CONTRIBUTION of the PERSONAL RAPID TRANSIT (PRT) SYSTEMS to the ROAD SAFETY: A SCENARIO-BASED COMPARATIVE EVALUATION

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Abstract

Though the number of "real ground" PRT projects are few, it can be possible to deduce some hypothetical safety conclusions. For the very optimist assumption that the control algorithms will only "allow" them to operate in non-collision mode on the network, the safety figures are re-evaluated for two urban settings: First (1) is the case where the urban design was fully recreated based on PRT system, as in the Masdar City, in which no other transport mode is allowed. The other (2) is the hypothetical PRT system would be embedded into the existing transportation system. The two cases of the safety measures and cost figures are compared and evaluated to evaluate the opportunities and pitfalls by the application of a PRT system via the scenario analysis. By doing so, after description of the present situation, there comes the construction of possible alternative futures to compare with the present one. It can be deduced that, even if the safety figures of PRT system are hypothetical, PRT-based urban environments promise a lot in terms of safety levels (as far as 80 per cent) with, however, the expense of financial burden for the local government. Yet, for low-cost solution, PRT-embedded urban environments also provide promising results compared to "doing nothing" as far as 30 per cent reductions, in accidents in total and 44 per cent in deaths.

Keywords: Personal Rapid Transit (PRT), Road Safety, Traffic Accidents, Sustainable Transportation, Scenario-based approach

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1. INTRODUCTION

Today the death toll at the roads has almost reached at a level that is equal as the population of the big-size cities, more than 500,000. Moreover the number of injuries and related loss has left behind irreplaceable loss of labor, social problems and grievance. Similarly, in Turkey, around 4000 people lose their lives every year and, an average of 250,000 people gets injured in road accidents. Although so often, the driver error is cited as the major cause of the accidents, the main reason stems from the conjoint effects of other external factors such as road conditions, insufficient infrastructure, weather situations, poor technical procurements, etc. All these factors, implicitly or explicitly, cause drivers to be prone to make more mistakes and cause accidents. On the other hand, it is well-known quite long that transportation is a sector which is both a major energy consumer and a source of greenhouse gases. Today it is time to speak more loudly that humanity needs much more safer and environmentally friendly transportation system. PRT systems promise to alleviate crash possibility with automatic driving and less harm towards environment. In this study main objective is to expose that PRT system would bring positive impacts on traffic safety analyzing in two different cases: First is the more realistic integration of the existing system (named as PRT-embedded), and the other is highly hypothetical by replacing the PRT with the current one. The findings show that (1) hypothetical PRT systems applied to the conventional transport system of city of Izmir would totally eliminate the accident risks and (2) if PRT were to be utilized solely during the peak traffic, this would also overcome the risk of safety. For measuring the safety level, the data of the years 2005 through 2007 are employed (either street-by street comparisons or in sum of the seven streets). For the current traffic flows, the traffic counts collected by video-cameras installed at the seven streets in summer and fall period of 2010, by applying six categories of hours to detect time differences (two of which represents the peak hours) along the weekdays and weekends.

2. The PRT and ITS PROMISE TOWARDS a ZERO- ACCIDENT FUTURE

It is long known that in the traditional rubber-tired transportation system, accidents are inseparable part of our daily life. In addition to the environmental and social costs, there is huge asymmetrical trade-off between the benefits provided by the existing system and the costs of making the system safe through the expensive precautions. If the system is institutionalized as a social contract, it would be fulfilled as zero accident and fatality. On the other hand the development of the Intelligent Transportation systems (ITS) reveals highly promising features as cheap costs, low risk of crash risk and more environmentally friendly. For achieving zero accident, the elimination of the human driver factor by replacing the drivers with the automatically guided vehicles which operate under human supervision, is very promising. Thereof as an autonomous system, PRT means no-crash since it designed to do so at the very beginning by its nature. Private automobile has long been criticized for its high energy consumption, harmful emissions to the atmosphere and self-esteemed social behavior. The reasons why the existing system is far from meeting the personal transportation, need further examination:

