Design of a transportation system for workers in a Cuban resort area

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Abstract

The objective of our work is to solve the problem of transferring workers from a resort set on two cays (islets sandy) in the Sabana-Camaguey archipelago, north of Cuba, from their home areas to the resort and vice versa. We start with an economic analysis of the possible alternatives to solve the problem. Those that result most favorable economically are then subject to an environmental analysis, for tourism development in the area is based on the physical environment of high ecological and landscape that surrounds it. After completing the environmental impact study of each alternative, we choose the most appropriate and favorable one. In the case of the introduction of a means to transport workers, we proposed light rail as the most economically feasible option, due to the conditions of our problem. Finally, we arranged the transfer of workers using buses from the terminal to the various hotels in the resort area.
Keywords: transportation, workers, sustainability, optimisation.

1 Introduction

Jardines del Rey is a resort area composed of *cayos* (islands linked to the mainland by a narrow road bridge or *pedraplen*), of recent and increasing development. As shown in Figure 1, it is located in the Sabana-Camaguey archipelago, north of the Cuban province of Ciego de Ávila, some 300 miles east of Havana and just 3 miles from the southern edge of the Old Bahamas Canal, a major international maritime corridor. The area, ranked the third largest and second in beach length of Cuba, is becoming one of the strongest tourist destinations in the region. The main *cayos* in Jardines del Rey, and the ones where the resort activity is concentrated, are Cayo Coco and Cayo Guillermo. Cayo Coco, the largest one, contains the international airport, and is linked to Turiguano, in the province of Ciego de Ávila, by a 17 km *pedraplen*, and to Cayo Guillermo by a smaller one.

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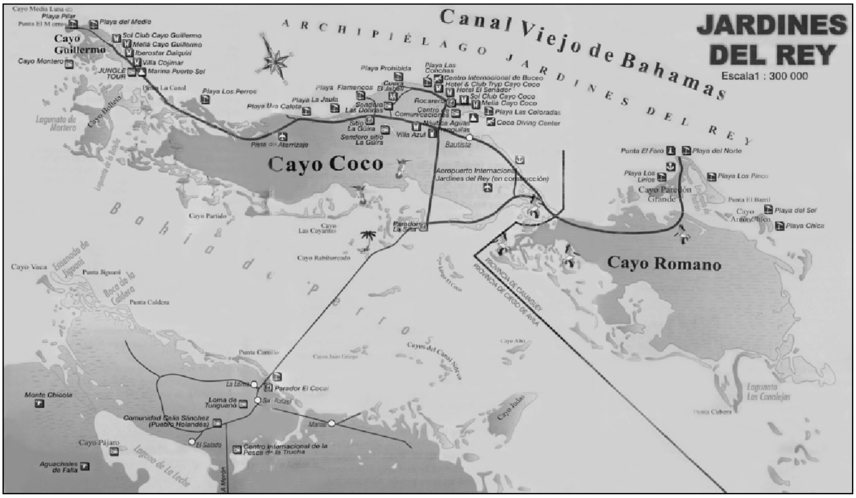

Figure 1: Main islands in the Jardines del Rey area (source: cuba-junky.com).

The only buildings in Jardines del Rey correspond to hotel and resort premises, which means that there are no resident towns in the area. Hotel workers live in the mainland, in the Ciego de Avila province, in towns like Ciego de Ávila, Morón, Ciro Redondo, Ceballos, etc., and need to be commuted to the hotels every day.

The current transportation system is organized with buses, operating from the towns of Ciego de Ávila and Morón (see Figure 2 for the distances between the main nodes in the transportation graph, and Table 1 for the description of the buses included in the current transportation fleet). These buses, which are only used for the cayos service, are provided by the Cuban government, and the hotels pay an annual fee for the service. Tourists use a different type of buses, driving on the same roads, which are in a rather bad state of conservation. They are designed for a speed of 100 km/h, but because of their state the actual speed of buses does not exceed an average 60 km/h. The existing transport infrastructure manages to cover the current needs for transportation, but the expected growth in the area is more than likely to saturate it in the near future.

Table 1: Current bus fleet used in the transportation system.

