Initializing PRT at the Adriatic coast

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Abstract

This paper presents an initial feasibility study of a Personal Rapid Transit (PRT) network located in the city of Rimini, Italy. The motivation is to drastically reduce car traffic and parking space within the city and along the coastal-line. In particular, the envisaged project would allow a "protected" coastal area with exceptionally high life quality and thus increase the attractiveness of Rimini as a holiday resort and conference site .

The basic idea has been to close the most precious coastal area of Rimini to non-residential car traffic; The transport of visitors to and from this area would be exclusively through a PRT network: a bidirectional PRT line would connect a Park&Ride near the highway exit south-west of Rimini, the conference center, the railway station and the numerous hotels, beaches, restaurants, bars and amusement centers along this dedicated coastal area. The PRT network would also be complementary to the coastal metro-line which is already in an advanced planning stage. PRT could provide a high quality, exclusive transport that would help the city of Rimini to follow a more sustainable city development while maintaining an excellent accessibility to, and between, its main tourist attraction. The question arises whether such a PRT network would be economically viable and whether is technically appropriate for the transportation task it should provide. In particular, we have tried to find out whether the Rimini case could qualify for an early PRT application, dispite the fact that some generally claimed net-effects such as the economy of scale, mass production of vehicles and guideway or a dense, area-covering network of guideways are not yet present.

For this reason, the main objectives of this study have been: (1) to estimate the investment and maintenance costs of the planned PRT network on one hand and the potential annual ridership and revenues on the other hand; (2) to estimate the waiting times and vehicle link-flows on the network during the year's worst-case peak hour in order to assure the PRT network is able to provide indeed a high quality transport service.

A particular challenge is the new conference center which is 3km inland, thus causing a considerable commuter traffic between the hotels along the coast and this major conference site. We have addressed this challenge, by a novel concept of an empty vehicle management that is based on a combination of demand prediction and vehicle-buffer stations.

1. Introduction

One of the most significant properties of Personal Rapid Transit (PRT) is that a dense, arbitrarily shaped network can offer a nonstop transit between all origins and destinations within the covered area. In contrast with line-oriented services, this network approach has the benefits that stations can be placed closer to the user and that traffic flows can be distributed on the various links such that capacity requirements are less stringent.

However, the first PRT networks are likely to consist of single lines or smaller networks and will only successively be extended to larger networks. Consequently, PRT services must start without the aforementioned network benefits. This fact puts some serious constraints on the choice of initial PRT lines, in particular in absents of public financing: the potential costumer should accept high ticket prices for a

high service quality; short average trip length; no competing, subsidized PT service; the travel demand should be below capacity limits but constant throughout the day.
The case of Rimini, Italy which is presented in this paper may offer good conditions for an initial PRT network. Currently, the attractiveness of Rimini as tourist attraction and conference site is jeopardized by an unsustainable level of car traffic: its centre is located between the main generators to the west (two highway-exits, the federal road and a conference hall) and the main destinations to the east (2000 hotels, restaurants, bars and amusement centers concentrated on a small corridor along the coastal line).
This feasibility study conducted on behalf of the province of Rimini has the objective to find an economically viable solution with PRT that would allow a significant reduction of car-traffic through central parts of the city as well as a shortage of public parking-space in a dedicated zone along the beach.

The basic business concept is to establish a high-quality transport service for tourists and visitors between the highway exit and conference center (south west of the city center) with the beach area, hotels and restaurants (to the east of the center). The envisaged solution necessitates the following conditions:

- The dedicated area at the beach which is covered by the PRT network would be closed car traffic for non residential.
- There will be no subsidized bus-line from the highway exit to the beach-area.
- The cost of a one-way ticket with PRT is well below the cost of a taxi ride (approximately 10€).
- The cost of a return ticket with PRT includes parking at a P&R.