- Public transportation means that people are unable to travel privately, independently and freely, either they cannot afford to buy a car, or they are disabled or elderly.
- Today, time is valuable, especially for the highly qualified people employed at the core businesses. Their travelling demands and sustainability of the economic activity heavily depend on the private car. Time requirement of the new economic system cannot be met by the existing public transportation.
- Those who take public transportation expose to the distress, loss of time and discomfort especially during heavy traffic hours.
- Since PRT provides privacy like a private car, it may attract the car owners.

Though the current public transportation systems are usually introduced as meeting the “public interest” and providing equality among urban people, at the same time, it causes inequality between various social groups. Actually, the shift in the rate of transit ridership from private car to the public modes has not been high as expected (not more than 20 per cent) (Duvarci & Mizokami, 2009; Chapman & Chapman, 2011).

As a radical solution to safety on urban roads, the PRT systems have been on the scene as a technical and sustainable solution demanding less energy use since the 1950s (Edelman 2010). Modern PRT concepts began around 1953 when Donn Fichter a young graduate transportation planner explored ideas about the new urban transportation systems (Anderson, 2009). He made the first sketches of the *podcar*, called "Veyar". He asserted that only if the system provides private personal travel needs and the comfort equal to those of private cars, people are willing to abandon the use of private cars and begin to use it as public mode. PRT is thus, a special mass transportation system which may privately use by a person, or group of persons. It operates on a special guideway, though not necessarily inevitable. Since it is designed rather for private travel needs, the vehicle is directly routed up to the point taking the shortest path without stopping on the way. Basic peculiarities are given in the Table 1.

Table 1: The Comparison of traditional transit with the PRT

Traditional Public Transportation Systems	***The PRT System***
A vehicle can accommodate large groups of passengers	A pod can only carry a small group of people (between 3-6 pass.)
Destinations and stop points are always the same	Private demand-responsive, & passenger determines the destination
Less privacy, less flexibility, and public	More privacy, as flexible as private automobile, and public for those who do not own cars
Pre-scheduled time-table & tariff, the travel has to endure many stops & writings which increase the travel time. Travel time is longer at peak hours, distressful & uncomfortable.	There is no pre-scheduled route & times (no time-table). No loss of time at stops. The service quality is much higher.
Get exposed to congestions and usually higher safety risks	More convenient, & safe due to the computer- based control mechanisms
Require large infrastructure investments, & have environmental, visual and audial impacts	Requires smaller and not heavy infrastructures. Has lesser visual & audial impact
Construction & operations costs are high	Both construction & operation costs are lower
High emissions & energy consumptions. Serious environmental pollution	Environmentally benign, no emission & very low energy consumption. No pollution.

In 1970s, few projects were launched, among them, ARAMIS of France, which failed, the *Cabinentaxi* of Hamburg and CVS of Japan (URL 1). CVS Project ended mostly due to the heavy infrastructure and associated costs of the systems requirements, capacity insufficiency and immature IT technology. Nonetheless beside all the failure and inconclusiveness, all these projects have contributed enormously today's PRT design and operations (Carnegie et. al. 2007). Its first application has appeared in testing areas and/or closed areas as such airports, campus areas, etc. (Frost & Sullivan, 2009).

In the urban areas designed totally on the rubber tire transportation system, the 30 per cent of the urban plot allocated to transportation infrastructures in the housing areas, whereas the ratio has reached 50- 70 per cent in the CBD (Anderson 2005). On the contrary PRT systems consume smaller areas and can serve with frequent interval capacity (min. 1 second) (Tablo 2) (Carnegie et.al., 2007). The substantial contribution of PRT is that, without abandoning the conventional system it can be integrated with the existing public transportation system, creating additional capacity.

