

# **Aerial Ropeways as Catalysts for Sustainable Public Transit in Egypt**

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**ABSTRACT:** Mobility is not only about facilitating accessibility for everyone but also providing broad social, economic, and environmental benefits. While many countries in the developed and developing parts of the world are moving towards the development of smart mobility and sustainable transportation systems, the ropeway transit system (RTS) has imposed itself as an environmentally, socially, and economically effective mode of public transportation. However, the use of RTS in urban environments as a public transport system has not yet been studied thoroughly. The traffic congestion and air quality deterioration, the problems associated with transportation, appears even more in the high-density populated areas such as Greater Cairo, Egypt, where the two banks of the Nile River are linked with only eight bridges, which, along with the Cairo Metro and the ongoing sustainable transport project in Egypt, have not yet solved these problems. Thus, this paper aims to (a) develop a theoretical background on RTS systems, (b) review the existing statement of transportation in Egypt, and (c) highlight the possibility of applying this type of transport in Egypt and develop a set of recommendations for addressing the traffic congestion problem in the Greater Cairo area through an RTS.

**KEYWORDS:** Aerial ropeways, Gondolas, Tramways, Public transport, Greater Cairo, Egypt

## **I. INTRODUCTION**

### *A. Negative implications of transportation*

The rapid growth of the transport sector, particularly motorized transportation, has led to major impacts related to socio-economic and urban sustainability, such as the problems of long-term traffic congestion and traffic accidents affecting quality of life and financial productivity, as well as the significant environmental impacts of excessive consumption of energy resources, high levels of pollutants caused by fossil fuel combustion (GHG emissions, mainly carbon dioxide and monoxide), climate change, and noise pollution, all of which cause harm to humans and sensitive ecosystems. The transport infrastructure occupies a space that could be used in other ways in urban areas, and this is clearer in high-density countries. Moreover, the basic infrastructure of all modes of transit has a negative impact on landscapes and urban aesthetics [1-6].

Public transit is the base of any smart growth system within cities, attributable to saving energy, reducing harmful emissions, reducing congestion, and achieving fast access, especially if it has dedicated lanes separated from other traffic [7]. Nevertheless, the development of traditional mass transit modes, namely buses, trains, tramways, or subways, requires much time and investment in road and infrastructure construction and, in many cases, the resettlement of the population [2].

The transformation to sustainable mobility, giving priority to non-motorized transportation, is therefore pivotal if urban sustainability levels are induced and greenhouse gas emissions from transportation in urban areas are reduced. This shift can be achieved by combining sets of measures that enable the reduction of the total transport volume and the transition from motorized to non-motorized (pedestrianism and cycling), the encouragement of user-to-user services (ride-sharing or car-sharing), and the provision of mass public transport [3]. Despite the worldwide recognition of cycling as an important means of sustainable transport, its application is still occurring on a small scale, and it is still seen as a kind of daily leisure [4]. Among the schemes introduced as pathways to sustainable mobility are the provision of alternative propulsion forms such as electricity, renewable energy-based fuel [3], biogas-driven vehicles [8], and

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cable cars or aerial ropeways [3] which have recently imposed themselves on the urban scene as means of mass transport. The below section is dedicated to reviewing ropeway transit systems (RTSs).

## II. RELATED WORK

### A. Ropeway transit systems (RTSs)

In recent years, ropeways have gained growing interest worldwide as attractive and cost-effective transit routes for the urban terrain. An RTS is an aerial public transport mode that relies on rope-mounted cabins (rail-supported cable cars) that belong to the category of cable-propelled transit technology. The technique was initially used in ski resorts (namely the Téléphérique and gondolas) and then used in rugged terrain where the traditional transit service was difficult to execute [9, 10]. In addition, they are used for recreational purposes. Since ropeways were mainly developed for rugged terrain [2, 9], they can be used for all types of natural obstacles, such as rivers, lakes, ports, and railways, as well as urban obstacles on normal terrain, such as in densely populated urban areas [11]. As a result, they have been used recently as public transport systems [10, 11]. Although the ropeway systems are reminiscent of developed countries, there are also recent projects in developing countries like Colombia, Bolivia, and Nigeria, which have already demonstrated their effectiveness in reducing congestion [2], and in improving accessibility in informal settlements [12], such as in the Metrocable in Colombia. The Metrocable of Medellin, Colombia is the first RTS in the world to be used as a public transport system, where the system is directly linked to the city's metro system [11]. The erection of new road networks in densely built-up areas may require the removal of the existing structures and hence the relocation of the local population, while RTSs add capacity to the transport network without further pressure on the road network [10]. Despite the recent growing trends towards the use of ropeways in urban areas [2], the use of RTSs in urban environments as a public transport system hasn't been studied thoroughly so far [6].

### B. Components of RTSs

The components of an RTS include carriers (cabins), motors, terminals (stations), towers (pylons), ropes (cables), and an evacuation and rescue system [9, 13] as shown in Fig.1. The components of the RTS will be summarized as follows:

