Research Assessment Exercise 2020
Impact Case Study

University: The Hong Kong Polytechnic University (PolyU)
Unit of Assessment (UoA): 16 – Civil Engineering and Building Technology

Title of case study: Sustainable Transport and Infrastructure

(1) Summary of the impact

Reliable, efficient, safe and environmental-friendly transport infrastructure is essential to providing sustainable transport systems, especially in densely populated cities. The UoA's transport team's research has focused on three main areas to help meet this demand. The first involves road and walkway pavement materials such as eco-blocks and recycled bitumen. The team's work on these new materials has helped them to be used more widely in Hong Kong. The second area is developing efficient algorithms for the implementation of intelligent transportation systems (ITS). The UoA's work has reduced the number of detectors needed to manage such systems in Hong Kong and Bangkok and so decreased their costs substantially. Finally, innovative technologies have been developed to monitor railway safety that are now widely used to optimize railway maintenance and management in Hong Kong as well as Brazil, China and Singapore.

(2) Underpinning research

The research activities that underpin this Sustainable Transport case study range from construction of transport infrastructure to consideration of its operation, maintenance and management systems. They include the development of sustainable construction materials, efficient intelligent transportation system operation and innovative monitoring technology for railway safety and system maintenance. We summarise below the underpinning work of the research team, which is composed of six current academic members: William Hing-Keung Lam, Zhen Leng, Yi-Qing Ni, Chi-Sun Poon, Agachai Sumalee and Yuhong Wang. Since October 2013, they have led the supervision of 61 PhD students and 178 research staff in investigations into the main related topics addressed by the UoA.

Sustainable infrastructure materials: The world's very long road networks, which are usually capped with asphalt (bitumen) pavements, represent our planet's most massive civil engineering structures. The UoA's transport research team has developed new test apparatus to better simulate, assess and model the ageing-related durability of such asphalt pavements which has been applied to study scientifically asphalt pavement durability and the behaviour of recycled asphalt [R1] as well as safety aspects of working with asphalt. The team has also developed low-noise road surface paving technologies. To enhance the sustainability of road construction, the team has actively investigated the recycling or up-cycling of waste materials for pavement construction, by selecting specific waste materials and developing appropriate physical and chemical treatment methods for waste materials [R2]. Waste sewage sludge ash and waste plastics have been converted to additives/modifiers to reduce the construction temperature and enhance the moisture damage resistance of asphalt pavements. The team has also conducted research since early 2000 to develop technologies to recycle construction and demolition (C&D) waste and waste glass for road pavements applications [R3]. The scientific challenges include: the presence of attached cement mortars in the original C&D wastes, leading to generally inferior initial properties; high variability in the recycled aggregates; and the detrimental alkali-silica reaction due to the use of reactive glass cullet as aggregates in concrete products. Theoretical and experimental investigations have addressed and resolved the above challenges.

Efficient Intelligent transportation systems (ITS) for transport operations: ITS are central managing modern cities. The UoA's transport research team has developed new multiple ITS solution algorithms for Hong Kong and Bangkok that harness information from multiple sensor systems to develop effective real-time travel time estimation and management systems. These algorithms tackle

challenging problems, such as different types of traffic sensor data and sample sizes, limited number of traffic sensors/detectors due to high installation cost and limited traffic data due to privacy issues. The UoA's team tackle ITS problems for which existing commercial solutions are ineffective. They have extended their algorithms to provide reliable driving information and routes to allow motorists to increase the effectiveness of their journeys through the explicit consideration of road network uncertainty due to day-to-day demand variations [R4]. The research team also developed a data fusion algorithm for real-time traffic sensor data analysis and a stochastic cell transmission model for short-term traffic state estimation/prediction for traffic management. This was applied to the expressway network in Bangkok in an approach that addressed the stochastic nature of the traffic data [R5].

Monitoring technology for railway safety and maintenance: Improving safety is one of the most challenging problems in the railway industry. The UoA's transport research team has made substantial progress in R&D activities related to this aim. Collaborating with top-tier universities and high-speed rail (HSR) manufacturing enterprises all over the world, the team has developed a proprietary Optical Fibre Sensing Technology (OFST) for monitoring railway safety. A series of OFST systems have been established that can provide real-time online monitoring of structural conditions of various train components including bogies and wheels as well as the rail tracks. [R6].