Tablo 2: PRT Performance Comparison – Capacity*

Mode	**Heavy Rail**	**Light Rail**	**Busway**	**PRT**
Headway (second)	120-200	60-360	15-300	0.5-3
Vehicle/ Train Capacity	360-3000	240-360	40-70	3-6
Theoretical Line Capacity (1k persons/ hour)	6-90	2-30	0.5-16	3.6- 28
Peak load factor	0.4-0.8	0.5-0.7	0.3-0.6	0.2-0.5
Observed (1 k persons/ hours)	6-50	1-10	1-11	1-9

Source: TCRP Transit Capacity Manual (cited from http://www.princeton.edu/~alaink/Orf467F07/PRT%20Exec%20Briefing%20DRAFT%20v4.pdf)
* Overall line capacity is determined by headway between vehicles, capacity of vehicles and load factor

In actuality, there are limited PRT applications available at the moment, among them the most prominents are Heathrow ULTra PRT and Masdar City. Heathrow's PRT project was started in 2006 and began to operate in spring of 2010. It is expected that ULTra PRT is able to reduce 50,000 total bus journeys directed to Heathrow airport. The system has carried more than 100,000 passengers since it began to operate (URL 2).

Figure 1. Heathrow podcars, Masdar City (http://faculty.washington.edu/jbs/itrans/prtquick.htm)

The other PRT application in the Masdar City of UAE, the first ecologic city designed totally on clean technology, zero carbon emissions, zero waste depending on renewable energy sources is functioning on the PRT network without allowance of the private car uses. PRT system constructed by a Dutch firm is designed to carry 135,000 peoples a day (URL 3). The system is not completed yet.

3. METHOD

Basic tool for explaining the possible road safety impact of the "zero-accident" PRT systems, can be the "what if" scenario analysis of different possible situations and applications with different assumptions that could happen in the near future (Klosterman 1999). "[S]cenario model can reduce uncertainties regarding the likelihood of the future development for the decision-makers in a way of depicting a picture of the possible future" (Baycan-Levent et al. 2007). Here, the two hypothetical cases are proposed to compare the safety levels of the current system. Assumptions are found below:

- The proposed PRT system would never have any incidence of accidents and total safety is provided by the PRT.
- People would easily prefer the PRT due to safety promise and willing to leave their own car and/or public transport.
- Although, the capacity of the PRT systems can be increased up to 2,500, or 3,000 cars /hour, for the 1.5-2 second headways, 1,500-2,000 pod cars can be dispatched into the system. The descendant rate of 1,500 cars is chosen as a baseline in the study.
- If the PRT system would serve the population traveling on these lines efficiently, then they would be accepted as the PRT users equivalent to the capacity on the street, and then this amount would be deduced from the current traffic flows, as well as the accident numbers proportionately.
- Here the assumption is that the accidents would proportionately decrease because of the reduced amount of traffic on the streets.

The proportionate accident deductions are taken from the observed flow data taken by the week days including the weekends. By the hour type used to define traffic flows, peak-hour flows and/or peaking flows can be detected enclosed with the accident data, which shows both the accidents at normal and peak hour times. The scenario analyses are constructed by the accident types (deaths, accidents involving injury, and all accidents) and traffic flow periods (week days, peak hour, off-peak hours, etc.

4. SAFETY DATA of IZMIR CITY

As can be seen in Figure 2, the density of the all accidents largely remained on the major transportation axes in the Izmir metropolitan area, which are found by the *kernel density function* of the GIS tool. In this study, the safety data (7701 accidents in total) of the seven pilot streets (mostly major traffic axes) collected in the years between 2005-2007 for a government-funded project study, is employed. The data largely provide the necessary information about the TAR (traffic accident records) as well as the traffic flows at the moment of the crash and the accident locations in the streets. The incidence of accidents taken from the nine streets can be seen in the Table 2. These streets are chosen for their quality of having highest accident scores per kilometer in the city (Figure 3). Traffic flow data were collected in 2011 for 5 months, and then were aggregated to the hourly flows for six hour categories in a day throughout a week. Thus, the data reflects weekly temporal changes in order to observe the flow peaking.