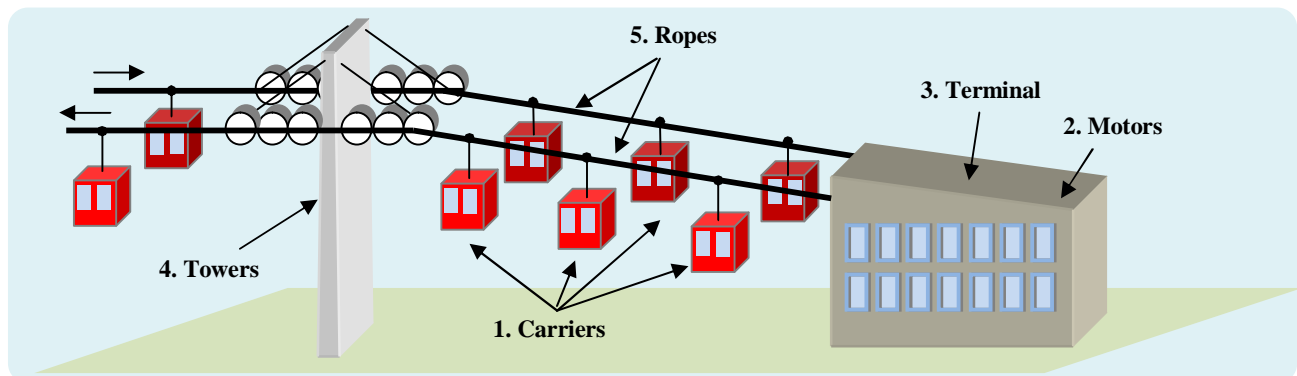


Fig.1 Components of RTS, source: author

- **Carriers.** The carriers are the units that carry and transport passengers. Each carrier consists of three parts: a grip, a hanger, and a cabin. There are two main types of grips: the fixed grips and the detachable grips. Fixed grips are used in aerial tramways, and detachable grips are used in gondolas, as will be detailed later. The hanger is the part that ties the cabin to the ropes. Cabins may be large, as in the case of aerial tramways with an approximate 80-passenger capacity, or small and medium, as in the case of gondolas with approximate 15-passenger capacities. The cabins are free of motors, have no brakes, and can be equipped with photocells [9, 13].
- **Motors.** The cabin cars are directly connected to the stations through haulage ropes which are propelled by the bull-wheels and engines positioned in the terminals [13].
- **Terminals.** Each RTS line consists of two terminals, one at the line's beginning and the other at the end, and at least one intermediate terminal to drop off and pick up passengers between the two main terminals [9, 13]. The design of each terminal is unique, as its design depends on the specific characteristics of the existing natural or built

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environment as shown in Fig.2. Thus, balancing between variance and standardization is one of the major challenges in RTS design [14]. The smallest terminal's dimensions are about 10 meters for width and 25 meters for length (50 meters for intermediate terminals) [15]. Leitner states that the extension by five meters makes for higher performance in design and more comfortable boarding and deboarding [14]. The core element in each station is the bullwheel that drives the system (the bullwheel's diameter is about six meters, such as in the Emirates Air Line, London). The core functions of the station, such as ticket rooms, staff rooms, and mechanical and electrical equipment rooms, are placed under the bull wheel [16], often to make the most of the space in favor of the route of the cabin cars movement.



Fig.2 Various design configurations of RTS terminals

- **Towers (pylons).** The towers, often steel-framed, pylon-shaped towers, are the structures that support the haul and track ropes between the stations [9]. The towers are made of tubular steel with different lengths and diameters and wall thicknesses. The towers are divided into small sections and are then transported from the factory to the construction site and reassembled. If the height of the tower is more than 30 meters, it is built as a tubular or lattice tower with two or more legs. The towers are equipped with ladders and maintenance platforms [17]. Pylon design alternatives can include cantilever, whalebone, box, arch, and single pylons [18].
- **Ropes.** The rope is the base of the RTS. RTSs use one or two fixed ropes, called track ropes, for support and one movable rope, called a haul rope, for propulsion. Each rope consists of a group of intertwined strands, which in turn consist of a set of wires. The grip of the aerial tramway's cabin is fixed onto the haul rope and cannot be separated from it during operation. In gondola systems, the cabins are detachable. Determining the type of rope, whether haul ropes, track ropes, or both, is a critical point and depends on the technology used [9, 11]. The cable diameter depends on its type, either a haulage rope or a track rope. The diameter of the cable of the haulage rope is about 2.85 cm, and that of the track rope is 4.76 cm for a bi-cable system or 3.49 cm for a gondola system [9]. A safety distance of four meters should be left between the RTS route and the nearest housing facility, whether it is a building, a railway, a danger, or electrical wires. However, if these four meters are not available and there is no safety related concerns, this distance could be shortened to be 2.5 meters, otherwise protective barriers should be used. The standard inclination angle for cables should be less than 30°. It can be increased to 45° if the necessary strengthening provisions are taken. An inclination angle of 30° should be maintained between the station and the nearest pylon for safe braking requirements. A height of two to three meters should be left from the bottom of the cabins to any obstacle below, such as a tree or a building [19].
- **Evacuation and Rescue System.** Every RTS must contain an extra petrol or diesel engine in the case of an electrical power failure. With regard to the evacuation system, all RTS systems must contain measures to evacuate passengers to the ground level [10, 13, 20]. The potential risks of the system vary among mechanical risks, electrical risks, thermal risks, exposure to noise, environmental-related hazards, infrastructure-related hazards, and exposure to severe weather. Nevertheless, experiences from using RTS systems in developed and developing countries suggest

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that the risks of such system are preventable because of the standards and laws governing the industry. Mechanical risks in the case of gondolas may include the grip not being reattached after it has been detached or not properly reattached. In this case, there should be electronic monitoring devices that stop the gondola automatically. If the RTS line passes over a dense urban area, signs and lighting should be installed to clarify the pathway and to secure the required area in case of a vertical rescue operation. Nevertheless, this latter measure may not work in cases of impassable terrain, vast water areas, or too-high elevation over the earth's surface. An independent rescue cabin can help in this case, like the one installed in the TDG system in Koblenz (Germany) [13]. The cabins must be equipped with communication tools between passengers and operators, such as intercoms [10], CCTV (closed circuit television), and lighting, as well as incorporating a daily shift of the transit police [20].

### C. RTS technologies

There are two types of ropeways or aerial lifts, aerial tramways and gondolas [6], and there are two differences between them. The first is that the two cabins of the tramways move back and forth on the cables, while the cabins of the gondola are suspended from hauling cables and continuously move and circulate around two terminals. The second difference is, as mentioned before, that the grip of the cabin of the aerial tramways is fixed into the haul rope while the cabins of gondolas are detachable [15]. More details about both technologies will be elucidated below.

