International Journal of Technology (2015) 4: 670-679
ISSN 2086-9614

DEVELOPING CONCEPTUAL DESIGN OF HIGH SPEED RAILWAYS USING VALUE ENGINEERING METHOD: CREATING OPTIMUM PROJECT BENEFITS

Mohammed Ali Berawi[1,2*], Abdur Rohim Boy Berawi[1], Isti Surjandari Prajitno[3], Nahry[1,2], Perdana Miraj[1,2], Yusuf Abdurachman[1,2], Erwin Tobing[1,2], Antonius Ivan[1,2]

[1] *The Center for Sustainable Infrastructure Development (CSID), Faculty of Engineering, University of Indonesia, Depok 16424, Indonesia*
[2] *Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, Depok 16424, Indonesia*
[3] *Department of Industrial Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, Depok 16424, Indonesia*

(Received: September 2015 / Revised: October 2015 / Accepted: October 2015)

ABSTRACT

As a consequence of an improvement in productivity, due to shorter travel time and further development in connectivity, a High Speed Train (HST) project is one kind of infrastructure which has a potential for positive impact on economic development and growth. However, HST project feasibility rarely meets related stakeholders' expectations, since the benefits and added value are considered low, when compared to the value of investment. Therefore, a comprehensive study is required by producing innovative ideas to improve the feasibility of HST projects, from the viewpoint of both technical and economic aspects. This study is aimed at improving the feasibility of project investment for the conceptual design of Jakarta-Surabaya HST project by using Value Engineering (VE). The methodology uses both qualitative and quantitative approaches through in-depth interviews and life cycle cost analysis. Route 1 selected as the best scenario that has 4 stations connecting Jakarta to Cirebon to Semarang, and to Surabaya. The HST project requires a budget of IDR 36 Trillion with operational and maintenance costs estimated for about IDR 1.2 Billion per year for 685 km of high speed train infrastructure.

Keywords: Conceptual design; FAST diagram; Feasibility study; Infrastructure; Jakarta-Surabaya high speed train; Value engineering

1. INTRODUCTION

As a result of reduction in distance between regions and establishment of connectivity between national and international markets within competitive costs, infrastructure is one of the important factors in improving the economics of a country, (World Economic Forum, 2012). The significance of infrastructure can be seen from the United States' experience where infrastructure contribution to the economic growth is about 60% (Dikun, 2010).

Development of a transport infrastructure relates to the need of creating connectivity between cities within a specific allocated travel time. Jakarta and Surabaya, as two major economic powerhouses in Indonesia, still need improvement in term of connectivity. Compared to air transportation that connects the two cities, the development of a High Speed Train (HST)

---

* Corresponding author's email: maberawi@eng.ui.ac.id, Tel.+62-21-7270029, Fax. +62-21-7270028
Permalink/DOI: http://dx.doi.org/10.14716/ijtech.v6i4.1743

infrastructure project is not only expected to reduce the travel time, but also to increase regional economic activity along the route. Currently, HST projects are considered as a significant technological breakthrough in transportation, where more than 20,000 km of HST networks have been constructed around the world, thus providing various benefits, such as reliable transportation (Givoni, 2006; Campos, 2009), fast loading – unloading time, accessibility improvement and spatial agglomeration (Levinson, 2012; Monzón et al., 2013).

In 2012, the Government of Indonesia launched the development plan for a HST project, namely Argo Cahaya, connecting Jakarta and Surabaya over a distance of 685 km by using a 1,435 mm gauge railway with an operational speed of around 300 km/hour. The project will require IDR 233 Trillion in investment costs (Ministry of Transportation, 2011). The Argo Cahaya HST project is planned with nine railway stations located in Jakarta (Manggarai), Cikampek, Cirebon, Tegal, Pekalongan, Semarang, Gambringan, Cepu and Surabaya (Pasar Turi). However, the progress of the HST project in recent years is still unknown. At the moment, the Government of Indonesia has also put the HST project from Jakarta to Bandung on hold, due to technical and financial obstacles.

The high investment costs and high noise factors are considered as two critical aspects in HST project development (Levinson, 2012). On the other hand, demand also plays a critical role and is one of the main considerations in the development of HST systems around the world. HST systems in the United States require 6–9 million passengers per year to meet the targeted return on investment. On the contrary, most of the HST lines with a high occupancy factor only reach a maximum of 3.4 million passengers per year.

