand from September to December 2019 and for the entire year 2020. As shown in Fig. 4, during the year 2020, line 2 of the Panama metro did not exceed the annual European standard of trips of 25 million trips, due to the Covid-19 Pandemic, which caused restrictions mobility, confinement, virtualization of studies, and increase in teleworking from home and suspension of employment contracts. All these caused the demand for trips on line 2 of the Panama metro not be as expected (Fig. 4).

For the purposes of this research, the authors present the calculations of the socio-economic externalities of line 2 for the year 2020, based on the real annual demand [23] and the minimum wage. Additionally, calculations of the socio-economic externalities are presented for the 2020-D-2035-D scenarios based on the projections of the Panama Metro studies (Table 8).

Table 8

Projected scenarios of line 2 and its corresponding daily and annual demand

Year	Demand and characteristics (Line 2)	Passenger number	
		Daily	Annual
2020D	Line 2 with trains of 5 cars and interval of 3.8 min	233,550	74,736,000
2025D	Line 2 with trains of 5 wagons and interval of 3 min	276,500	88,480,000
2030D	Line 2 with trains of 5 wagons and interval of 2.7 min	317,340	101,548,800
2035D	Line 2 with trains of 5 wagons and interval of 2.4 min	334,780	107,129,600

According to scenario D projections, the daily average travel time of a person in public transport was projected in 67.61 minutes [30] . However, by 2020, the average travel time by public transport from the eastern sectors of Panama City to downtown Panama City during peak time is close to 90 minutes and may reach more than two hours[23]. Therefore, the estimates for 2020 have been presented in 4 scenarios. These scenarios are the ideal-real, the real-projected, the most probable and the pessimistic. The four possible scenarios for the calculation of the externalities of line 2 are presented in Table 9. In the general scenario of 2020 D, both lines, 1 and 2 are operating, in addition to the metro bus. The corresponding configuration will be maintained until the year 2035 [31-33].

Finally, scenario 5 presents three projected cases, for years 2025, 2030 and 2035, with three possible travel times. Using this information, it was possible to project the value of the economic externalities, as seen in Table 9, with a growth in the absolute and relative value of the externalities.

Table 9

Quantification of the economic externality of PML2 2020-2035

Parameters	2020 D	2020D	2020D	2020 D	2025 D	2030 D	2035 D
Travel time highway (minute) [23, 28]	90	120	67.61	67.61	69.23	68.89	69.94
Travel time subway (minutes)	35	35	35	35	35	35	35
Saved travel time	55	85	32.61	32.61	34.23	33.89	34.94
Real annual demand /projected [23]	19.51	19.51	19.51	74.74	88.48	101.55	107.13
Minimum salary/hour[34, 35]	4.3	4.3	4.30	4.30	4.52	4.74	4.98
Real economic externality value (millions of US$)	77	119	46	175	228	272	311
1: Most probable scenario, 2: Pessimistic Scenario, 3: Ideal-Real Scenario, 4: Ideal-proyected Scenario, 5: Projected scenarios							

5. Conclusions

Based on the above, it is possible to conclude that, although the investments required for this class of projects are large, especially for small countries like Panama, their recovery based on positive externalities makes them highly profitable from a social point of view. The importance of studying the impact of the externalities of the railway transport sector allows to have an order of magnitude of those social benefits that are not directly tangible. However, they are of vital importance for planning, design, construction, and operation of railway transport networks. This type of research expands the capacities for the comprehensive analysis of the benefits of public transport networks and is understandable for a multiplicity of transport professionals, who can discern these results for strategic decision-making in urban planning.

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