- **Aerial Tramways and Dual-Haul Aerial Tramways.** Aerial tramways consist of one or two fixed cables for support (track rope) and a third moving cable for propulsion (haul rope). The grip of the cabin shall be mounted on the propulsion rope and cannot be separated from it. There are two types of aerial tramways: the single-haul aerial tramway, or the conventional aerial tramway, and the dual-haul aerial tramway as shown in Fig.3: a, b. Dual-haul aerial tramways are similar to single-haul aerial tramways but the first system is more advanced than the latter. While the two cabins of the single-haul aerial tramway have one shared loop (with its own two-track ropes and haul rope), each cabin of the dual-haul system has its own loop (with its own two-track ropes and haul rope). In other words, every cabin is operated independently. This single-cabin operation allows for easier maintenance and evacuation procedures. Another feature of the dual-haul system is its stability in high winds, attributable to the horizontal distance of about 4.2 meters between the two independent cables [9, 13].
- **Gondola Systems.** There are three types of gondola systems, mono-cable detachable gondolas (MDGs), bi-cable detachable gondolas (BDGs) and tri-cable detachable gondolas (TDGs) [9] as shown in Fig.3: c, d, and e. The common feature among the three types of gondola systems is that they are detachable. The cabins are detached from the propelled rope at the terminals, are then slowed down, unload and reload passengers at a very slow speed, and are then accelerated to reattach the haul rope for high speed travel on the loop between stations. Unlike aerial tramways, MDG systems are both suspended and propelled by the same cable [9, 11]. In this type, distances between towers are limited to between 600 to 800 meters according to Certtu et al. and Carlet [11, 15], while, according to Alshalalfah et al., the distance is about 350 m [21]. BDGs combine between aerial tramway systems, with their separated rope systems (one rope for support and the other for propulsion), and gondola systems, where their cabins are detachable. Both features lead to BDGs covering long spans (with longer distances between towers) and having much higher capacities [9, 11] as shown in Fig.4. TDG beats BDG with its tramway-like technology as it has two fixed ropes for support and the third for propulsion. And, by possessing the feature of detachability, TDG beats the other gondola systems with their very long spans of up to 3,000 meters, their low power consumption [9], and their outstanding wind stability that could reach 100 km/hour, such as in the TDG of Lagos, Nigeria [10]. Although it is more costly than MDG and BDG, its higher passenger capacity and higher speed can offset its higher cost [9]. When comparing between aerial tramways and gondola systems, the latter is preferable. The continuous circulation of gondolas with the large number of cabins provides a continuous service with several departures per minute and consequently decreases waiting times [22]. Moreover, the required infrastructure for small cabins is lighter than that for large cabins of tramways. From table 1, it is noted that despite the lower cabin capacity and lower operating speeds of MDG and BDG systems compared to aerial tramway systems, they have higher transport capacities of up to 3,600 passengers per hour per direction. Therefore, the TDG system, as it combines the advantages of MDG, BDG, and aerial tramways, is considered the most advanced ropeway technology [9].

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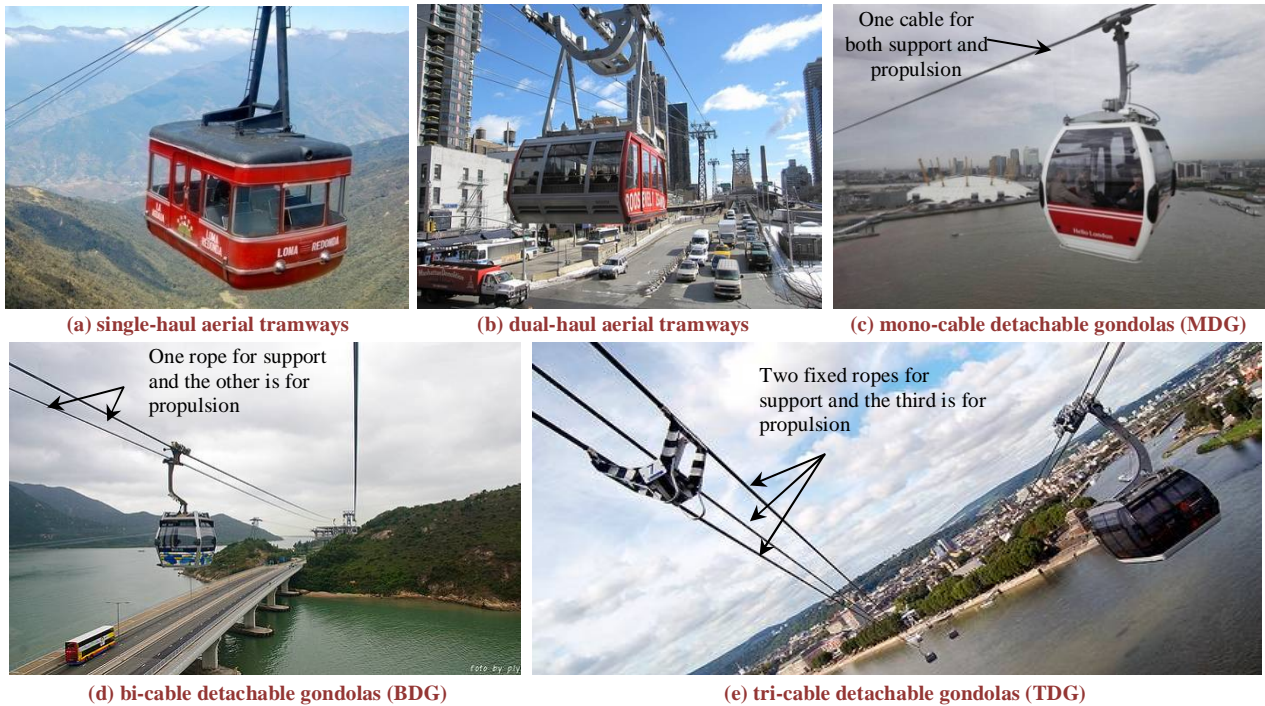


Fig.3 Types of RTS technologies

## D. Integration with urban environments

Ropeways can be easily integrated into the existing transport network [23]. Terminals should be placed near bus stations and taxi lanes to allow for easy interchanges and thus ensure continuity of voyage, such as in the La Paz ropeway, Bolivia [10]. The integration of an RTS into the existing transport infrastructure is inexpensive when compared to the costs of bus transport or light rail [11]. Ropeways, due to their small footprints, can be readily integrated with the present architectural concepts of the city through the pylons and stations where the pylons can be designed individually to suit their surrounding architectural environment and at the same time offer a distinctive landmark for the city [23]. The architectural designs of the terminals vary from case to case with the use of different concepts and different materials. There are elegant structures, there are simple façades with little visual impact, and there are structures that display their architectural and urban surroundings [13] as previously shown in Fig.2. Nevertheless, the integration of terminals into urban areas may be restricted in high-density and high-occupancy areas, as it depends on how much space is available. The space area required to build the terminal depends on the level at which passengers enter the station [15].