Based on above situation, a comprehensive study with innovative ideas is required to improve the feasibility of HST projects in Indonesia. In order to gain maximum value from the investment, this study will use a Value Engineering (VE) approach. The use of VE has been proven in analysing the function of a system to produce an optimum outcome for a project in terms of quality (Fong & Shen, 2000; Woodhead & Berawi, 2007) and the use of new technologies (Berawi, 2004; Yang et al., 2012), as well as increased efficiency (Berawi et al., 2014) and innovative creation (Chen et al., 2010).

The application of Value Engineering in developing the conceptual design of High Speed Train infrastructure is expected to generate optimum added value that is innovative and effective to increase the feasibility of a HST project.

2. METHODOLOGY

This research combined quantitative and qualitative methods. The quantitative method used a Life Cycle Cost (LCC) analysis. It will be carried out as means of the evaluation process used in this research that takes into account initial cost, as well as operational and maintenance for HST project development. In the qualitative method, participatory action research was conducted through in-depth interviews. These interviews involved a minimum of three persons from the Ministry of Transportation, including academics and practitioners. The interviewers were selected to represent High Speed Train development expertise, due to the limited number of respondents with knowledge about detailed elements of the HST systems.

The process of this research started with the identification of problems and development potential embedded within the project. Population levels and obstacles related to technical difficulties were determined in order to identify optimum routes during the HST project development. Meanwhile, Value Engineering is conducted to produce innovative ideas that potentially could be integrated in the project by using the Function Analysis System Technique (FAST) diagram (Hammersley, 2002; SAVE Standar, 2007). It is a tool that constructs the logical interrelationship between functions and graphically presented in order to assist in the decision making process (Snodgrass, 1986).

Life Cycle Cost (LCC) analysis in this research only considers construction cost and railway Operations and Maintenance (O&M) cost without incorporating additional functions from the VE process. The LCC calculations with additional functions and revenues will be discussed in further research papers.

3. RESULTS AND DISCUSSION

3.1 Jakarta-Surabaya HST Route Planning

3.1.1. Jakarta-Surabaya HST route analysis based on contour

In undertaking HST line development, "hill climbing" is a problem that should be avoided. Steep-gradients not only result in expensive construction, but also impact the train speed and economical operations. The limit of slope gradient for a high speed train is between 2.5% to 4.0%. Furthermore, the slope needs be maintained at less than 1.5% when the lines also serve for freight trains. Figure 1 shows digital elevation mapping in Java Island that can be used to determine suitable contours for HST route development.

Most areas in the center of Java Island, from the Bogor area towards the eastern cities, have high elevations and contoured topography with mountains and steep cliffs. The cities categorized in green areas with flat surface are recommended as being suitable for HST lines. However, HST lines are still able to serve the cities that are located in the yellow color areas (+500 m), as long as the location surpasses the targeted requirement for development. The contour analysis produce accessible and non-accessible cities for Jakarta-Surabaya high speed train route development. There are 33 accessible cities located on flat surface planes in the Java contour map and 34 inaccessible cities, due to high elevation locations or those isolated by the mountains.