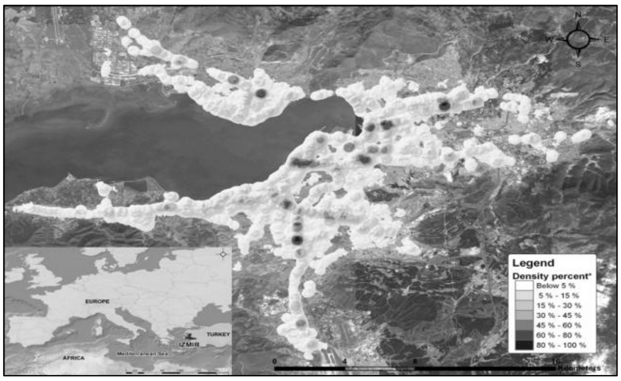
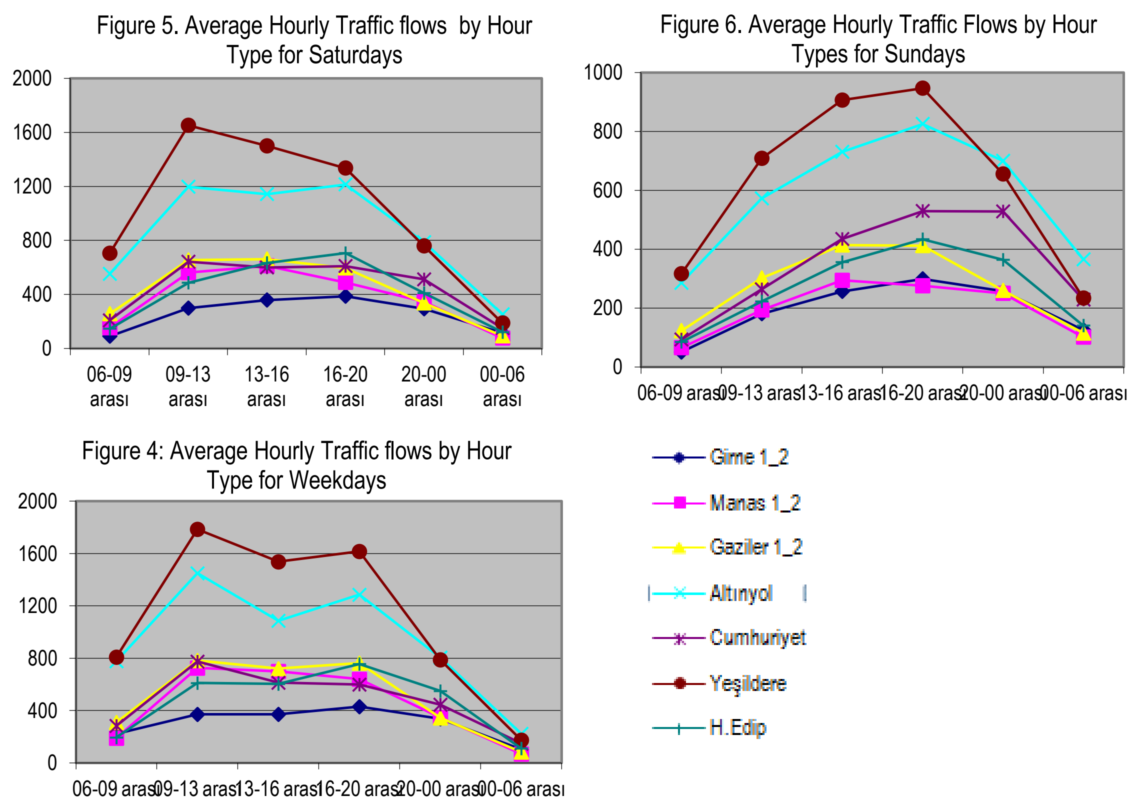