When passengers enter the station at ground level, an adequately barrier-free area must be considered to allow the cabin cars to be lifted to the proper height for the transition [15], where the minimum elevation should not be less than 1.5 meters [19] as illustrated in Fig.5:b. So, the entry of passengers at the normal high level of cabin cars could solve this problem [15, 19] as shown in Fig.5: b, c, but it requires much larger terminals. However, it is possible to use the spaces below the stations to store the cabins or to host other activities, such as shops, restaurants, bicycle parking, etc. [15]. Alshalalfah et al., had an opposing viewpoint. They stated that the flexibility of RTS comes from the flexible choice of the location of the terminal [13].

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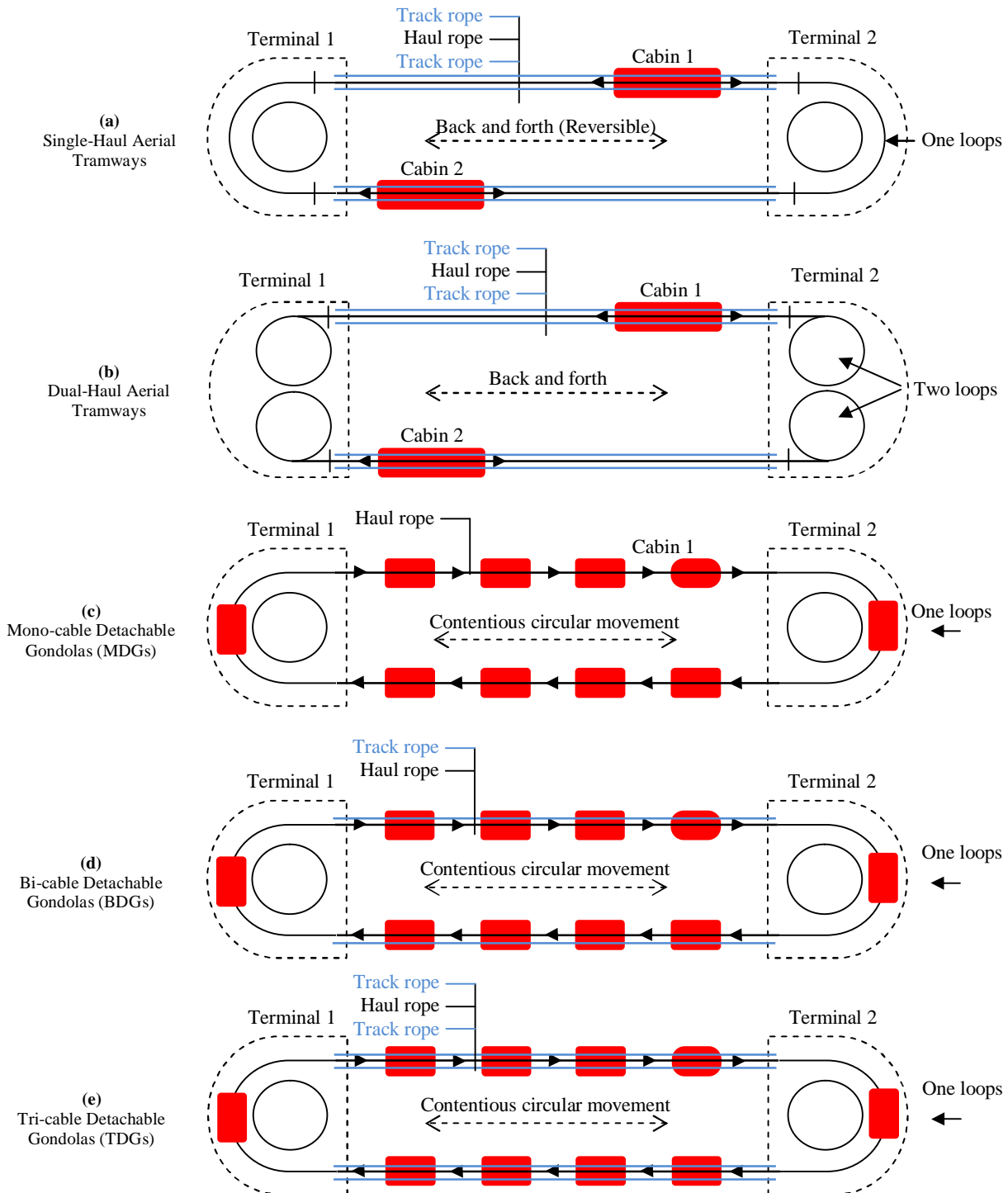


Fig.4 Detailed illustrations of RTS technologies (source: the author)






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TABLE 1  
COMPARISON BETWEEN TYPES OF AERIAL LIFTS (ROPEWAYS). Source: the author after [9, 21, 24]

	Tramways		Gondolas		
	Single-Haul Aerial Tramways	Dual-Haul Aerial Tramways	Mono-Cable Detachable Gondolas (MDGs)	Bi-Cable Detachable Gondolas (BDGs)	Tri-Cable Detachable Gondolas (TDGs)
Illustration photo					
Cabin capacity	Large 20-200 passengers	Large Up to 100 passengers	Small-medium 4-15 passengers	Small-medium 4-15 passengers	Small-medium Up to 35 passengers
Line capacity	500-2800 passengers per hour per direction	Up to 2000 passengers per hour per direction	Up to 3600 passengers per hour per direction	Up to 3600 passengers per hour per direction	Up to 6000 passengers per hour per direction
Rope type	One or two track ropes and one haul rope	One or two track ropes and one haul rope	One rope for support and propulsion. (propelled and supported by the same cable)	Two separate cables, one for support (track rope) and the other (haulage rope) for propulsion.	Two cables for support (track ropes) and a third for propulsion (haulage rope).
Grips	Fixed grips	Fixed grips	Detachable grips	Detachable grips	Detachable grips
Operating speed	Up to 43.2 (km/h)	Up to 27 (km/h)	Up to 21.6 (km/h)	Up to 21.6 (km/h)	Up to 30.6 (km/h)
Cost/km (\$M)	15-25	20-25	5-10	10-20	15-25
Maximum number of terminals	3 terminal stations	Multiple stations	Multiple stations	Multiple stations	Multiple stations
Maximum distance between towers	Less than 1000 m	Less than 1000 m	350 m	700 m	3000 m
Loop	One back and forth loop	Two separated back and forth loops	Continuous circulating loop	Continuous circulating loop	Continuous circulating loop
Loop circulation	The two reversed cabins have the same loop (two track ropes and a haul rope). The loop shuttles back and forth between two end terminals.	Each cabin has its own (two track ropes and a haul rope). This result in single-cabin operation.	They consist of a loop of steel cable that is strung between two stations and that continuously moves and circulates between the two terminals.		
Movement	The loop shuttles back and forth between two end terminals (reversible system).		The cabin cars continuously move and circulate between the two terminals (continuous system).		