Clearly, the consequence would be that all visitors or tourists who want to make business or holidays in the dedicated beach area will have access only trough the PRT network, except bikes, taxis and buses. We are fully aware that this solutions would require a series of difficult political decisions. In particular the day tourists as well as visitors during night-time would face an increase in costs compared with the current costs for parking (1€ per hour). It is assumed that the increase in live-quality within the PRT covered area will at least outweigh the increase in travel costs such that the total number of visitors will not decline due to the costs of a PRT ticket. Therefore, we performed our initial demand estimations on data from year 2008. From this base scenario we made different hypothesis on potential increases and studied the impact on costs and transport service-level. Further market analyses are required to better understand the expected changes of visitor types: the share of visitors who are ready to spend more money for more quality is expected to rise.

2. The PRT network

The principle PRT network would begin as a bidirectional line at a (yet to be constructed) Park and Ride (P&R) near the highway exit south-west of Rimini. This car-park is of strategic importance as it would capture national and international car traffic from the highway as well as local traffic from the federal road which is also the main bypass road of Rimini.
The PRT line would lead from the car park east-wards to the congress hall (Pala congressi). This congress center is the major congress site of Rimini. This facility is currently being extended to become Italy's biggest congress hall. Note that the PRT will not be used to travel from the car park to the congress center. Visitors arriving by car at the conference will use directly the car-parks of the conference center instead of the P&R (see section 3).
From the congress hall, the bidirectional PRT line follows the main road toward the railway station. The station is not only a transfer terminal for national and international visitors but it also connects to a metropolitan network (called Trasporto Rapido Costriero, T.R.C) that will be build along the cost from Ravenna down to Cattolica, in parallel to the railway lines. This regional transport service has stations every 500m in average and trains are scheduled every 10 minutes.

Fig.1: Schematic outline of the analyzed PRT network at Rimini, Italy with major activity centers along the PRT line. The thick cyan lines are bidirectional PRT lines while thin lines are unidirectional.

Approximately 500m from the railway station, the PRT line bifurcates toward the coast. The are PRT stations each 300m along the coastal area, to bring clients as close as possible to hotels, restaurants, clubs and bars. Apart from a small strip to the south (Via Tripoli), the PRT covered coastal area is delimited by natural boarders: to the west by the railway, to the east by the Adriatic sea and to the north by the canal. This fact would make car access control particularly easy.
In this area the PRT network design has been particularly challenging. Apart from the transport-specific characteristics (such as short travel times for the most significant origin-destination pairs), we have tried to satisfy the following constraints:

- All hotels in the PRT covered zone should be no more than 150m from a PRT station.
- PRT guideways should not pass through major streets with partial or full pedestrian zones.
- Exceptional views (mainly towards the sea) should not be disturbed by a PRT guideway.
- PRT guideways should not cross parks and green space.

However, not all constraints could be satisfied for the entire network.

3. Travel demand estimation

The travel demand analyses is particularly important since PRT has no “squeeze” factor, meaning that everybody is seated and, unlike in conventional collective transport, vehicle occupancy (and therefore line capacity) cannot be increased by squeezing more passengers into a vehicle. Consequently the total number of journeys per year must be compatible with the scenario of the worst peak hour of the year. This is why we tried to estimate for each demand component:

1. *The minimum and the expected total number of annual trips* (used for cost-benefit analyses).
2. *The worst case peak hour scenario of the year*. In particular, we were searching for the origin-to-destination matrix (ODM) that produces the maximum link flows. This scenario has been used by the micro-simulator to make sure that a good level of service in maintained even during the orst peak hour.

The non-systematic demand of the targeted user-groups (tourists, congress visitors and business travelers) is in general difficult and costly to estimate by calibrating standard models. However, one advantage of this particular project is that the number of potential users can be estimated or at least bounded by examining the capacities of the different facilities used by different user types, as for example the number of hotel-beds, the size of conference rooms, the number of parking space, even the number of umbrellas at the beach is an ultimately limiting the number of beach visitors. Such bounds helped considerably in the cases we insufficient data.

The total travel demand is made of different components are explained in the following subsections. For each demand component we have estimated or reconstructed the present demand (mostly based on 2008 data made available by the office of Statistics of the Province of Rimini) and the demand for 2013 when the new congress center is expected to be fully operational.