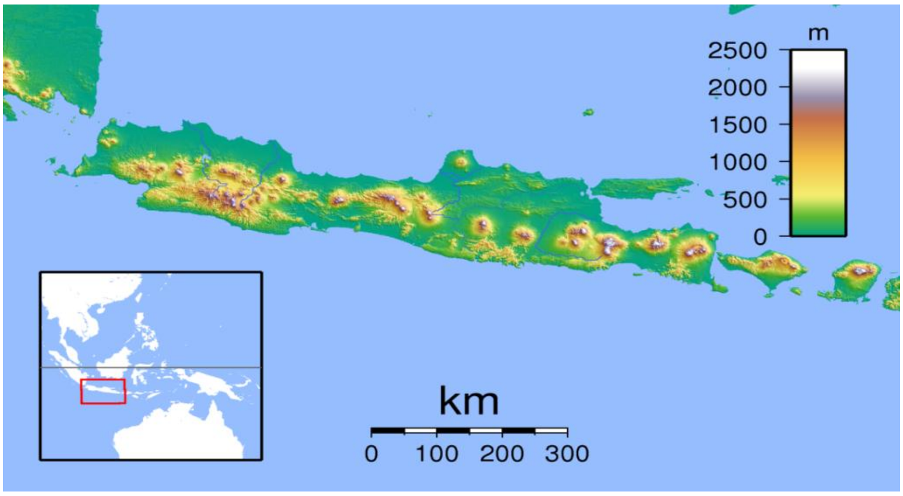

Figure 1 Elevation Map of Java Island

3.1.2. Jakarta-Surabaya HST route analysis based on population

By considering major cities and their populations in Java Island, further route analysis was performed to consider targeted demands, thus creating optimum route selections. The data is retrieved from Statistics Indonesia (2014), to rank those cities based on population and their projected population growth. The ranking of cities is shown in Table 1 below.

Table 1 Rank of cities on population and population growth in Java Island

Rank	**City**	**Population (2014)**	**Rank**	**City**	**Population Growth**
1	Jakarta	10,200,000	1	Surabaya	6.48%
2	Surabaya	3,400,000	2	Purwokerto	4.17%
3	Tangerang	3,000,000	3	Tuban	2.72%
4	Bandung	2,600,000	4	Jepara	2.34%
5	Bekasi	2,500,000	5	Cirebon	2.19%
6	Karawang	2,288,254	6	Pandeglang	2.18%
7	Cirebon	2,223,089	7	Bekasi	2.17%
8	Indramayu	1,900,000	8	Bandung	2.08%
9	Cilacap	1,750,000	9	Pamanukan	2.06%
10	Grobogan	1,550,000	10	Pamekasan	2.01%

From the previous analysis, out of 33 accessible cities, 10 of the most populated and 10 highest population growths of cities then selected for possible HST stations placement as shown in Table 1 above. Current population growth projections show that Bandung; Bekasi; Kerawang and Cirebon, with more than 2 million inhabitants each, are potential cities for HST stations. With an estimated 4.17% population growth forecast, Purwokerto has the potential to become the next urbanized conurbation and it is considered eligible for an HST station.

Alternatives in developing HST lines in Java Island have been conducted by various researchers. Acharya and Morichi, (2013) suggest HST stations be located in Jakarta, Cirebon, Tegal, Semarang, Surabaya. Meanwhile, the Directorate General of Railways from the Ministry of Transportation (2014) is planning to designate Jakarta, Semarang and Surabaya as major HST station hubs, yet the designation of supporting stations remain unpublished. Since 2011, JICA has been developing a feasibility study on a High Speed Train Project for the Jakarta-Bandung section, which would produce two alternative routes: a coastal route and a southern route. However, the supporting documents of JICA development for the Jakarta-Surabaya HST project are still limited in public records. Data are limited on such topics as station placements, detailed technology selections and even generated revenues.

Considering selected cities are filtered from data based on contour and population analysis, there are 9 cities which may be selected for potential HST station placement. The route variations consist of Jakarta, Karawang, Cirebon, Bandung, Pekalongan, Semarang, Grobogan, Blora and Surabaya. These cities produce two route variations that have designated lengths, which will affect initial costs of the overall project development. The detail route variations can be seen as Table 2.

Table 2 Route variations

Route	Variation	Length (km)	Stations							
1	1 (green)	685	Jakarta	Cirebon	Semarang	Surabaya				
2		685	Jakarta	Karawang	Cirebon	Semarang	Blora	Surabaya		
3		685	Jakarta	Karawang	Cirebon	Pekalongan	Semarang	Grobogan	Blora	Surabaya
4	2 (red)	736	Jakarta	Bandung	Semarang	Surabaya				
5		736	Jakarta	Bandung	Cirebon	Semarang	Blora	Surabaya		
6		736	Jakarta	Karawang	Cirebon	Pekalongan	Semarang	Grobogan	Blora	Surabaya

From Table 2, there are two alternatives for the HST route. Both routes can be distinguished by station placement and route length. Route 1 that connects coastal route has 685 km with minimum 4 stations located at Jakarta, Cirebon, Semarang and Surabaya (shown as a green line). On the other hand, Route 2 that connects Jakarta–Surabaya via Bandung has total 736 km with minimum stations located at Jakarta, Bandung, Semarang and Surabaya, (shown as a red line). The detailed visualization of both routes can be seen in Figure 2.