Figure 2. Accident densification in İzmir metropolitan area

Figure 3. The spatial distribution of the accidents happened on the concerning nine (9) streets

Table 2. Accidents data gathered from the TAR files for the pilot streets in consideration

Streets	**Number of deaths**	**No of deaths at peak hours**	**No of accidents with injuries**	**No of accid's with injury at peak hours**	**Total no of accidents**
1. Yesildere Str.	7	**1**	111	**43**	1412
2. Fevzipasa Blv.	1	0	43	**22**	323
3. Halide Edip Blv	4	0	62	**17**	880
4. Manas Blv.	0	0	35	**11**	546
5. Özmen Str.	0	0	12	**6**	159
6. Gaziler St.	1	**1**	95	**24**	1195
7. Cumhuriyet Blv	1	0	40	**13**	894
8. Altınyol Str.	2	0	112	**14**	1278
9. Girne Blv.	0	0	75	**26**	1014
Total	**16**	**2**	**585**	**176**	**7701**



Figures 4, 5, 6. Traffic Flows According to the Day Type (Weekday, Saturday, Sunday)

The flows were observed by the video-cameras placed on the banners over the streets and the average values in the Figures 4, 5,6 are found per lane. Multiplied by lane numbers, flow values are shown in Table 3. The peak hours are shown shaded in the table.

Table 3. Traffic flows observed at the concern Streets as multiplied by the lane numbers (June to November, 2010)

The Street Traffic Flows at the Week Days							
lanes		x2		x2	x2		x3
Hour types	**Girne 1-2**	**Manas 1-2**	**Gazile 1-2**	**Altınyol(n)**	**Cumhur.(n)**	**Yesilder(n)**	**H. Edip(n)**
06 - 09	450	400	520	2370	560	2390	600
09 - 13	740	**1420**	**1585**	**4315**	**1560**	**5350**	1815
13 - 16	770	1395	1412	3164	1216	4600	1842
16 - 20	**850**	1272	1532	3831	1196	4838	**2310**
20 - 00	750	774	712	2418	896	2360	1686
00 - 06	252	188	195	633	288	531	313
	For Saturdays and Sundays						
Hour types	**Girne 1-2**	**Manas 1-2**	**Gazile 1-2**	**Altınyol(n)**	**Cumhur.(n)**	**Yesilder(n)**	**H. Edip(n)**
06 - 09	138	226	456	1700	415	2171	543
09 - 13	632	1152	1264	3570	**1260**	**4911**	1450
13 - 16	722	**1195**	**1280**	3495	1184	4458	**1878**
16 - 20	**790**	972	1176	**3624**	1190	4011	1520
20 - 00	566	722	626	2370	1024	2328	1240
00 - 06	250	212	220	744	492	558	399
Hour types	**Girne 1-2**	**Manas 1-2**	**Gazile 1-2**	**Altınyol(n)**	**Cumhur.(n)**	**Yesilder(n)**	**H. Edip(n)**
06 - 09	88	136	254	873	182	942	240
09 - 13	356	394	596	1715	530	2121	708
13 - 16	530	**585**	814	2181	874	2727	1046
16 - 20	**586**	550	**816**	**2466**	**1066**	**2824**	1287
20 - 00	512	515	513	2076	1062	1980	1098
00 - 06	256	206	215	1107	444	675	405

5. HYPOTHETICAL PRT CONSTRUCTION for TWO SCENARIO MODEL

Scenario 1 Analysis: According to the major assumption of the Scenario 1, the new safety situation is re-evaluated at the chosen streets where the hypothetical PRT system is utilized totally, which means that in the urban design is based on PRT system, no other modes of transport are allowed into the pilot project area. Bearing in mind that in this hypothetical case, it is assumed, PRT can only accommodate 1,500 pcu (per car unit) units, as if it replaced all private automobiles on the streets. The results of the Table 4 have shown clearly the pcu values for the streets. It is also assumed that each PRT podcar will carry the same amount of passengers in each vehicle (two persons).

