THE APPLICATION OF VALUE ENGINEERING IN RAPID TRANSIT PLANNING AND DESIGN

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1. INTRODUCTION

Value engineering (VE) was firstly utilized in the planning and design works of Taipei Metro Projects in 1987 and from which the Client, the Department of Taipei Rapid Transit System (DORTS) gained many benefits. Thereafter, VE study becomes mandatory to be applied to each Taipei metro project at the planning and detailed design stages to deliver the best value for the DORTS. There are many stages in the lifecycle of a metro project including planning, basic design, detailed design, construction, operation, maintenance, improvement and renewal. VE can be applied at any point. However, typically the earlier it is applied the higher the return on the time and cost invested. Fig.1 shows that the value benefit curve decreases over the timeline of a metro project.

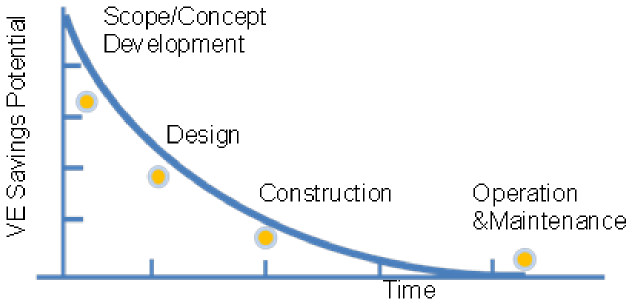


Fig.1 Cost saving vs. the time to use VE

It is noted that the cost invested in a metro project during its whole lifecycle is very tremendous and the design life of metro facilities will reach as long as 100 years, of which almost 90% is in the operation. So, it can be expected that the expenses used in the on-going operational stage are much higher than the initial capital cost occurring in the design and construction stages. Therefore, it is more appropriate that the VE should be evaluated on the basis of whole lifecycle of the metro project so that the real benefits can be displayed. And also, involvement of VE study at earlier stages of the project to get better value is recommended. The effect of VE execution can be evaluated by the formula which is given as follow:

$$Value_{max} = (Performance_{max}) / (Cost_{min}) \quad \text{......................................(eq.1)}$$

In eq. (1), where performance may include functionality, quality, time and other needs of the client. From the viewpoint of a metro project, the best value is achieved to provide a safe and comfortable riding circumstances, fast and convenient metro system for passengers at the lowest lifecycle costs including capital, staffing, energy, maintenance etc... This study will take SanYing Line Metro Project of the New Taipei City for example to discuss the effects of value engineering performed in the basic design stage. The value methodology is used to identify new improvement ideas and develop these ideas into new and alternate proposals to the project's base case.

2. PROJECT OVERVIEW OF SANYING LINE

After Pre-VM Workshop Study Phase and Information Phase, the parameters to be considered in the basic design of SanYing Line Project are given below:

- System Type: Medium-capacity Rapid Transit System
- Full automated guided system (UTO), with CBTC technology

- Track System: Elevated tracks
- Minimum curve radius : 50m
- Budget : NTD 50.5 billion
- Route Length : 14.3 KM
- Stations : 12 stations & 1 depot

The route of project phase I starts from Dingpu Station, the terminal station of Ban-Nan Line, passing through three Districts, namely Tucheng, Sanxia and Yingge, where the National Freeway No.2 and Dahan River are to be crossed with long span bridges, and finally stops at the Fongming Junior High School from where the phase II route will stretch to the Bade City Gengliaojiao area.