Bus capacity	No of available buses
6	52
70	45
19	33
2	30

As a continuation of the economic analysis that we completed in a previous research work [1], our objective here is to assess the selected mobility solution (light rail) from an environmental point of view, which is not a negligible one given the natural and landscape richness of the Jardines del Rey area.

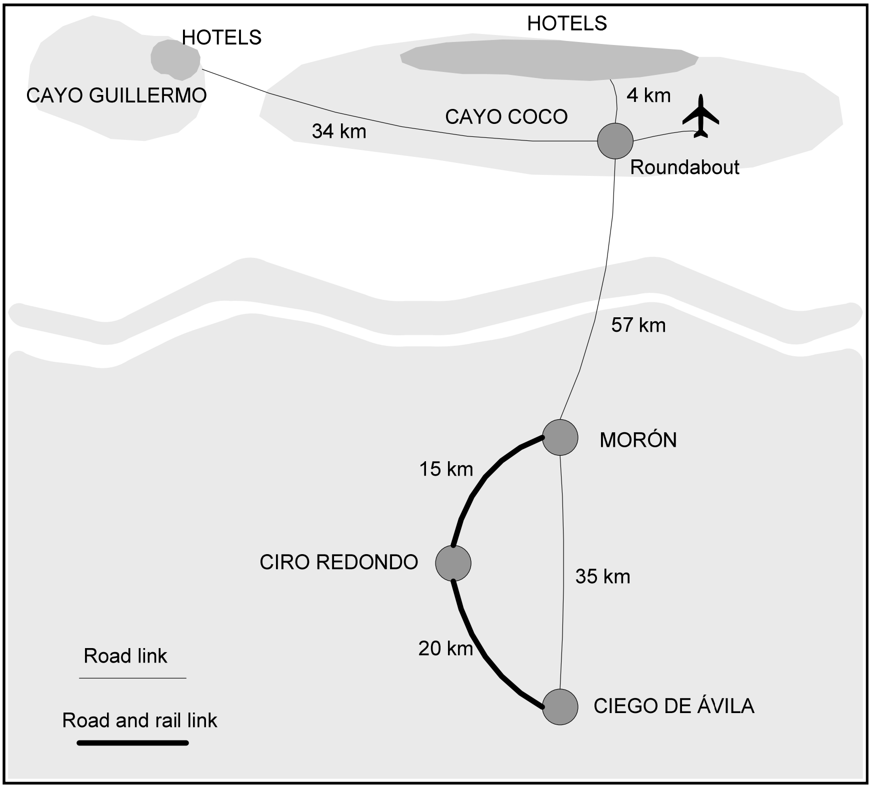

Figure 2: Schematic representation of the area, with the towns of Morón, Ciro Redondo and Ciego de Ávila in the mainland and the hotel areas of Cayo Coco and Cayo Guillermo.

2 Description of the mobility problem

The Jardines del Rey hotels are visited by 320,000-350,000 tourists every year. Current data (year 2010) shows a total amount of 4,000-5,000 hotel rooms in Cayo Coco and Cayo Guillermo, requiring some 3,700 workers per day. Furthermore, the current growth rate of the area should result in a 100% increase by 2020, which represents 765,000 tourists per year, 12,400 hotel rooms and more than 8,000 hotel workers. This are a daily averages of data for the whole year, but the numbers of tourists and workers are very different in high and low seasons.

In the current scenario, workers need to arrive at the hotels in three different shifts (6:30, 8:00 and 14:30), and also have three different return times (16:30, 18:00 and 24:00). To provide an overall picture of the mobility problem, Table 2 shows the number of workers that need to arrive at each destination in each one of the shifts, and Table 3 shows the number of workers that go back.

Table 2: Number of workers arriving at each destination in the *cayos* in the morning.