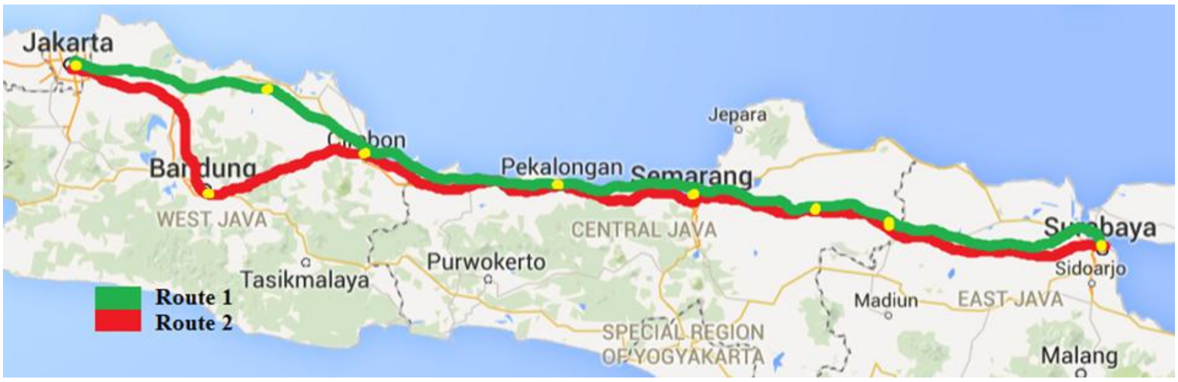

Figure 2 Jakarta- Surabaya high speed train alternative design

3.2 Value Engineering of Jakarta-Surabaya HST Project

VE study was performed on the Jakarta-Surabaya HST project development, using a VE job plan. The creativity phase in this study was expected to produce innovative ideas that can be integrated into the HST project. This VE study produces several alternatives for additional functions through a Function Analysis System Technique (FAST) diagram.