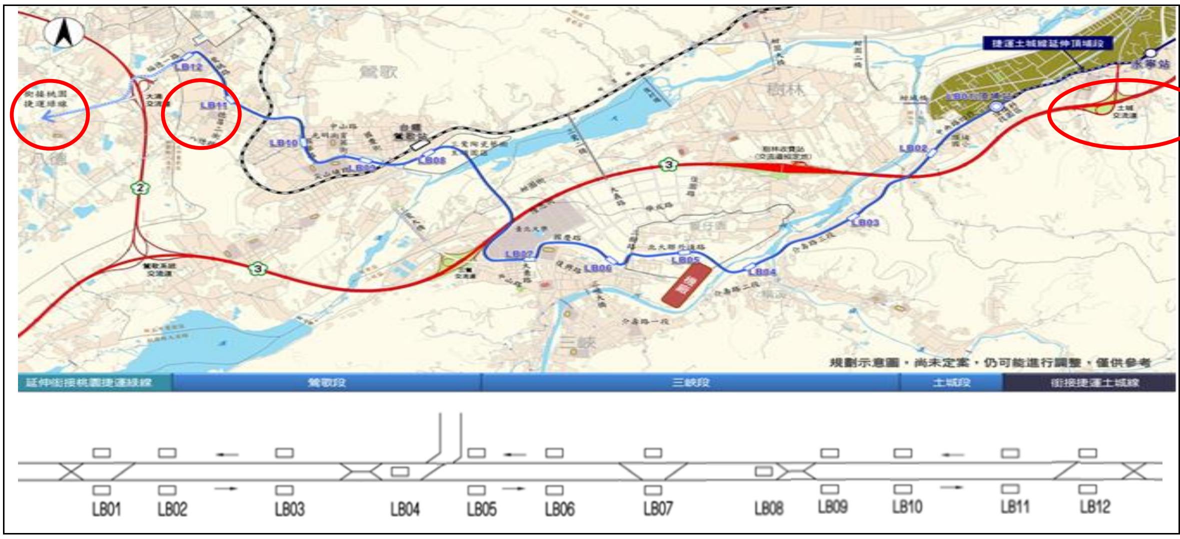


Fig. 2 Route map of Sanying Line

As mentioned above, value engineering (VE) is requested to be employed in this MRT project to save lifecycle cost without impairing system functions. Of course, like such big project, there are many issues to be worth discussing in VE study. Among which, the key issue about the benefit comparison for different train operation models between 60m-long train at 3.5 minutes headway and 40m-long train at 2.2 minutes headway is presented in this paper after Function Analysis, Creative Phase and Evaluation Phase. The former (hereafter called long train) is originally proposed in feasibility study while the latter (hereafter called short train) is the final alternative option selected from many options during VE study process. Comparison between long train and short train will be made from various aspects including construction and operation stages and are illustrated as follow.

3. STUDY BETWEEN SHORT TRAIN AND LONG TRAIN

Basic Assumption

From the above phases, the minimum requirement of 8790 passengers per hour per direction (pphpd) shall be met. Then we go into the Development Phase.

By using the short train with the high density service, it could simplify the facilities, minimize the station size, and vary the operation. In order to achieve the objective of reducing costs and improve efficiency.

✓ Original Option : Tain length of 60m & 3.5 minutes headway which can provide 520p/train(6p/m^2)
Calculation is made to check if the pphpd greater than 8790 passengers
520p/T(stand 6p/m^2)×17 train/hr=8840 p/hr＞8790 【OK】(headway = 210 sec)

✓ Alternative Option : Train length of 40m & 2.2min headway which can provide 330p/train(6p/m^2)
330p/T(stand 6p/m^2)×27 train/hr = 8910 p/hr＞8790 【OK】(headway = 132 sec)

Since the study on the acquisition and maintenance of rolling stock is often based on the car unit or train, it is necessary to calculate the number of cars.

Using the following two types of cars that are available on the market in order to facilitate the calculations :

- Ansaldo Copenhague Metro : L=13m , Configuration A
- Bombardier Innovia ART 300 : L=17m, Configuration B

Table 1 Two types of cars Configuration

Configuration	330 passagers/train (6p/m^2)	520 passagers/train (6p/m^2)
A	3 Cars (39m)	4 Cars (52m)
B	2 Cars (34m)	3 Cars (51m)

Comparison in Detail

The following criterias are taken into account to compare the option of short train and long train :

- Passenger Comfort
- Passenger Safety
- Operating Flexibility
- Cost (including investment costs, operating and maintenance)

The comparisons are tabled as below, and the advantages are highlighted in blue color.