Morning (mainland to cayos)		Number of workers								
		Low season			Medium season			High season		
	Destination	6:30	8:00	14:30	6:30	8:00	14:30	6:30	8:00	14:30
1	H. Sol Meliá Coco	111	182	177	133	219	200	160	261	238
2	H. Senador	179	57	158	216	69	188	258	83	223
3	H. Tryp	125	143	93	149	172	111	177	205	134
4	H. Playa Coco	61	132	94	74	158	114	89	188	137
5	H. Sol Guillermo	35	37	28	42	45	33	50	54	39
6	H. Meliá Guillermo	25	33	33	30	40	40	36	48	48
7	Villa Cojimar	33			40			48		
8	H. Iberostar Daiquiri	37		35	44		42	52		50
9	H. Blau Colonial	101	72	111	122	87	135	146	103	162
10	Non-hotel	68	72		81	86		96	102	
11	Ruteros Guillermo	128	40	69	153	48	84	182	57	101
12	Airport		99			120			144	
13	Customs office		94			113			135	
14	Cubacanán	33			40			48		
15	Marina Port		33			40			48	
16	Caracol		42			50			62	
17	Others Cayo Coco	35	192		42	233		50	280	
TOTAL		971	1228	798	1166	1480	947	1392	1770	1132

Table 3: Number of workers leaving each destination in the *cayos* in the evening.

Evening (cayos to mainland)		Number of workers								
		Low season			Medium season			Low season		
	Destination	16:30	18:00	24:00	16:30	18:00	24:00	16:30	18:00	24:00
1	H. Sol Meliá Coco	74	182	177	88	219	200	106	261	238
2	H. Senador	204	32	158	246	39	188	294	47	223
3	H. Tryp	97	134	93	116	161	111	140	192	134
4	H. Playa Coco	61	107	94	74	128	114	89	152	137
5	H. Sol Guillermo	35	37	28	42	45	33	50	54	39
6	H. Meliá Guillermo	25	33	33	30	40	40	36	48	48
7	Villa Cojimar	33			40			48		
8	H. Iberostar Daiquiri	37		35	44		42	52		50
9	H. Blau Colonial	101	72	74	122	87	90	146	103	108
10	Non-hotel	40	100		48	119		57	141	
11	Ruteros Guillermo	128	40	69	153	48	84	182	57	101
12	Airport	99			120			144		
13	Customs office	94			113			135		
14	Cubacanán	33			40			48		
15	Marina Port	33			40			48		
16	Caracol		25			30			36	
17	Others Cayo Coco	33	194		40	235		48	282	
TOTAL		1127	956	761	1356	1151	902	1623	1373	1078

3 Light rail system

The choice of a light rail system to transport workers to the hotel, which could also be used to transport tourists to the mainland for one-day visits, was economically justified in [1]. Light rail allows for steeper slopes and smaller turning radiuses than conventional rail systems, and also presents lower entry/exit times for passengers due to its low platform. The rail system would use the existing railroad infrastructure (see Figure 2), extending it to the main roundabout in Cayo Coco.

Given the current data shown in Tables 2 and 3, the commuter demand could be covered using only two trains, each one of them doing two return trips per day, with the schedules shown in Table 4. The trains would be based in Ciego de Ávila and travel to Ciro Redondo, Morón, Cayo Coco and back. The difference between this scheme and the 150 buses currently used is evident, given also the significant reduction in travel times.

Table 4: Proposed schedules for the light trains between Ciego de Ávila and Cayo Coco.

Train	C. de Ávila–Cayo Coco	Cayo Coco–C. de Ávila
A	6:30–8:00	13:00–14:30
	14:30–16:00	18:00–19:30
B	8:00–9:30	16:30–18:00
	22:30–24:00	24:00–1:30

4 Environmental impacts of the light rail scheme

Our concern was then to evaluate the light rail system from an environmental point of view, given the need for sustainable policies that help preserve the *cayos* as much as possible in their original state. In the first place, it is important to note that the energy consumption per person and per km. is 3.4 times higher in buses than in light rail systems, while the capacity of the light train is around 2.3 times higher [2, 3]. Besides, the emissions generated by the light rail system are not concentrated in the cayos, but in the electric plant, where they can be dealt with in a much more efficient way.

We therefore concentrated on the environmental impact analysis of the light rail system. We did this by in the first place identifying the relevant impacts of the system implementation in the environment. We then evaluated the significance of each phase of the project on each environmental factor, and estimated its severity using the available data.