Hotel guests

Hotels are located along the coast and in particular within the protected zone which is covered by the PRT network. The trips between P&R-cost and station-coast have been estimated based on the number of arrivals at hotels during the year 2008. These data on arrivals include tourists as well as congress visitors. Taking into account the share of hotel-beds offered by the PRT-covered zone (14%), and an occupancy of 2-3 persons per vehicle and an assumed modal split between car and train (85% car) we could reconstruct the trips between the car parks and coast as well as station and coast.
Data on arrivals in August allowed us to estimate the number of trips during a peak hour at a Saturday morning in August.

Commuter travel between hotels and congress hall

This demand component covers exclusively the commuter trips between hotel and congress hall. We have detailed information on each single event in 2008, including the number of participants, duration, transport mode used, as well as the number of visitors who booked hotel rooms. With this information, combined with the previously mentioned share of hotel beds accessible through PRT, it has been possible to reconstruct: (1) the annual number of trips hotel-congress hall and station-congress hall. (2) the number of peak hour trips on the same links for the largest event in the year 2008. For this event we assumed to fill the conference within 2 hours.

Small and medium size congresses

In 2006 the number of small and medium size events (less than 500 participants) account for 96% (5993 out of 6188) of all events within the province of Rimini. We have identified the share of these medium size events within the PRT covered area and reconstructed the number of annual participants and PRT trips (for single day events only). Making again assumptions on the modal split car-train we could estimate the number of morning peak hour trips on the links station-hotels and P&R and hotels.

Day tourists

Day tourists typically arrive at the beach in the morning hours of a sunny day of a weekend, pass the day at and return in the evening. A second important group of day tourists arrives at the evening, spends the night at restaurants, bars and night clubs and returns during the night. This demand component is significant, but the most difficult to estimate.

Our approach has been to count the total parking space available within the PRT area along the coast. Then we identified the share of parking space already occupied by residents, hotel gusts or others. The remaining parking space is assumed "fill up" each day in on a sunny week end and each day in a weekend during the summer period. We have also added a 15% fill-up for eek-days during season.

We have analyzed the weather in Rimini for the past 10 years and found that 65%-70% of all weekends have been sunny. The volume of parking space multiplied by number of "fill-ups" allowed us to estimate the number of annual trips that visitors would make from the P&R into the PRT-covered zone at the coast. Allowing 3h to fill-up the beach we could also estimate the peak-hour traffic during a typical Saturday morning in August.

Demand summary

The annual demand for each component is summarized in the table below. For the future scenario (2013) we take into account that the new Congress hall has been built and the commuting between hotels and congress hall more than triples. These estimates are based on projections from the congress hall association. In addition e assume an annual growth of 4% for the number of hotel-related travels.

Table 1: Annual number of trips by demand components

Component	*Minimum trips per year 2008*	*Expected trips per year 2008*	*Minimum trips per year >2013*	*Expected trips per year >2013*
Hotel guests (Tourists + congress participants)	241316	440751	305341	557690
Congress-hall commuters	55531	85490	153762	247118
Congressi piccoli	251860	253729	251860	253729
Day tourists	317898	422693	317898	422693
Total trips per year	**866604**	**1202662**	**1028861**	**1481230**

4. Simulations

As this is a feasibility study, the microsimulations in this work are focused on the evaluation of the waiting times at stations during the worst peak hour scenario of the year. The simulations are also used to identify the number of required vehicles in order to satisfy the demand.

The iTS micro-simulator

As micro-simulations software, we used a PRT simulator called *innovative Transport Simulator (iTS)*, developed by the Transportation Engineering Institute of the University of Bologna. This micro-simulator mimics the movement of each vehicle and individual passengers on an arbitrary PRT network. PRT networks can be edited ith a graphical editor.