By reviewing the RTS stations all over the world, they have found that the stations are located next to congested neighborhoods, next to high-rise buildings, in industrial areas, in parks, or on hills. The station can also be combined with the existing public transit modes or the already existing pedestrian bridges [13]. They also stated that RTS terminals can be integrated into existing commercial buildings as in the Hong Kong Ngong Ping cable car and in the

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Caracas cable car, Venezuela [9]. If the terminal is incorporated into an existing building, as in the case of the Portland aerial tram, Oregon, USA, it is recommended to design the upper station as a stand-alone structure to avoid vibrations [10]. Regarding the alignment of the terminals, all stations do not have to be horizontally aligned. If there is a major change in direction, angle stations will be needed, and this is one of the challenges facing RTS design. However, there are such stations in Hong Kong and Caracas [13].

Overall, locations for the construction of the RTS terminals can be allocated in consultation with the local community and the relevant transit organizations, so that the selection criteria for these sites are as follows: (a) the extent to which the RTS route affects the privacy of residential properties, (b) the sizes and locations of pylons, (c) the compatibility of the RTS with its surrounding natural and built environment so as not to create a harmful visual impact, (d) the level of integration with other transport modes, and (e) the characteristics of the served areas [13].

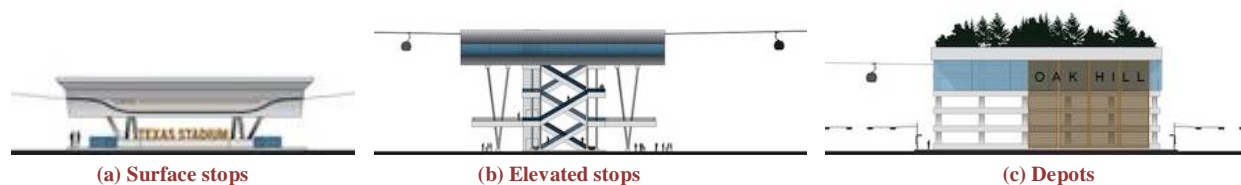


Fig.5 Types of RTS terminals [25]

### E. Merits and defects of RTSs

- RTSs do not need large construction works on the ground's surface and thus do not require large investments in infrastructure like the other transport systems do, where the construction work is limited to the construction of stations and pylons. This low surface impact makes RTSs ideal for densely populated areas where it is difficult to build rail infrastructures [2]. They effectively connect remote locations over rugged terrain and water bodies without affecting the existing physical and natural environments [9]. In addition, the short construction time allows urban planners and policy-makers to quickly address the resulting demographic changes and to link the existing public transport infrastructure with the newly developed residential areas. RTSs do not interfere with other traffic systems, and thus they are easy to realize and run as independent systems [2]. However, an RTS can be easily integrated with the existing transportation networks [23] if required. Further, due to the limited construction works of ropeways compared with other means of transportation, the time horizon of ropeways is short, making it an excellent alternative to buses [2].
- The electricity-based drive system of RTSs partly depends on gravity and counterbalancing methods for propulsion (balancing between an ascending cabin and a descending cabin in a loop.) So, they are represented as energy-efficient systems. This feature lowers the emission rates of RTSs. In particular, there are no engines on the cabins' board, and the RTS line has one electric motor in one terminal to run the system. Consequently, this results in a significant reduction in GHG emissions [9, 13, 20]. Compared to other means of transportation, the environmental impacts of RTS are low [2], where the CO<sub>2</sub> pollution emitted by a gondola full of eight passengers is less than that emitted by a gasoline car, a diesel bus, and an electric train [20, 26]. The estimations are as follows: 27, 248, 38.5, and 30 (grams CO<sub>2</sub>/pers.km) respectively [26]. Additionally, the short construction time of the system in tandem with the daily operation contribute to lowering the environmental impacts of RTS [2].
- The noise pollution from conventional transportation varies depending on the transit mode. The noise produced from road transport results from interference between engine noise and friction between tires and the ground. The noise resulting from railways is caused by the vibration of the above-ground railway structures, the aerodynamic impact, the rolling noise (the contact between the steel wheel and a steel rail), and the noise of the motors. The serious effects of noise on humans vary from simple annoyance to pathological reactions. So, it is found that, compared to conventional transportation modes, gondola produce very little noise when traveling between stations. To reduce noise at towers, noise and vibration preventative measures should be considered to reduce noise at those points [1, 20, 27].
- Besides their environmental and energy efficiency, RTSs save time by eliminating the need to travel on long congested roads [9] besides contributing to eliminating traffic congestion since a gondola can offset a huge number of cars and buses. To explain this, to transport 10,000 passengers/hour, we need one gondola, 100 buses, or 2000 cars [23]. Nevertheless, and contrary to [23], other literature has indicated that the capacity of an RTS is deemed



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much less compared to semi-rapid transportation (rail and buses). Increasing its capacity depends on a number of factors including speed, cabin capacity, waiting time, the achievable longest span of the unsupported cable, and the heaviest weight that can be carried by cables [9]. In an example given by Tezak et al. (2016), the largest capacity for an aerial tramway is 2,000 people/hour and up to 4,000 people/hour in gondolas, while the largest capacity in means of traditional transportation ranges between 36,000 people/hour on a metro, 11,800 people/hour on light rail, and 9,000–35,000 people/hour on rapid transit buses [6].