4.1 Identification matrix

We chose the Identification Matrix [4] as the method to analyze impacts. This matrix (see Table 4) considers all the possible pairs between project actions and environmental elements. Every row corresponds to a project action (primary impact generator), and every column to an environmental aspect which may, or may not, be affected by the different actions. Each cell in the table indicates whether the environmental aspect is affected by the corresponding action, and also the gravity of the effect.

Table 4: Identification Matrix between project actions and environmental aspects (A: severe impact; B: medium impact; C: light impact).

PROJECT ACTION \ ENVIRONMENTAL ASPECT		Air quality	Geomorphology	Hydrology	Land	Vegetation	Fauna	Landscape	Socioeconomic	Social reaction	Use of resources	Quality of life
CONSTRUCTION PHASE	Powder emissions	B		C		C	C					
	Pollutant emissions	B		B		B	A			C	B	C
	Noise						B			C	B	B
	Earth movement		A		B	B		A		C		
	Waste disposal			B		B	B	A		C		C
	Truck movement				C			C				
	Spatial occupation				C			C				
EXPLOITATION PHASE	Acoustic emissions						A			C	A	B
	Pollutant emissions	A				A	B			C	A	B
	Water runoff			A	C	C					C	
	Lane reduction										C	C
	Transportation of persons								A	A	B	B
	Vehicle movement							A				

4.2 Impact comparison

The joint consideration of all the alterations or impacts generated by the light rail system, which is known as the Global Environmental Impact, represents the final filter for its environmental justification. This impact should be compared with those of all the other solutions considered to solve the mobility problem.

Thus, as a complement to this Identification Matrix, we developed a direct comparison of the positive and negative effects of the light rail implementation with respect to the current systems of transportation of workers (and tourists) using buses. It is important to note that, for the current bus system, we considered as indispensable the repaving of the existing road, since it would not be able to provide a sufficient degree of service to the amounts of workers and tourists expected in the *cayos* over the next few years.

In the comparison, the main advantages of the light rail system are:

Lower transfer times
- Less accidents and higher levels of safety
- Smaller energy consumption per person transported
- Zero or low degree of pollutant emission
- Lower noise levels
- Higher levels of comfort
- Excess capacity that can be used for tourist transportation
- Better overall image of the transportation service
- Lager transport capacity
- Right of way in intersections
- Reduction of overall traffic congestion in the road and *pedraplén*

On the other hand, the main disadvantages of light rail with respect to buses are:

- It requires high structural stability of the *pedraplén* in order to allow for train sustentation and vibrations
- Higher visual impact
- Lower service frequencies for a given demand
- Need to incorporate new infrastructure in case of service extension
- Lower accessibility, which requires transfers. Possibility of longer overall displacement times.
- Longer implementation period
- Reduction of the available space for vehicles and pedestrians
- Possible safety implications

As a result, the advantages of the light rail system cannot be assumed to clearly outperform the disadvantages. The implementation required a series of preventive and corrective measures which minimized of eliminated these disadvantages and the corresponding impacts identified in Table 3. The following section describes the measures that were suggested for this particular project.

5 Preventive and corrective measures

For each negative impact of the light rail system to the *cayos*, we describe here the measures or actions that help minimize it [5]:

Impact #1: Noise emissions during the construction phase
Actions:
- Use low-noise equipment
- Adjust the schedule of construction works so as to minimize the impact on the population
- Arrange detours avoiding residential areas
- Avoid works during weekends or tourist high seasons

Impact #2: Powder emissions during the construction phase
Actions:
- Water unpaved machinery trails and areas once a day
- Install lateral protections to retain particulate materials
- Wet arid materials during loading, unloading, transportation and storage operations
- Unload materials from heights lower than 1 m. when possible
- Cover storage heaps

Impact #3: Generation of acoustic emissions during the exploitation phase
Actions:
- Avoid low turning radiuses and steep slopes
- Speed control
- Design the infrastructure incorporating ballasting structures, elastic rail bearings, insulation screens, etc.
- Use cars with disk brakes, elastic wheel bands, noise absorbents, anti-vibration structure, etc.
- Adequate machinery maintenance