Table 2 Comparisons table for Passenger service

	Short Train	Long Train
Waiting time in peak hours	Short headway will reduce the average passenger's waiting time.	The average passenger waiting time is longer.
Waiting time in off peak hours	In order to guarantee the service level, the maximum headway should be limited, these two options can be considered as identical	
Waiting habit	All the trains have the same length, the waiting time is more regularity. It will be favorable to establish the passengers' waiting habits, and to improve the user experience.	The varied headway of the long train at peak/off hours will lower the users' experience, especially for the tourist and the occasional users.
Station comfort	Since the station length and station facilities are reduced, the passengers will receive a good level of service, safety and comfort.	Since the station dimention is bigger, the infrastructure will be heavier (such as platform length... etc.)
Transferring Comfort	The passenger flow is more balance in the interchange station, it won't cause the congestion at the platform or the transferring passageway.	The imbalance passenger flow in interchange station will casue congestion.
Downgrade mode	The platform will be filled quickly with the passengers during operation interruption because of lacking of adaptability in the station.	The platform dimension is big enough to cope with the massive passenger flow during the operation interruption.
Exceptional situations	Lacking of adaptability in the station in exceptional events (such as football matches... etc.), the platforms will be filled faster with massive passengers.	The platform dimension is big enough to cope with the massive passenger flow.

Table 3 Comparison table for Passenger Safety

	Short Train	Long Train
Safety on Board	The passengers can circulate between each car, it increases safety in case of fire, aggressive behavior or evacuation.	Since a long train has to carry out the coupling / decoupling to connect the cars, each car is independent and closed for the evacuation in case of
Safety in the station	It is easier to monitor the platform area by camera because the station length is shorter.	More difficult for mornitoring.
Safety of get on and off the train	Better traffic flow, fewer risks.	The late arriving passengers can block the door of a departing train because of a long headway.
Evacuation in station	The evacuation is easier in a short platform and train, and the evacuation is faster.	A long platform increases the evacuation time and distance.
Evacuation in interstation	It is possible to evacuate by front of the car and the lateral spaces can be reduced in order to optimize the tunnel diameter.	Using the front evacuation is inappropriate for several coupled car units, the evacuation should by lateral.

Table 4 Comparison table for Operating Flexibility

	Short Train	Long Train
Evolution of short term traffic	In short term, a short train is more suitable for the low traffic due to short waiting time and a better management of the train dispatching. The short trains are more flexible in terms of operation for ensuring a good service level (short headway) and operating effectiveness (reducing train running* km).	A long train is not suitable for the low traffic in short term, due to the risks of longer headway, the difficulty of optimizing the capacity, the high operating costs and a lower management of train occupancy.
Evolution of long term traffic	Less margin of reserved capacity, and close to the traffic saturation.	More margin of reserved capacity, especially if the long-term traffic
The management of service trains in peak hours and in off-peak hours	The short trains are more flexible in terms of train management in peak hours and in off-peak hours.	Risks of longer headway, unoptimized capacity in off-peak hours (minimum occupied seats), high operating costs.
Coupling and decoupling	Not necessary. Transportation service adjustment can be easier controlled by the varied headway.	Considering the difference between the peak hours and off-peak hours, coupling / decoupling becomes useful for operating in coordination with the passenger flow, while the headway should be acceptable.
Downgrade mode	More difficult to control and manager by the operators.	More margin for the traffic control in the downgrade mode.
Out of service	If one train is out of service, it will have less impact due to the numbers of train fleet.	

Table 5 Comparison table for Investement Costs

	Short Train	Long Train
Civil Engineering	Shortening the length of the platform can effectively reduce the size of the station and the civil work's cost.	Higher construction on station's infrastructure.
Track	Shortening the turnback track and pocket track's length.	Higher construction cost on track work.
Expropriation	The alignment design of short train is more flexible to reduce the difficulty of obtaining land and the demolition. The volume of land expropriation and	More diffcult for land expropriation.
Rolling stock cost	A very small difference between the two options. However, at the beginning of operation, the pphpd does not reach the predicted value, the short train can better optimize the train dispatch and operation efficiency, the number of trains can also be reduced.	
On-board equipment cost	Increasing the number of trains will raise the number of on-board signalling equipment ; especially to improve the reliability objective of automatic driverless system will need to have the "redundancy" function	Reducing the number of on-board equipment, and lowering the equipment cost.
Signalling	Two options are basically the same, or a very small difference.	

In terms of need in rolling stock, the rolling stock investment cost is decided by transportion capacity.

In long term, the short train option can meet the maximum station passenger flow in the peak hours without reducing the system function and comfort, mainly in the following points :

- ✓ Reducing the platform length in order to effectively lower the cost of civil works;
- ✓ Shortening the passenger's waiting time in order to improve service quality and passenger comfort;'
- ✓ Executing the evacuation from the front of car.