- Other defects of RTSs involve the design of RTS terminals. Although RTSs have fewer footprints than the traditional transit modes, the terminals of RTS have larger footprints than their counterparts, as they host cabin car storage yards and maintenance bays. Another considerable challenge facing the construction of RTS terminals is choosing a location where the space area of the selected site will allow consideration of the design of the terminals, in addition to the possibility of linking them to the conventional transit networks and the main axes to make accessibility easy and clear [9].
- Coupling between multiple RTS lines is not currently possible, as the lines are independent and not capable of branching [11, 23]. Lines can be branched only at terminal points. Fig.6 shows two examples of branched RTS networks.
- Other issues with RTSs include safety in the case of power failure. However, this problem can be addressed by a backup diesel engine [9, 24]. Additionally, some disadvantages of RTSs include extensive controls and maintenance and the lack of an air conditioning system in the cabins [6]. Nevertheless, one study has pointed out that RTSs are being continuously improved and developed to meet the new requirements for today's conveniences, such as air conditioning, entertainment systems, and Wi-Fi in the cabins [10].
- Privacy is an issue associated with RTSs, as cabins fly over private properties, causing population rejection and lowering property values [9, 24]. The socio-economic benefits of RTSs, coming from the conjunction of RTSs with new utilities, spaces, and services, is represented in reducing travel times to jobs; increasing investment; lowering crime rates; and supporting community involvement and civic pride, contribute to increasing the property values in poor areas. Nevertheless, the property values have been affected by privacy issues and result in residents' rejection of the location. One study has suggested that reducing the elevation of the RTS route would solve the privacy issue and hence reduce the population's opposition to the project but, of course, only after taking into account the safety conditions and the lower insurance costs. Notably, the property values have been adversely influenced in rich residential areas [13].

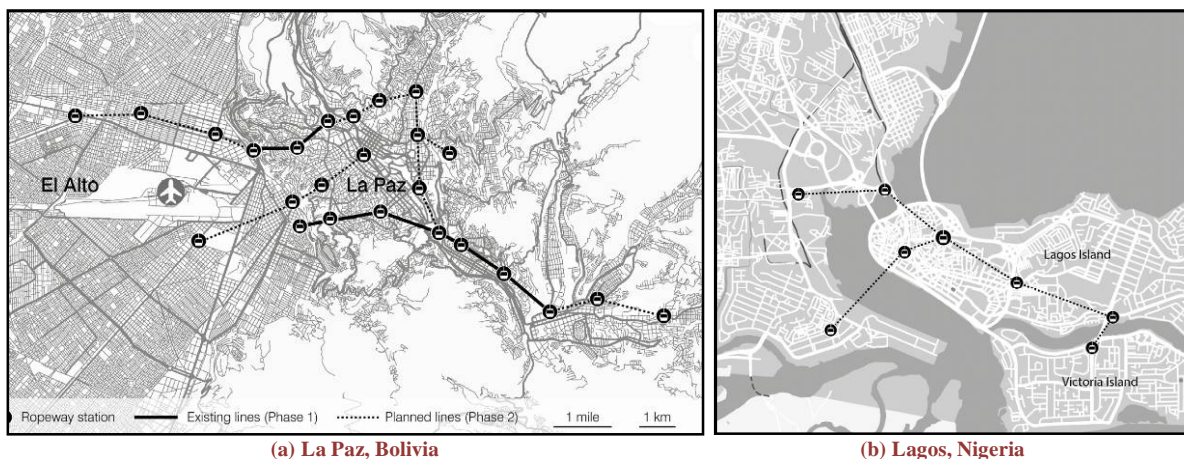


Fig.6 Examples of branched RTS networks [10]

### III. TRANSPORTATION IN EGYPT

The transport sector in Egypt is one of the major energy-consuming sectors and a major source of pollutant emissions. The total energy consumption of the oil-based transport sector accounted for 23 % of the total final energy demand during 2012-2013 and 48% of the total petroleum energy consumption. And, therefore, it was responsible for 26 % of

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the total CO<sub>2</sub> emissions in all economic sectors, and this is expected to worsen if energy efficiency measures are not taken. The transport sector in Egypt relies mainly on roads for both passengers and freight transport, where the road transport accounted for 68% of the total transport followed by railways with 32% and about 0% for river transport during the period between 1981/1982 and 2011/2012. Although Egypt railways are some of the oldest railways in the world, the lack of the effective policies for railway development and infrastructure combined with poor maintenance and failure to integrate them with other means of transportation are the central reasons for their relatively low share compared to road transportation. During the period between 1990 and 2012, private cars represented the majority of the total vehicle fleet with 49%, followed by motorcycles and three wheelers (3Ws or tuktuk) with 26.1 %, trucks with 14%, and buses with 1%, while the remaining represented 4%. Cairo, Giza, Kalyoubia, and Alexandria governorates account for the highest percentage of the use of private cars with more than 56% of the total vehicle fleet [28].

The inhabitants of Egypt are increasing by 1 to 1.5 million people per year. Along with the growing economy, the pressure on the country's transportation system will inevitably increase. This problem is particularly evident in the greater Cairo region (GCR), one of the world's mega-cities, which ranks 17<sup>th</sup> with a population of more than 17 million [2, 29], where the demand for mobility has exceeded the capacity of the public transport system. Initially, this gap was bridged by privately-owned and shared taxis (informal mode of transport). As a result, overcrowding has become a prime problem, and air quality has deteriorated to an alarming level, especially with annual deaths in Cairo attributable to air pollution estimated to be between 10,000 and 25,000.

It was estimated that with the continued increase in population and the increase in the ownership of private cars and shared taxis at the expense of public transport modes, the average speed of all routes will decrease and the travel time will increase with the consequent negative environmental and economic effects. This is in addition to the expected huge increase in GHG emissions [29].

The evolution of transportation in the GCR over the past three decades has shown an increase in the use of private cars and taxis, which represent about 25% of the motorized transport market, while public services (buses), light railways (trams and the Heliopolis metro), and heavy railways (the metro) suffer from a similar decline. On the other hand, taxis have increased their market share strongly [29]. GCR's urban structure consists of the downtown area, informal areas, historical Cairo, which occupies large parts of the central core, and the new cities, which occupy 2.2 times the existing Cairo built-up area and lesser population than that of the central core of Cairo. The centralization of historical Cairo in the city core created many problems related to accessibility and traffic congestion, particularly for the new cities, which suffer from the large travel distances from the downtown, which could reach more than 60 km as illustrated in Fig. 7: a, b. The typical transport problems in GCR include (1) no clear functional hierarchy of roads, (2) chronic traffic congestion, (3) poor public transport, (4) inadequate parking and bus stops, (5) inadequate side-walks, (6) bad planning, and (7) air and noise pollution (see fig. 8) [30].