Table 4. Traffic flows to be eliminated that can rather be served by PRT (if less than 1500 vehicle/hour then shown zero) by hour type

The Street Traffic Flows at the Week Days							
lanes		x2		x2	x2		x3
Hour types	**Girne 1-2**	**Manas 1-2**	**Gazile 1-2**	**Altınyol(n)**	**Cumhur.(n)**	**Yesilder(n)**	**H. Edip(n)**
06 - 09	0	0	0	870	0	890	600
09 - 13	0	**0**	**85**	**2815**	**60**	**3850**	315
13 - 16	0	0	0	1664	0	3100	342
16 - 20	**0**	0	0	2331	0	3338	**810**
20 - 00	0	0	0	918	0	860	186
00 - 06	0	0	0	0	0	0	0
	For Saturdays and Sundays						
Hour types	**Girne 1-2**	**Manas 1-2**	**Gazile 1-2**	**Altınyol(n)**	**Cumhur.(n)**	**Yesilder(n)**	**H. Edip(n)**
06 - 09	0	0	0	200	0	671	0
09 - 13	0	0	0	2070	**0**	**3411**	0
13 - 16	0	**0**	**0**	1995	0	2958	**378**
16 - 20	**0**	0	0	**2124**	0	2511	20
20 - 00	0	0	0	870	0	828	0
00 - 06	0	0	0	0	0	0	0
Hour types	**Girne 1-2**	**Manas 1-2**	**Gazile 1-2**	**Altınyol(n)**	**Cumhur.(n)**	**Yesilder(n)**	**H. Edip(n)**
06 - 09	0	0	0	0	0	0	0
09 - 13	0	0	0	215	0	621	0
13 – 16	0	**0**	**0**	681	**0**	1227	0
16 - 20	**0**	0	0	**966**	0	**1324**	0
20 - 00	0	0	0	576	0	480	0
00 - 06	0	0	0	0	0	0	0

In accord with the first assumption that there would be zero accident with the introduction of the PRT due to the reason by implanting it in place of existing traditional accident-prone systems, the calculation of the accident reductions would simply be proportional to the amount of PRT replacement on the streets. We simply subtract the values from the available capacity of PRT on these lines; if the values are lower than 1,500, then we assume that the hypothetical PRT capacity will cover all demand appearing on these hours as in Table 4 by simply assigning only 0 value to these hours. The subtracted leftover value is assigned, meaning that this value is never met by the PRT system, with an assumption that this amount will be channelized to other routes. Then, the associated safety figures will be calculated accordingly as in the Table 5.

Table 5. Reduced number of accidents according to the 1st Scenario

Streets	Number of deaths	No of accidents with injuries	Total no of accidents
1. Yesildere Str.	3.6	58.1	739.5
3. Halide Edip Blv	0.5	8	114
4. Manas Blv.	0	0	0
6. Gaziler St.	0	0.57	6.6
7. Cumhuriyet Blv	0	0.15	3.5
8. Altinyol Str.	0.85	48	548
9. Girne Blv.	0	0	0
Total **(with originaltotals)**	4.95 **(15)**	114.8 **(530)**	1411.6 **(7219)**

In total, from 7,219 accidents in total, about 5,807 of them can be eliminated, which corresponds to the 80.4 per cent of reduction in the number of accidents. There is 67 per cent of success in the reduction of death tolls (from 15 to 4.95), and 78.3 per cent success in the accidents involving injuries.

Scenario 2 Analysis: Contrary to the first scenario's quite utopian perspective, the second one is more realistic and/or more integrative quality of PRT that it is not the competing with the other modes by replacing one with another; it is complementary, especially where the existing system is clogged as in peak hours. The concept of second scenario is in reverse position to the first one; PRT demand in this scenario starts from the top of the flow figures because of the intention of overcoming excessive flows in the peaking traffic. Simply the toppings (peaks) of the flows, up to 1,500 cars are replaced by the PRT only during the peak hours with above the 1,500 pcu vehicles per hour on the road (Table 6, only for the weekdays), but also in some arterial roads that are heavily loaded not only peak hours but in throughout the day similar to the peak hours.