Furthermore, the short train option can meet the required passenger flow in peak hours and in off-peak hours in order to get the better operation efficiency and flexibility. It is more flexibility in management of backup and / or maintenance trains.

(1) Rolling Stock Cost :

Estimation of the number of rolling stock is based on the following parameters:

- ➢ Comfort Index : 6p / m^2
- ➢ Travel speed : 30km / hr
- ➢ Turn back time: 3 minutes
- ➢ Reserved train : 10%

Option 1：ANSALDO-BREDA，Brescia，13m，3-car short train（capacity：396）； 4-car long train（capacity： 528）；

Option 2：BOMBARDIER ART 300，17m，2-car short train（capacity：370）；3-car long train（capacity： 555）。

All the configurations should meet the requirement of 8790 pphpd in peak hours.

The final results of the number of trains are shown in the table below in bold and highlighted in green.

Table 6 Calculation of Fleets Size

missions	km	Capacity 6p/m²	PPHPD	Required trains in peak hrs	Nbr of trains - operation	Reserve (10%)	total nbr of trains required	Total nbr of cars	Transport Capacity max
Option 1： ANSALDO-BREDA, short train Brescia, 13m, 3-car (headway mini of 132 sec)									Headway 90sec
LB01-LB08	10.057	396	8790	11	26	3	29	87	18000
LB01-LB12	13.78	396	8790	15					
Option 1：ANSALDO-BREDA, longt train, Brescia, 13m, 4-car (headway of 210 sec)									
LB01-LB08	10.057	528	8790	7	16	2	18	72	24000
LB01-LB12	13.78	528	8790	9					
Option 2：BOMBARDIER ART 300, short train, 17m, 2-car (headway mini of 132 sec)									
LB01-LB08	10.057	370	8790	11	26	3	29	58	14800
LB01-LB12	13.78	370	8790	15					
Option 2：BOMBARDIER ART 300 long train, 17m, 3-car (headway mini of 210 secs)									
LB01-LB08	10.057	555	8790	7	16	2	18	54	22200
LB01-LB12	13.78	555	8797	9					

In order to satisfy the traffic requirement (8790 PPHPD) no matter of the long train or the short train, it is basically the same number of trains. The rolling stock costs of the two options **are basically the same**.

Table 7 Comparison table for Operation / Maintenance Cost

	Short Train	Long Train
Operational Staff	The operation cost will be increased because of more on-board staffs by increasing the number of trains However, the number of platform staffs can be reduced because of shortening the station length	Reducing the operation cost because of decreasing of number of trains.
Traction power Consumption	If the both options provide the same transportation capacitym then the traction power consumption of short train is slightly lower than the long train. The small difference between short train and long train is negligible	
Station equipment's power consumption	A small station provides less passenger service, and the facilities' consumption will be reduced, then the operation cost will be decreased.	Bigger station size and more station euipment will increase operating costs.
Track/civil work's maintenance cost	No difference	
Rolling stock's maintenance cost	No difference	

In long term, the option of short trains is a good solution for reducing the costs in the following items :

- ✓ Reducing the platform length in order to effectively lower the cost of civil engineering;
- ✓ Shortening the passenger waiting time in order to improve service quality and passenger comfort;'
- ✓ A better operational efficiency and flexibility
- ✓ More flexibility in management of reserved train and maintenance train in order to reduce operating and maintenance costs.

4. DESIGN CHANGES ON STATION AND PLATFORM LAYOUT

After confirming that the short train can meet all the requirements of Sanying project, the alternative station designs are carried out in order to minimize the structures of bridges and stations size to save construction costs.

(1) The requirements of station space and funtions

According to the functions and uses, the space of station is generally planned as public area, staff area and the technical area.The public area is designed for the public and passengers. It's the main area which provides the transportation services and facilities. Station infrastructure generally refers to provide above-mentioned services and facilities for the public and passengers. The number of facilities is calculated by the forecasted passengers volume and design specifications.

Generally, the calculation of basic facilities includes the number of escalators, platform widths (normal and emergency evacuation), the number of automatic fare collection equipment, the total width of evacuation exits, and the number of transfer facilities ... and so on.

The following table is an example to shorten the length of the platform from 60m to 40m for reducing the actual cost of the civil works of Sanying Line project.