Regarding the PRT system, the simulator is adopting an asynchronous vehicle follower control approach, where each vehicle adapts its speed to the speed of the preceding vehicle (or eventually a vehicle on a parallel track in merge and diverge situations). The vehicles keep always a safe distance to the vehicle in front. This safe distance depends on the speed and on the dynamic characteristics of the PRT system.
For the present simulations, we assume a PRT system which can guarantee 1.5m/s^2 acceleration and deceleration during normal operation and an emergency brake deceleration of 2.5m/^{2}. We further assume that the brick wall stopping criteria must be satisfied (vehicle in front can stop instantly) and the time from detecting an emergency case to the actuation of the emergency brake is below 0.5s. The maximum line speed is 12m/s (43km/h) and the headway is approximately 3s at maximum speed. These data are similar to the systems Urban Light Transport ULTra (2009), 2getthere (2009), Vectus PRT (2008).

Passenger origin and destinations are determined by passing an Origin-to-Destination Matrix (ODM) to the simulator, along with a variety of other parameters such as boarding time ranges (see subsequent paragraph).

Concerning the logistics we have implemented an *innovative empty vehicle management* that allows to cope with a particular problem of this PRT network: there are remote stations with a high demand (such as the station at the P&R). This is a challenge for conventional PRT logistics because empty (or full) vehicles must be send to the remote car park *before* the users arrive, otherwise prolonged waiting times are the consequence. If, in the contrary, the central control is sending more vehicles to a remote station than needed for users (who may or may not arrive at some time in the future), then there is the risk that vehicles which are already under way, are no longer needed at the station at the time they arrive. The problem is that these empty vehicles would be needed elsewhere else in the network. Moreover, if there is not enough vehicle buffer capacities at the remote station, the empty vehicles in excess must be send back and add to the vehicle flow in other parts of the network.
We have tried to limit these negative effects by some substantial enhancements to the control strategies:

- Special “buffer” stations which should be placed at a strategic points where the empty vehicles enter a (remote) car-park area. These buffer stations have two roles: (1) to absorb and buffer empty vehicles that arrive at the car park and that are no longer needed. (2) to dispatch the empty vehicles in the buffer to local car-park stations that are most in need for empty vehicles. The idea behind is that if vehicles are located in a buffer-station closer to a potential destination stations, then they can be assigned to high demand stations with a high probability of success (empty vehicles are still needed when they arrive).
- Simple demand predictor: the predictor estimates the future demand for each station, assuming constant arrival rates. It is clear that arrival rates are not constant. For this reason the predictor updates its arrival rate estimation with the arrival time of every newly arriving passenger. In addition the aforementioned vehicle buffers can average out irregularities of user arrival times. Finally the estimated arrival rate is used to determine the rate at which the vehicle management must send vehicles (either empty of full) to a specific station. This strategy is particularly effective for long-range empty vehicle missions.

However, we had still problems with long waiting times at stations with virtually no demand. For these cases we implemented a parallel scheme where a vehicles are distributed to station based on a maximum waiting time criteria.

Simulation of today's traffic load

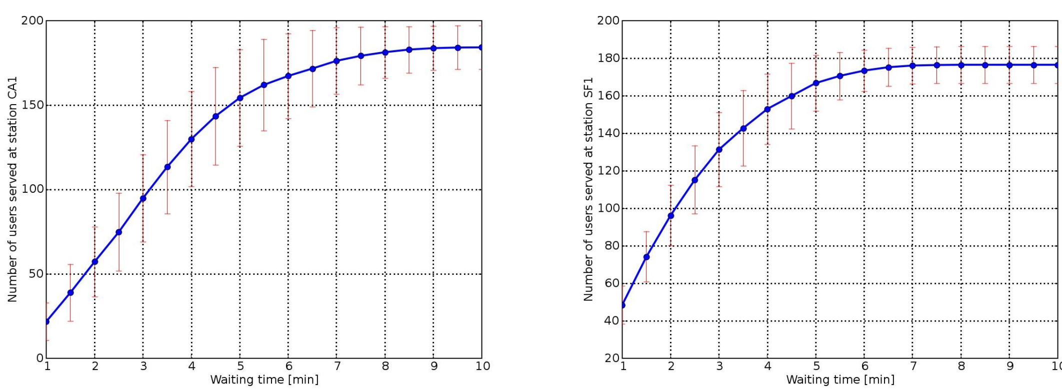
With the previous demand analyses we constructed several origin-to-destination matrices in order to find out which scenario would be the most difficult to cope with for the PRT network. The scenario with the highest peak-hour traffic is in the morning of a work day in May during the biggest congress of the year (in 2008 there have been 2 congresses of this size, all others have been less then half in terms of traffic