Impact #4: Reduction of the available space for vehicles and pedestrians
Actions:
- Reduce the width of road lanes
- Increase the width of the roadbed by the acquisition of additional land
- Redesign crossings to increase operational efficiency and safety

Impact #5: Possible safety implications
Actions:
- Visual and acoustic signaling in shared platform areas
- Increase precautions in the design of transfer points and stations
- Guarantee preventive maintenance
- Professional training of drivers and operators
- Appropriate and frequent medical monitoring of personnel

Impact #6: Water pollution
Actions:
- Locate oil and waste containers at least 30 m. away from water courses

Impact #7: Higher visual impact
Actions:
- Limit the height of infrastructures as much as possible
- Install visual screens close to urban areas, using natural elements
- Keep the work area clean during the construction phase

Impact #8: Lack of knowledge on environmental laws and regulations for preserved areas
Actions:
- Generate, apply and monitor environmental plans
- Implement an environmental strategy to integrate touristic development in extremely fragile ecosystems
- Create a public infrastructure specialized in environmental issues, which enforces an adequate level of protection

Impact #9: Water runoffs
Actions: ▪ Build settling basins, infiltration ditches, artificial humid soils, course channelling, etc.

Besides these actions, an environmental impact analysis should also include an environmental monitoring programme to control the evolution of impacts and the efficacy of corrective measures. The impacts identified in the previous section and the prophylactic measures proposed here should be under scrutiny during the construction phase and over the first few years of exploitation in order to guarantee the soundness of the initial estimations and prevent the excessive alteration of any sustainability parameter.

6 Shuttle service for workers

The fact that the light rail system presents lower accessibility (in terms of door-to-door service) than buses, with the extension of the existing railroad planned only until the main roundabout in Cayo Coco, results in the need for an additional shuttle bus service to transfer the workers (and tourists) arriving by train to the hotels in Cayo Coco and Cayo Guillermo. However, sustainability policies require that shuttle service to be provided by the minimum number of vehicles, covering the minimum possible distances and thus consuming the minimum amount of energy.

We built an optimization model to minimize the number of required buses, starting from the existing fleet described in Table 1, and the distances to be covered by them when transferring the workers from the Cayo Coco roundabout to their hotels. The model is built on a graph with n nodes, where the base node i=0 corresponds to the Cayo Coco roundabout and the rest to the different hotels, and the available bus fleet is assumed to be the one described in Table 1. The model contains the binary variables y_{ik} to represent whether hotel i is served by bus k, and δ_k to represent whether bus k is used for the shuttle service, and the integer variables x_{ik}, which account for the number of workers transported to hotel i in bus k. With respect to the data, c_i is equal to the distance between hotel i and the base node; $d_i = 2 \cdot c_i$; c_s is equal to the distance between the base node and the hotel areas (c_s = 4 km for Cayo Coco and 34 km for Cayo Guillermo, see Figure 2); b_k is the capacity of bus k; a_i is the number of workers of hotel i; and C is the fixed cost (in distance units) of using an additional vehicle in the fleet. The model is as follows:

$$Min \quad \sum_k \sum_i d_i y_{ik} - \sum_k 2c_s \left[\sum_i y_{ik} - 1 \right] + C \sum_k \delta_k - \sum_k 2c_s (1-\delta_k) \qquad (1)$$

s. to:

$$\sum_k y_{ik} \geq 1 \quad \forall i = 1,\ldots,n \qquad (2)$$

$$y_{ik} \le \delta_k \quad \forall i = 0,1,...,n; k = 1,...,K \tag{3}$$

$$x_{ik} \le y_{ik} b_k \quad \forall i = 0,1,...,n; k = 1,...,K \tag{4}$$

$$\sum_i x_{ik} \le b_k \quad \forall k = 1,...,K \tag{5}$$

$$\sum_k x_{ik} = a_i \quad \forall i = 0,1,...,n \tag{6}$$

$$y_{ik}, \delta_k \in \{0,1\}; x_{ik} \text{ integer} \tag{7}$$

The objective function (1) minimizes the number of buses used in the fleet and the total distance covered by them in their daily services. The first term calculates this total distance, but the second term subtracts the savings generated when the same bus services two hotels in the same trip; the third term penalizes the use of additional buses, and the fourth one eliminates the savings for those buses that were not used at all. With respect to restrictions, (2) forces all hotels to be serviced; (3) ensures that only used buses can service hotels; (4) imposes that only those buses servicing a given hotel may transport workers to that hotel, and (5) ensures that the amount of workers transported is limited by the bus' capacity; (6) is the demand restriction, and (7) describe the feasible values that can be taken by the different variables.