The quality of the research is demonstrated by the team's total research grant income of over HK$144 million since 2000 together with their awards from local, national and international bodies over the past six years, including State Technological Innovation Award, Gold Medal of the 45th International Exhibition of Inventions of Geneva, 2014 APEC Science Prize for Innovation, Research and Education, 2018 Hong Kong Green Innovations Award, CIC Innovation Award 2015, HKIHT Highways and Transportation Excellence Award 2015 and three Paper Awards [S1]. A national-wide engineering center "The Hong Kong Branch of National Rail Transit Electrification and Automation Engineering Technology Research Center" has also been established in 2015 with an annual budget of HK$10 million (https://www.polyu.edu.hk/cnerc-rail/about/director-s-message).

(3) References to the research

R1. Yu, H. Y., **Leng, Z.**, Zhou, Z. Y., Shih, K. M., Xiao, F. P. and Gao, Z. M. Optimization of preparation procedure of liquid warm mix additive modified asphalt rubber. *Journal of Cleaner Production*, 141, 336-345 (2017) [DOI: 10.1016/j.jclepro.2016.09.043] (Highly Cited Paper in Web of Science Core Collection)

R2. **Wang, Y. H.** The effects of using reclaimed asphalt pavements (RAP) on the long-term performance of asphalt concrete overlays. *Construction and Building Materials*, 120, 335-348 (2016) [DOI: 10.1016/j.conbuildmat.2016.05.115]

R3. Ling, T. C., **Poon, C. S.** and Wong, H. W. Management and recycling of waste glass in concrete products: Current situations in Hong Kong. *Resources Conservation and Recycling*, 70, 25-31 (2013) [DOI: 10.1016/j.resconrec.2012.10.006]

R4. Chen, B. Y., Li, Q. and **Lam, W. H. K.** Finding the k reliable shortest paths under travel time uncertainty. *Transportation Research Part B*, 94, 189-203 (2016) [DOI: 10.1016/j.trb.2016.09.013]

R5. **Sumalee, A.**, Zhong, R. X., Pan, T. L. and Szeto, W. Y. Stochastic cell transmission model (SCTM): A stochastic dynamic traffic model for traffic state surveillance and assignment, *Transportation Research Part B*, 45(3), 507-533 (2011) [DOI: 10.1016/j.trb.2010.09.006]

R6. Ye, X. W., **Ni, Y. Q.** and Yin, J. H. Safety monitoring of railway tunnel construction using FBG sensing technology. *Advances in Structural Engineering*, 16(8), 1401-1409 (2013) [DOI: 10.1260/1369-4332.16.8.1401]

(4) Details of the impact

Sustainable infrastructure materials: The UoA's transport research team has worked closely with the Highways Department of the Hong Kong SAR Government on various studies to develop new

materials, technologies, and specifications, which have significantly enhanced the sustainability of Hong Kong's road network by improving its durability and reducing its environment impact [S2]. The UoA's research led one major Hong Kong Contractor (K. Wah Asphalt Limited) to purchase new paving equipment that could apply a method developed from the team's research to reduce harmful effects of working with asphalt on construction site operatives [S3]. The method can reduce more than 70% of emission from hot-mix bituminous production. The team's pavement research also led to a change in practices in resurfacing the pavement friction course. This saves the milling of 30 mm asphalt wearing course when the friction course is resurfaced, so bringing significant economic and environmental benefits [S3]. The research team has also worked closely with Hong Kong Asphalt (Green) Limited [S4] for projects from the Environmental Protection Department and the Highways Department of the Hong Kong SAR Government to develop low-noise road surface paving technologies. A trial section of low-noise asphalt pavement material has been constructed, which shows satisfactory mechanical performance, and outstanding low-noise performance. The construction of this trial section was also positively reported by local media (http://orientaldaily.on.cc/cnt/news/20170113/00176_032.html). The custom-designed paving technology employing a special waste tyre rubber and asphalt mixture design won the 2018 Hong Kong Green Innovation Silver Award [S1] which recognised the benefits achieved in recycling waste tyres (1 lane-km recycles approximately 13 tons of waste tyres), improving durability (better than conventional asphalt pavement without modifiers), decreasing construction temperatures (at least 20^{o}C lower), and reducing tyre-road noise (by 4.4dB(A) lower than conventional asphalt pavements).