Table 6. Traffic flows to be eliminated only at the peaking times when replaced by PRT for the second scenario (the figures in the parentheses are where the PRT system is to be used and the reduced ones)

lanes		x2		x2	x2		x3
Hour types	Girne 1-2	Manas 1-2	Gazile 1-2	Altınyol(n)	Cumhur.(n)	Yesilder(n)	H. Edip(n)
06 - 09	450	400	520	(870)	560	(890)	600
09 - 13	740	(0)	(85)	(2815)	(60)	(3850)	(315)
13 - 16	770	(0)	(0)	(1664)	1216	(3100)	(342)
16 - 20	850	1272	(32)	(2331)	1196	(3338)	(810)
20 - 00	750	774	712	(918)	896	(860)	(186)
00 - 06	252	188	195	633	288	531	313

Table 7. Reduced number of accidents according to the second scenario for the concern pilot streets (current accident numbers are given in parentheses for comparison)

Streets	Number of deaths	No of deaths at peak hours	No of accidents with injuries	No of accid's with injury at peak hours	Total no of accidents
1. Yesildere Str.	4.1	**0**	64.2	**0**	816.3
2. Halide Edip Blv	2	0	30.2	**0**	428.7
3. Manas Blv.	0	0	27	**3**	422
4. Gaziler St.	0.3	**0**	65.4	**0**	823.3
5. Cumhuriyet Blv	1	0	36.1	**9**	807.1
6. Altinyol Str.	1	0	56.8	**0**	648.8
7. Girne Blv.	0	0	75	**26**	1014
Total	8.4 **(15)**	0 **(2)**	354.7 **(530)**	38 **(148)**	4960.2 **(7219)**

In accord with the second scenario's forecasts, where the PRT system was injected into the existing systems, the total number of accidents has dropped to 4960.2 as compared with the existing number of 7219, which corresponds to the 31.2 per cent of success in reducing the accidents. Though this approach, in special is applied for the peak hours, there is more success obtained in reducing the number of accidents with injuries: 74.3 per cent with the reduction down to 38. The reduction in the total number of accidents with injuries (it includes also the peak times) is 33 per cent, with the figures of reduced accidents equal to the 354.7 in which the actual figures is 530. The number of death toll in the accidents may drop 44 per cent (with existing value of 15, and calculated value of 8.4). These risk reductions are important figures to consider, and verifies the importance of PRT that it should be taken into account.

6. CONCLUSION

PRT systems of the advanced computer technologies highly promise for a much safer, secure and sustainable urban transportation for the future. In this study, scenario-based approach based on optimistic assumptions gives an idea about the contribution of the system in the future. As a comparison between the two scenarios, the urban layout designed totally for PRT, provides much better safety results. On the other hand, it should be noted that the total replacement of PRT system as an alternative to the existing one, is highly costly and seems far from reality in spite of the incredible safety reduction in terms of death tolls and injuries.

The second scenario called “PRT-embedded transportation system”, mutually operates with the existing system, has primarily been useful for the elimination of accidents at the peak times. Yet, with this system, contrary to the low cost figure stemmed from technology deployment, the accident risk is not completely avoided. This extremely hypothetical scenario-based study is based on many assumptions, one should also consider that the study does not take into account of the logistic system of the cargo delivery, meaning that how the PRT could be replicable to the big lorries and trucks and how far it could met the demand of the economy.

It is proven that the PRT can theoretically provide a much safer environment for the users in the urban streets, for both the private car users or public mode users, therefore it must be envisioned as the real sustainable transportation system of the 21st century, and it deserves close attention and concentration to go further for the sake of the lives of millions.

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