volume). The corresponding origin to destination matrix is shown in table 2. The main contribution (750 trips) is in fact the traffic from the coastal area with the hotels toward the congress hall. The second most significant traffic (398 trips) is between the P&R and the coastal area. These trips are mainly the contribution of the small and medium size conferences. It turned out that the actual peak demand for this type of conferences is, on an average work-day almost twice as high (almost 800 trips).
But it is assumed that during a major event at the main conference hall, there will be less medium size conferences at the same day. We have therefore reduce the small-and-medium size conference-related trips by 50%.

Table 2: Zone-to-zone ODM of *today's* reconstructed worst case peak hour scenario during the biggest event of the year. The entries mean number of vehicle trips per hour.

	P&R	Station	Coastal Area	Congress hall	Center
P&R	0	0	398	0	20
Station	0	0	125	250	6
Coastal Area	20	13	0	750	20
Congress hall	0	25	75	0	38
Center	1	1	20	38	0

Note that we have also added some background demand to a station that is near the city center. Successively, we have distributed the zone-to-zone demand on the various PRT stations in case there were more than one station per zone. For the scenario described by the Origin-to-Destination Matrix (ODM) in Table 2 we assume passengers with light luggage only which will have relatively short boarding times (boarding 8s-12s and alighting 5s-10s).
The simulation results of this scenario showed that the network runs with 400 vehicles without significant congestions. Decreasing the number of vehicles led to an increase in waiting times. The average traveling speed has been 25km/h, including vehicle movements within stations, but excluding waiting times. The average traveling speed of networks with high demand is not significantly lower than the speeds observed with networks running at lo demand levels (31km/h).
Therefore , the main distinctive quantity are the waiting times. The PRT stations at the P&R and the Railway station have the longest waiting times. The number of user (or more precisely user-groups) that perceive a certain waiting time at those stations is shown in figure 2. The waiting times have been averaged over 30 simulations. Note that there are considerable variations from one simulation run to another as the error bars in Fig. 2 demonstrate.



(a) PRT station at P&R (b) PRT station at Railway

Fig 2: Waiting time statistics at worst stations under worst case scenario. Error bars indicate standard deviation from 30 simulation runs.

Figure 3 shows the waiting time statistics of all stations. One can read the share of users at each station that had to wait a certain time. For example at station CA2 (the second station at the P&R) 90% of all users are served within 6 min and 30 sec. However, at most stations, 90% of all users are served below 4 minutes.

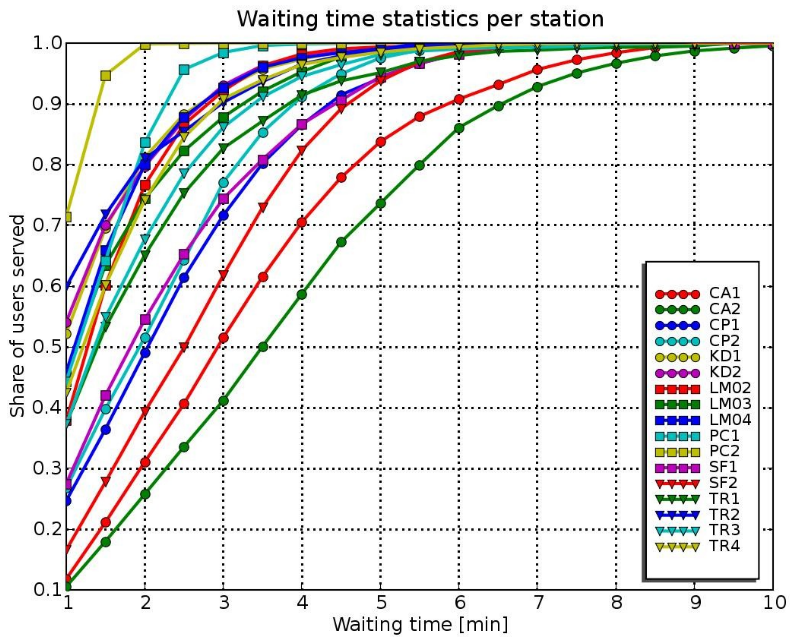


Fig. 3: Waiting time statistics of all PRT stations for worst case peak hour scenario.