We solved the model using the *gplk* toolbox in Matlab. We solved two different models, one for Cayo Coco and another for Cayo Guillermo, given the characteristics of the graph and the fact that buses would either serve one hotel are or the other, but never both at the same time. We also solved separate models for high, medium and low season. The results are shown in Table 5.

Table 5: Number of buses needed to provide shuttle service from the Cayo Coco roundabout to the hotels.

Season	Cayo Coco	Cayo Guillermo
High	13 buses seating 45	1 bus seating 52 and 2 buses seating 45
Medium	16 buses seating 45	2 buses seating 52 and 1 bus seating 45
Low	19 buses seating 45	3 buses seating 52 and 1 bus seating 45

Additional buses should be used for the other destinations shown in Table 6.

Adding up the figures, the optimal fleet size for the shuttle service should include 6 buses seating 52 and 35 buses seating 45, which represents a significant reduction with respect to the current values.

Table 6: Additional buses for other shuttle services.

		Season		
		Low	Medium	High
Cayo Coco	Airport and Customs office	4 seating 52	2 seating 52 3 seating 45	2 seating 52 4 seating 45
	Non-hotel destinations	6 seating 45	1 seating 52 6 seating 45	9 seating 45
Cayo Guillermo	Caracol	1 seating 45	1 seating 52	2 seating 45
	Marina Port	1 seating 45	1 seating 45	1 seating 52

7 Conclusions

After completing the analysis, a series of conclusions may be extracted from it. In the first place, we can conclude that the light rail system constitutes a sound and adequate solution for the commuting of workers to the hotels in the *cayos*. This was one of the best solutions selected from the economic point of view, and it has also proved environmentally sustainable, since its benefits outweigh its drawbacks, and the latter can be reduced or eliminated through the appropriate set of measures. This is a very important fact, due to the need to preserve the high environmental and landscape value of the area, whose increasing touristic development is precisely due to it. It is however this increase in touristic demand was will eventually render the bus system unsustainable.

The light rail system would then generate economies of scale not only economically but also environmentally, solving many of the pollution problems linked to the operation of the current bus fleet. Still, the use of buses is required to provide a shuttle service from the rail terminal, located in the main roundabout of Cayo Coco, and the hotels, which are between 4 and 34 km. away. In order to provide this service at the minimum economic and environmental cost, we built an optimization model to determine the size of the minimum fleet required to provide this service in low, medium and high season.

With respect to the future, if the growth in the area continues at the same rhythm and the light rail system to the Cayo Coco roundabout proves efficient, the possibility should be contemplated to extend the railroad until Cayo Guillermo. This would further reduce the number of buses used inside the *cayos*, thus also reducing their environmental impact and allowing for the sustainable development of the smaller island.

References

[1] Muñuzuri, J., Cortés, P., Onieva, L. and Guadix, J. (2007) How should workers be transported to a developing hotel area in Cuba? International Journal of Tourism Policy, 1(3), 232-245.
[2] Klingenberg, H. (1996) Automobile exhaust emission testing. Springer.
[3] García, A., Cillero, A. and Rodríguez, P. (1998) Operación de trenes de viajeros. Fundación de los Ferrocarriles Españoles, Madrid.

[4] Español, I. (1995) Impacto Ambiental. ETS Ingenieros de Caminos, Canales y Puertos, Madrid.
[5] Tiktin, J. (1998) Medidas correctoras del impacto ambiental en las infraestructuras lineales. E.T.S. Ingenieros de Caminos, Canales y Puertos, Madrid.