Table 8

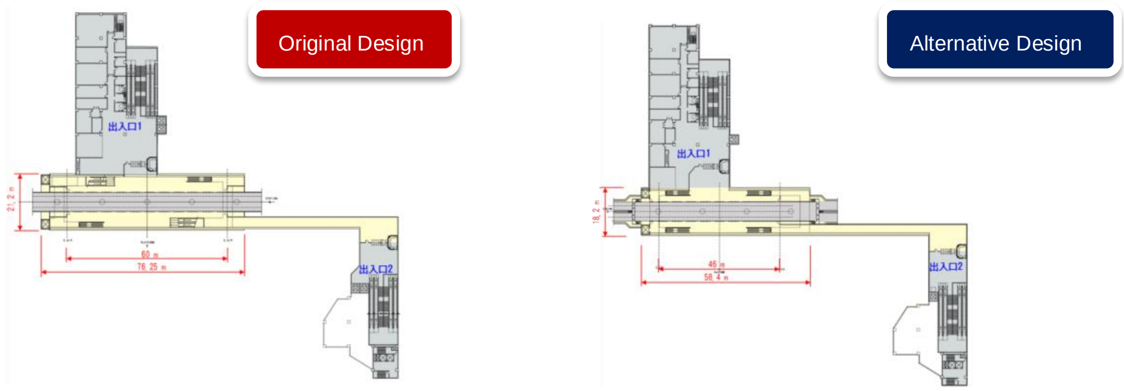
Station LB02: Original Design	Station LB02: Alternative Design
Station width : 21.2m, station length : 76.25m, platform length : 60m, two exits. Cost estimation : using steel structure for main part of station and the pile foundation.	Station width :18.2mm station length : 58.4m, platform length : 46m, two exits. Cost estimation : using steel structure for main part of station, and appropriate foundation by considering the geological conditions.
Advantage : Installation of escalators for reaching the up and down platforms.	Advantages : 1) The road width is 20m, and the station piles can be located at central traffic island. Since the station width could be shortened to 18.2m, a 6m distance between the station and buildings can be reserved. 2) In order to satisfy the pphpd in peak hours, shortening the station's length and width can reduce the station construction cost.
Disadvantage： A higher construction cost because of the longer and wider station (big station structure)	Disadvantage : To comply with the specification of no building construction at both sides of metro route, the distance between station and buildings should be more than 6m. Therefore the shortened station width can provide only the elevators for reaching the up/down platforms

Cost Analysis and Calculation：

	Initial Cost	Operation and	Toatl Cost

Station LB02: Original Design		Station LB02: Alternative Design	
Original Design	458,100,000		458,100,000
Alternative Design	427,240,000		427,240,000
Saving amount			30,860,000
Saving percentage			6.7%

Elevated station with split platforms, the platform height from the top of rail is 13.81m, two accesses



(2) The comparison table of each station costs

Station	Initial Design Cost	Alternative Design Cost	Percentage
LB02	458,100,000	427,240,000	6.7%
LB03	458,100,000	441,319,000	3.7%
LB04	412,300,000	343,004,000	16.8%
LB05	458,100,000	407,036,000	11.1%
LB04	458,100,000	443,509,000	1.4%
LB07	458,100,000	450,668,000	1.6%
LB08	421,800,000	304,262,000	27%
LB09	412,300,000	392,304,000	4%
LB10	412,300,000	394,770,000	4.3%
LB11	458,100,000	375,763,000	18%
LB12	458,100,000	420,190,000	8.3%

5. CONCLUSION

After Presentation Phase, following delivery of the VE preliminary report, the Client (Department of Rapid Transit System, New Taipei City Government) agreed upon the short train alternative to be implemented.

Value Engineering gives consideration to function and cost aspects. By shortening the length of the train and the high density of train service to minimize the facilities and stations, in order to provide flexibility of operation and to adjust the construction works, this method can not only improve system performance, but also increase the value of the project.

Sanying MRT project’s total direct construction fees has been estimated to be NTD 33.8 billion, and it is successfully reduced to 31.4 billion with changing the platform desgin to from 60m to 40m and other effort by VE study.

The results of the study shows the possibility of developing an alternative solution by using Value Engineering study and analysis without any impact to the transpotation service and required performance.