Simulation of future traffic load

As already mentioned in the demand analyses section 2, the future traffic load refer to the year 2013 when the congress hall will becomes fully functional. This means essentially that the passenger flow from the hotels and railway station toward the congress hall will more than triple with respect to the demand levels of 2008 which are already high for a 3s headway PRT system.

Nevertheless, with a few modifications to the PRT concept we obtained acceptable results:

- The occupancy of PRT vehicles directed to the congress hall must be increased from 2 to 4. This could be achieved by scheduling vehicles for the conference only (with the congress hall as fixed destination). Those vehicles would only depart when full. In this scenario the conference would receive tickets at a discount-rate but which work for those scheduled vehicles only.
- Only for the days of a major event, there would be a fast shuttle bus running non-stop between the railway station and the congress hall. If the shuttle bus can handle the entire demand from the railway station (approximately 1400 persons per hour), then the PRT network has sufficient resources to cope with the rest of the demand.
- During major event at the congress hall the small and medium size congress activities must be reduced (we assumed 50%). This is may also be in the interest of the organizers of such smaller events.

The zone-to-zone ODM which would emerge from such a scenario is shown in Table 3.

Table 3: Zone-to-zone ODM of *future* worst case peak hour scenario during biggest event of the year when congress hall is in fully operational. The entries mean number of vehicle trips per hour.

	P&R	Station	Coastal Area	Congress hall	Center
P&R	0	0	398	0	20
Station	0	0	0	0	3
Coastal Area	40	7	0	1169	20
Congress hall	0	0	117	0	38
Center	2	1	20	58	0

In order to take account of the scheduled vehicles to the conference hall, we increased the boarding and alighting time by 3s. We also increased the vehicle fleet by 25. The simulated waiting times of the PRT station near the P&R are shown in Fig. 4. Clearly, the service worsened compared with the present scenario (Fig. 4) by approximately 2 minutes. But it is still an acceptable service considering that this is the worst case of the biggest events only (90% will wait less than 8 min at the worst PRT station).

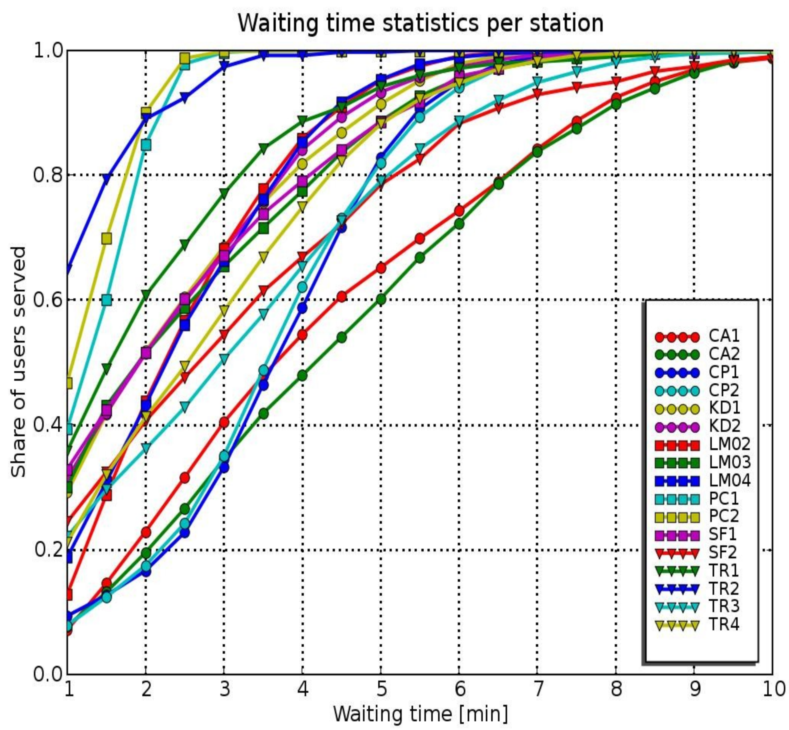


Fig. 4: Waiting time statistics of all PRT stations for future worst case peak hour scenario.