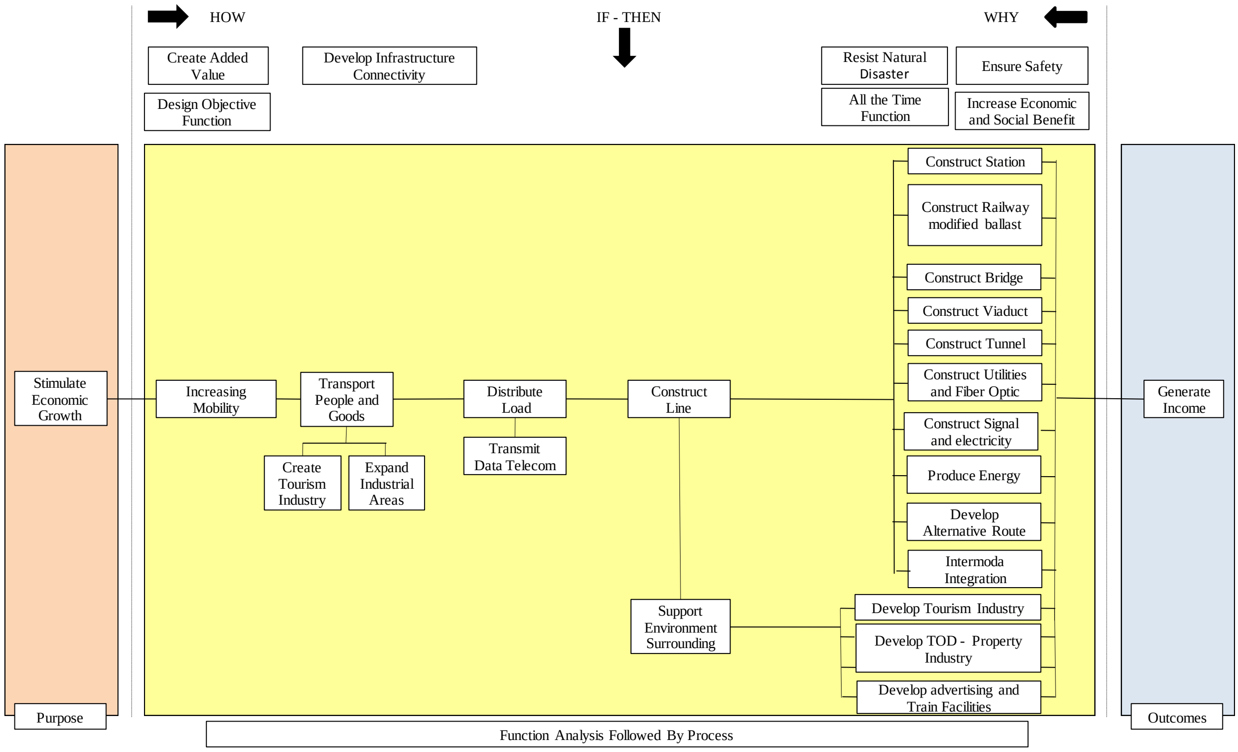

Figure 3 FAST diagram for Jakarta–Surabaya high speed train

The ‘how-why’ logical model is used to identify, classify, develop and select functions that could create greater value and benefit to the project development. The FAST diagram, as shown in Figure 3, produces several additional functions, such as the utilization of Bituminous Ballast, Transit-Oriented Development (TOD), utility service integration development, tourism area development, an electrical generator and a train service facility.

3.3 Initial Cost of Jakarta-Surabaya HST Basic Concept

The initial cost breakdown into several components, such as civil costs, structural works, tracks, stations, terminals, and intermodal connections. Benchmarking was conducted based on other successful HST projects in order to gain estimated investment costs. The exchange rate used in this research is about IDR 13,200 /US$.

The Jakarta-Surabaya HST Basic Concept comprises an analysis of 10 High Speed Train systems around the world, either in terms of concept or actual construction. HST systems include: LGV Atlantique and LGV Mediterranee, France (Arduin and Ni, 2005); San Francisco-Los Angeles, USA (California High Speed Rail Authority Business Plan, 2014); Honam and Suseo, Korea (Korea Research Institute for Human Settlements, 2015); Qingdao-Taiyuan, China (Sun et al., 2014); Beijing-Shanghai, China (Yin et al., 2015); Beijing-Guangzhou-Shenzhen-Hong Kong, China (UC Denver, 2012); Taiwan (Cheng, 2010) and Ankara-Istanbul, Turkey (Railway-Technology.com, 2011). The comparison of each selected HST project can be seen in Table 3.

Table 3 Initial cost of selected HST project development

Train Route	Length (Km)	Num. of Stations	Route Construction (IDR. Millions)	Stations, Terminals & Intermodal (IDR. Millions/km)	Route (IDR. Millions/km)	Station, etc (IDR. Millions/station)
LGV Atlantique	281	9	21,211,377	1,117,914	75,485	124,213
LGV Mediterranee	251	6	32,332,088	2,309,435	128,813	384,906
San Francisco – Los Angeles	1,288	24	325,877,398	43,657,514	253,010	1,819,062
Honam	230	6	86,389,181	5,957,875	375,605	992,979
Suseo	61	3	20,936,748	3,160,264	343,226	1,053,421
Qingdao–Taiyuan	873	30	125,384,312	9,287,801	143,626	309,593
Beijing-Shanghai	1,318	24	255,334,732	26,877,340	193,729	1,119,889
Beijing–Guangzhou–Shenzhen–HK	2,230	44	299,232,071	17,263,389	134,185	392,349
Taiwan	345	8	133,597,518	10,082,832	387,239	1,260,354
Ankara–Istanbul	533	5	26,162,467	3,018,746	49,085	604,749

As shown in Table 3 concerning a cost comparison of the ten railways, costs per kilometer and costs per station varied greatly for each country. The lowest cost per kilometer is about IDR 49 Billion/km for Ankara-Istanbul in Turkey and the highest is Taiwan HST with IDR 387 Billion/km of construction cost. The differences in various HST project costs may happen because of many factors, such as economic, material costs and even labor costs. However, these costs do not take into account the differences in the type of structures that are built. For example, the Taiwan High-Speed Railway might have a higher cost per kilometer, due to the fact that a large portion of the route is built underground, resulting in higher construction costs.

The lowest construction cost (Ankara-Istanbul) and the highest construction cost (Taiwan HST) will be applied to the Jakarta-Surabaya high speed train project to estimate the range of investment costs needed for the project. Route 1 would have a distance for about 685 km and Route 2 is around 736 km. A total of six scenarios will be assessed, with three variations for each route with 4-, 6- and 8-stations, respectively. Route 1 is expected to be more feasible when compared to Route 2. Route 1 has initial costs ranging from IDR 36 Trillion with 4 stations to IDR 275 Trillion with 8 stations over 685 km, whereas Route 2 has initial costs ranging from IDR 38 Trillion with 4 stations to IDR 295 Trillion with 8 stations over 736 km of high speed train lines. The details can be seen in Table 4.