A few initiatives have been developed to address some of the challenges facing the transport system in the GCR. The early reforms that have been undertaken in order to improve the energy efficiency and air quality in the GCR included the construction and development of Cairo's metro, the utilization of compressed natural gas (CNG) as a fuel for vehicles, and the greater Cairo region Old Vehicle Scrapping And Recycling Programme (OVSRP) [28]. Despite the positive results of introducing the metro in Cairo, which should not be overlooked, it no longer accommodates the large and growing population, attributable to its somewhat limited reach based on its current operated lines, 1 and 2, and the incomplete line 3. Fig. 9 shows the current and under-construction lines of the Cairo metro and the proposed BRT network. An additional major obstacle facing public transport in the GCR is the lack of separation between different means. In other words, the bus routes have no priority and do not have their own lanes, which create a mixed movement among the various means, which negatively affects the efficiency and effectiveness of public transport [29].

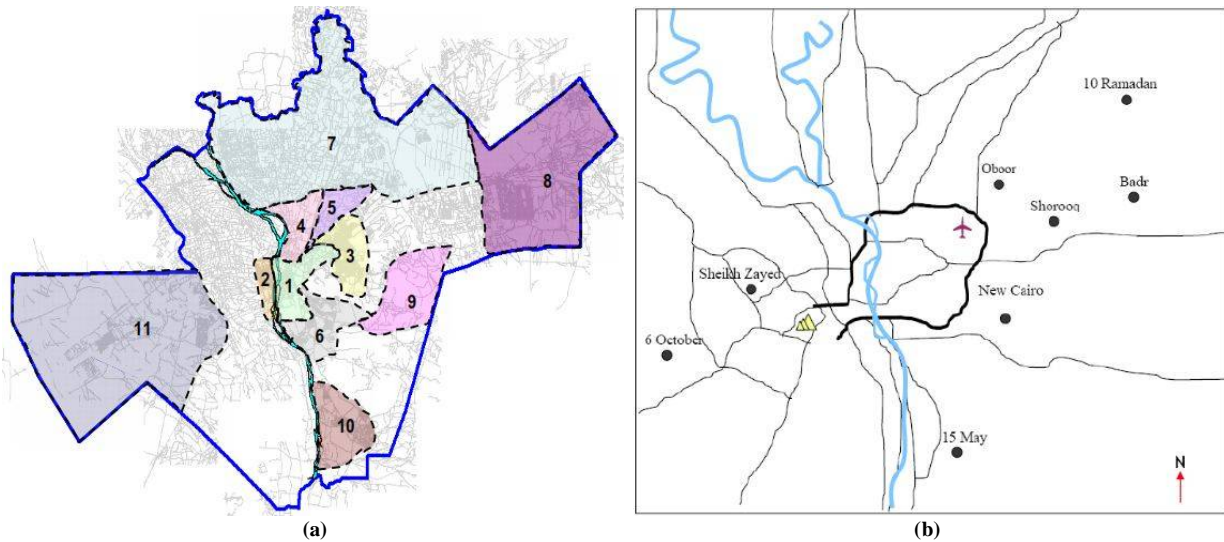


Fig. 7 (a) GCR major districts: (1) Central Cairo (including historical Cairo), (2) Central Giza, (3) Heliopolis/Nasr City, (4) Shoubra/Shoubr El Kheima, (5) Mataryia, (6) Maadi/Qatamiya Road, (7) Shbin El Qanater/ El Obour, (8) 10th of Ramadan/Badr/El Shorook, (9) New Cairo, (10) Helwan/15th of May, (11) 6th of October/El Sheikh Zayed. (b) Satellite cities locations around GCR. Source: [31]



Fig.8 Typical transport problems in GCR: (a) Traffic congestion, (b) Poor public transit, (c) Inadequate parking stops, (d) Inadequate sidewalks Sources: [30, 32]

For the sake of addressing these problems, the advent of the sustainable transport (ST) project in Egypt is intended to reduce energy consumption and greenhouse gas emissions, improve air quality, and reduce traffic congestion associated with the transport sector in Egypt through five objectives, including (1) the development of new transport services to the GCR on the basis of public-private partnership, (2) encouraging non-motorized transport (walking and cycling) in medium-sized sectors, and (3) promote awareness of planners in various aspects of sustainable transport during and after the project. So far, the project's accomplishments are represented in implementing pilot networks for cycling in both Fayoum and Shebin El Kom, as well as improving sidewalks to attract pedestrians. In addition, drivers are directed to the vacant spaces in parking areas through the installation of a variable message parking sign (VMS) system around downtown Cairo. In addition, determining the emission factors for some models of cars and taxis is deemed a pioneering step in the field of sustainable transport in Egypt. Moreover, initiating the shift from private modes of transport mode to public transport by launching the high-quality bus (HQB) to connect the 6<sup>th</sup> October city with Sheikh Zayed city using the metro network at Cairo University metro station in Giza, through seven lines [29]. Further maps of the HQB lines can be found at [33].

#### IV. RTS IN THE GCR, EGYPT

Connecting between the vast parties of the GCR in the east and west, notably the satellite cities, is an urgent demand to enhance accessibility and solve the transportation-related problems in the GCR, particularly since the existing lines of the Cairo metro, lines 1, 2, and the incomplete line 3, have not yet met this target. Despite the reforms being developed

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by the government to reduce traffic congestion in the GCR, the implementation of these plans is slower than expected due to the high motorization rates alongside urbanization and the growing economy [34]. Even if the problem is expected to be resolved with the completion of the next metro lines, line 4 (which is expected to be fully operated by October 2020) and the following lines (5 and 6), which are still under consideration (see Fig. 9), the RTS can act as a temporary alternative mode of transport due to its rapid implementation time, its small footprint, and its low capital and operation cost. Furthermore, it can continue to serve as a supplementary public transport mode even after the construction of the metro lines. It is worth mentioning here that the use of RTSs in Egypt is not new, where they have been used in Porto Sokhna as means of entertainment.