5. Cost analyses

A primarily cost-benefit analyses has been performed with the aim to verify whether the PRT network from section 2 could be economically viable with the demand analyses from section 3. The investment costs for the network of Fig.1 are summarized in Table 4. We have used some basic cost information from Tegnér G. (2007). Included is also a car park, but excluded are compensations for land property.

Table 4: Investment costs for entire system, including car park

Total Investment 8.3M€/km	€ 93,541,350.00
Network (4 km unidir, 7km bidir)	€ 64,915,750.00
12 Stations (8 berth equiv)	€ 6,125,000.00
400 vehicles	€ 20,000,000.00
Auxiliary facilities	€ 2,500,600.00
P&R for 4000 cars	€ 7,112,000.00

Table 5 shows the cost structure of the present (2008) and future (2013) scenario. For each scenario we made a conservative and a more realistic estimate.
The table shows also the Net Present Value (NPV) summed over 25 years at an interest rate of 4%. The NPV is very sensitive to the annual costs of maintenance, personal and consumables, as the annual benefits not much superior to the annual costs. This question is also linked with the reliability and insurance costs for the system.

Table 5: Cost-structure for “nothing changes” (2008) and future scenario with the congress hall in full operation (2013). Compare with trip estimation in Table 1.

	2008 min	2008 expected	2013 min	2013 expected
Benefits	€ 8,162,628	€ 10,515,034	€ 9,298,427	€ 12,465,010
Ticket sales (7€)	€ 6,066,228	€ 8,418,634	€ 7,202,027	€ 10,368,610
Freight movement	€ 0	€ 0	€ 0	€ 0
Advertisement	€ 2,096,400	€ 2,096,400	€ 2,096,400	€ 2,096,400
Costs	€ 835,825	€ 866,164	€ 909,001	€ 1,113,012
Electricity	€ 104,789	€ 124,892	€ 124,409	€ 179,110
Personnel	€ 445,000	€ 445,000	€ 445,000	€ 445,000
Consumables	€ 286,036	€ 296,272	€ 339,591	€ 488,903
NPV over 25 years	€ 5,482,754	€ 27,248,063	€ 15,442,987	€ 43,211,904
Break even in years	22	15	18	12

Currently no freight movement activities have been studied, even though freight movement would be an ideal complement to fill the gaps between the various peak hours. The PRT network could bring freight pallets or packets from a store at the P&R into town, 150m from the end-consumer. This concept is called urban distribution center (UDC). Freight service is particularly useful during night time. A high degree of automation would be desirable. An automated fork lift that is loading and unloading pallets on the level of the station platform could be an option. However, a freight service will also have its costs and one must carefully analyze whether it is worth implementing.

Conclusions

We have proposed a PRT application that would notably reduce car traffic and parking space in the precious coastal zone of Rimini while maintaining or increasing accessibility for all. In this preliminary study we identified potential users and tries to estimate the total number of annual trips as well as the maximum flows during the worst peak hour period of the year. These estimates have allowed us to verify the economical viability of the project as well as the network capacity limits.
Despite the seasonal nature of the proposed transport service and a high peak hour demand due to the large congress hall, the PRT network can still offer a good service under maximal load. Furthermore, the cost benefit analyses showed a positive NPV, even for conservative assumption.

The PRT application, as connector between highway exit and a protected and precious coastal area could be applied to many cities along the Adriatic coast, even though each potential project must be studied case by case as there are many factors which can lead to a success or failure.
In conclusion, the “Rimini case” is a good candidate for an early PRT application, provided that some parameters become more certain, such as the 3 second headway or the costs for operating, maintenance and insurance. But these these are issues which will hopefully be better understood during ULTra's first year in operation.

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