Table 3 Initial cost comparison of two routes

Train Route	4 Stations (IDR. Millions)	6 Stations (IDR. Millions)	8 Stations (IDR. Millions)
Route 1			
Lowest	36,038,061	37,245,559	38,453,058
Highest	270,300,035	272,820,743	275,341,451
Route 2			
Lowest	38,541,384	39,748,882	40,956,381
Highest	290,049,217	292,569,925	295,090,633

3.4 Operation and Maintenance Cost of Jakarta-Surabaya HST Basic Concept

The components of HST maintenance cost mainly consist of the cost for track maintenance (67.40%), electrification (14.80%) and signaling (17.80%). The operational cost highly depends on train models and specifications. There are shunting (or track-switching) costs, train servicing, driving, safety costs and others. The Table 5 shows various types of HST operational and maintenance costs of selected train technology.

Table 4 Comparison of operation and maintenance costs for selected train technology

Type of HST	Length (Km)	Seats	Annual Operational Cost (IDR. Million)	Annual Maintenance Cost (IDR. Million)	Annual O&M Cost (IDR/km)
TGV Reseau	300/320	377	927,961.72	87,337.57	2,051,109.69
TGV Duplex	300/320	510	1,135,388.46	87,337.57	2,329,001.97
Thalys	300/320	377	1,353,732.40	103,713.37	3,275,159.03
ICE 1	280	627	1,946,398.16	155,111.42	4,203,019.16
ICE 2	280	368	1,300,934.50	70,050.32	3,427,462.05
ICE 3	330	415	895,643.37	80,057.51	2,323,097.32
ICE 3 Polyc	330	404	1,020,733.22	85,061.10	2,632,843.63
ICE T	230	357	775,557.11	90,064.70	2,404,505.01
ETR 500	300	590	777,028.74	90,235.60	2,409,067.59
ETR 480	250	480	1,057,761.70	160.418.84	4,229,793.53
AVE	300	329	743,194.29	90,939.39	1,774,752.51

AVE requires the lowest annual Operation and Maintenance costs of an estimated IDR 1.7 Trillion, while ETR 480 requires significantly higher operational and maintenance costs of an estimated IDR 4.2 Trillion per year. If the lowest O&M cost (AVE) and the highest O&M cost (ETR 480) range is applied to the Route 1 of Jakarta-Surabaya high speed train project, it will result in an estimated range from lowest to highest of IDR 1.2 Billion to IDR 2.9 Billion per year as shown in Table 6.

Table 5 O&M cost comparison of route 1

Type of HST	Length (Km)	Annual O&M Cost (IDR/km)	Annual O&M Cost (IDR)
Route 1			
Lowest	685	1,774,752.51	1,215,705,469.35
Highest	685	4,229,793.53	2,897,408,568.05

4. CONCLUSION

The Value Engineering approach for the Jakarta-Surabaya High Speed Train development is resulting in additional functions that potentially could be integrated into the project, such as the utilization of Bituminous Ballast, Transit-Oriented Development (TOD), utility service integration development, tourism area development, electrical generation, and train service facilities. Route analysis was performed based on contour analysis and population growth projections from potential cities in Java Island.

Considering route analysis and life cycle cost, Route 1 was selected as the best scenario. Route 1 with 4 stations from Jakarta to Cirebon to Semarang and to Surabaya has the lowest cost scenario that requires an estimated IDR 36 Trillion. It will require Operation and Maintenance costs of an estimated IDR 1.2 Billion per year for 685 km of high speed train infrastructure.