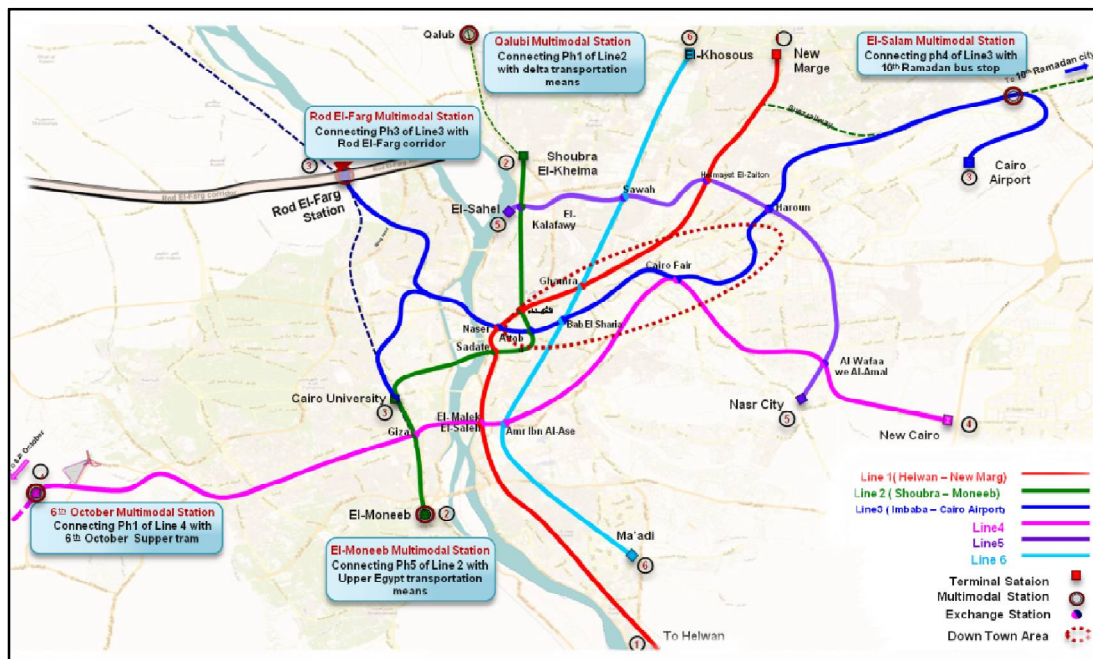


Fig.9 The current and under-construction lines of the Cairo metro and the proposed BRT network [34]

Initially, the introduction of an RTS into the GCR requires re-addressing planning decisions made years ago. The current surface-level rapid transit systems should be analyzed, considering their terminals as opportunities for development as intermediate stations for RTSs (see fig. 9). In addition to the importance of mapping the current locations of the traditional stations, the terrain map is very important because it will determine the different heights of the pylons with respect to the standard inclination angle of the ropes. On the basis that commercial buildings can serve as intermediate stations, it is important to allocate a map to determine the locations of these buildings and, thereafter, choose between these buildings to locate the appropriate proposals. Then, an in-depth analysis of a number of alignment options should be undertaken to identify the most sustainable solutions in terms of demand response, environmental impacts, vision considerations, and operation and capital costs.

The introduction of the RTS will be an addition to the development of both local and foreign tourism in Egypt, particularly with Cairo's wealth of historical monuments and the charming landscaping of the Nile River. This requires setting the tourist and historical attractions in Cairo and connecting them to the RTS terminals, taking into account the route alignment and the visual aesthetic considerations to enrich the viewing.

Understandably, based on the design's reliance on analysis, visualization, and maps, and based on its combination of many disciplines related to engineering, planning, transport, management, insurance, telecommunications, and business, GIS can be used as an integrated aided tool. Fig.10 shows the RTS design process layers.

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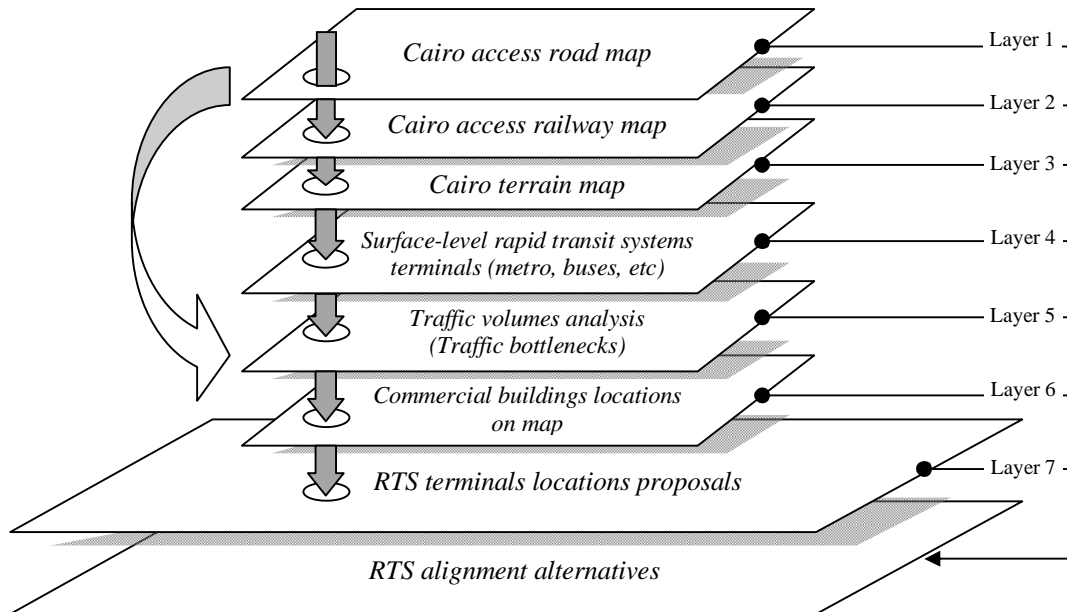


Fig. 10 RTS design process layers

## V. CONCLUSION

This paper is one of the earliest research studies to invite stakeholders, decision makers, and transit agencies to erect RTSs as public transport modes in Greater Cairo, Egypt. Traffic congestion is a serious problem in the GCR with significant adverse impacts on the economy and the quality of life. If this problem is not addressed, its negative impacts are expected to exponentially increase. Therefore, there is an urgent need for feasible solutions to the problems associated with the traffic congestion in Cairo. These feasible solutions mean introducing short-term quick fix solutions, expanding public transport means, and managing the growing transport demand by developing a sustainable transport system, all of which meet the benefits offered by the RTS. The success of many of the RTS experiences in the developed and developing countries and the availability of adequate circumstances in Cairo along with the political and administrative will of Egypt predicts the success of this technology in Greater Cairo.

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