5. REFERENCES

Acharya, S.R., Morichi, S., 2013. Introducing High Speed Rail (HSR) System in Developing Asia: Issues and Prospects. *In Proceedings of the Eastern Asia Society for Transportation Studies*, Volume 9

Arduin, J.P., Ni, J., 2005. French TGV Network Development. *Japan Railway & Transport Review*, Volume 40(3), pp. 22–28

Berawi, M.A., 2004. Quality Revolution: Leading the Innovation and Competitive Advantages. *International Journal of Quality & Reliability Management*, Volume 21(4), pp. 425–438,

Berawi, M.A., Susantono, B., Miraj, P., Berawi, A.R.B., Rahman, H.Z., Husin, A., 2014. Enhancing Value for Money of Mega Infrastructure Projects Development using Value Engineering Method. *Procedia Technology*, Volume 16, pp. 1037–1046

California High Speed Rail Authority, 2014. *San Francisco - Los Angeles High Speed Railway Business Plan*, Available at: http://www.hsr.ca.gov/docs/about/business_plans/FINAL_Draft_2014_Business_Plan.pdf

Campos, Javier, Gines de Rus, 2009. Some Stylized Facts About High-speed Rail: A Review of HSR Experiences Around the World. *Transport Policy*, Volume 16(1), pp. 19–28

Chen, W.T., Chang, P.-Y., Huang, Y.-H., 2010. Assessing the Overall Performance of Value Engineering Workshops for Construction Projects. *International Journal of Project Management*, Volume 28, pp. 514–527

Cheng, Y.H., 2010. High-speed Rail in Taiwan: New Experience and Issues for Future Development. *Transport Policy*, Volume 17(2), pp. 51–63

Dikun, S., 2010. *The Interface Report: Substances to Support the National Railway Master Plan*.

Directorate General of Railways, Ministry of Transportation, 2014. *Indonesia Railway Development*. Bangkok, 13–15 October 2014

Fong, P.S., Shen, Q., 2000. Is the Hong Kong Construction Industry Ready for Value Management?. *International Journal of Project Management*, Volume 18, pp. 317–326

Givoni, M., 2006. Development and Impact of the Modern High-speed Train. *Transport Reviews*, Volume 26(5), pp. 593–611

Hammersley, H., 2002. *Value Management in Construction*, Hammersley Value Management Limited, Coventry

Korea Research Institute for Human Settlements, 2015. *Plan for Honam High-speed Railway*, Available at: http://168.126.177.50/pub/docu/en/AD/BE/ADBE2006BAC/ADBE-2006-BAC003.PDF

Levinson, D.M., 2012. Accessibility Impacts of High-speed Rail. *Journal of Transport Geography*, Volume 22, pp. 288–291

Ministry of Transportation Republic of Indonesia, 2011. *National Railway Master Plan*. Ministry of Transportation, Republic Indonesia

Monzón, A., Ortega, E., López, E., 2013. Efficiency and Spatial Equity Impacts of High-speed Rail Extensions in Urban Areas. *Cities*, Volume 30, pp. 18–30

Railway-Technology.com, 2011. *Ankara Istanbul High-speed Train Project*. Available at: http://www.railway-technology.com/projects/ankara-istanbul/

SAVE Standard, 2007. *Value Standard and Body of Knowledge*. SAVE, United States of America

Snodgrass, T.J., Kasi, M., 1986. *Function Analysis - The Stepping Stones to Good Value*. Board of Regents, University of Wisconsin System, University of Wisconsin, Madison, Wisconsin

Sun, Y., Cao, C., Wu, C., 2014. Multi-objective Optimization of Train Routing Problem Combined with Train Scheduling on a High-speed Railway Network. *Transportation Research Part C: Emerging Technologies*, Volume 44, pp. 1–20

UC Denver, 2012. *Critical Issues of High-Speed Rail Development in China*, Available at: http://www.ucdenver.edu/academics/colleges/Engineering/research/CenterSustainableUrbanInfrastructure/LowCarbonCities/Documents/Wingtat_Hung/WTHung_high_speed_rail.pdf

Woodhead, R.M., Berawi, M.A., 2007. An Alternative Theory to Idea Generation. *International Journal of Management Practice*, Volume 3(1), pp.1−19

World Economic Forum, 2012. *The Global Competitiveness Report*. Geneva: World Economic Forum

Yang, L.R., Chen, J.H., Wang, H.W., 2012. Assessing Impacts of Information Technology on Project Success through Knowledge Management Practice. *Automation in Construction*, Volume 22, pp. 182–191

Yin, M., Bertolini, L., Duan, J., 2015. The Effects of the High-speed Railway on Urban Development: International Experience and Potential Implications for China. P*rogress in Planning*, Volume 98, pp. 1–52