Regarding the development of technologies for recycling construction and demolition waste in road pavement applications, the team's experimental research has led to the development of practical technologies that have been commercialized by local manufacturers through licensing agreements. Pilot plant production trials and stringent field trials were conducted (e.g. eco-block for walkway) to demonstrate the potential of the developed technologies. The successful demonstration has led to the promulgation of new government specifications and policies for their wide use in Hong Kong. Some of the developed products (e.g. eco-block for walkway) are now available commercially to industry. With the use of the UoA's developed technology, a new government regulation has also been formulated on the management of waste glass by the Environmental Protection Department of the Hong Kong SAR Government, which had been passed by the Legislative Council in 2016 [S5].

Efficient ITS for transport operations: The UoA's transport research team is a pioneer for provision of real-time traffic information in Hong Kong with partnership of Autotoll Limited [S6]. The novel solution algorithms in ITS projects for the Transport Department of the Hong Kong SAR Government [S7], include: (i) a Speed Map Panel (SMP) system (2013), (ii) an Update of Journey Time Indication System (JTIS) (2018/2019), and (iii) the Installation of traffic detectors on selected strategic roads (2018-2020). The team's solution algorithms have addressed ITS challenges that cannot be met with commercial solutions. The developed algorithms allowed the number of detectors required for real-time journey time and traffic speed estimation required for speed map panel systems to be reduced greatly by half. The real-time traffic information has also been broadcast, since 2017, on a local TV channel (https://www.youtube.com/watch?v=mNWck8lFgsQ), providing a very valuable public resource.

Another stream of ITS research that has led to considerable impact is the integration of multiple sources of real-time traffic data for projects in Thailand. The developed stochastic cell transmission model has been adopted, since 2014, for real-time traffic management by the Expressway Authority of Thailand, as well as, since 2015, for real-time traffic operation by the Department of Highways of Thailand [S8]. The application of the traffic management system has helped to improve road traffic in and around Bangkok and streamline the daily commute for the area's 12 million people. According to an independent assessment, the economic benefits of the system, when trialled on a 17-mile stretch of Bangkok expressway were estimated to be more than US$ 1 million/year since 2015 [S9]. The 2014 APEC Science Prize for ITS work [S1] recognised the system's practical and societal impact.

Monitoring technology for railway safety and maintenance: The research team's proprietary railway OFST condition monitoring systems have delivered important practical impact. The team was among the first to implement OFST on in-service high-speed trains for online monitoring of operational safety (http://www.takungpao.com.hk/mainland/text/2016/1227/49122.html). Apart from use in the Hong Kong Mass Transit Railway (MTR) system, this innovative technology has been adopted overseas, including the High-Speed Train and Metro lines in China, Singapore and Brazil. This includes: (i) On-board monitoring for two Olympic Metro Lines at Rio de Janeiro in Brazil (2016) (https://www.polyu.edu.hk/web/en/media/media_releases/index_id_6239.html), (ii) On-board condition monitoring of in-service trains running on Lanzhou-Urumqi HSR Line in China (2015/2016), (iii) Online wheel condition monitoring in collaboration with CRRC Changchun Railway Vehicles Co., Ltd. in China (2016/2017), (iv) Online condition monitoring of two metro lines in Singapore (2017), (v) Railway tunnel deformation monitoring in China (2017), (vi) Monitoring of load transmission from train vehicles and rail track to subgrade on Beijing-Shenyang HSR Line in China (2018), (vii) Acoustic emission based rail turnout crack monitoring, and (viii) Surface hardening technique for railway turnout frog made by manganese steels. Data collected from the monitoring systems has enabled condition assessment of these railway lines and helped to optimize their maintenance and management work. Project (viii), the laboratory performance of which corroborated by collaborative clients, is realised with a new flexible-controlled high energy peening technology, which can increase surface hardness of frog from 190~230 HB in the casted work pieces to 280~350 HB in the final serviced work pieces. The service life is expected to be lengthened to 3 times comparing to that of conventional pieces. Compared with the traditional pearlite tip rail, the overall cost with this technology incorporated can be reduced by 50% [S10]. Monitoring systems developed in Projects (v), (vi) and (vii) have been implemented and still in-service on multiple operating HSR lines, with satisfactory performance confirmed by our clients [S11].

(5) Sources to corroborate the impact

S1. State Technological Innovation Award, Gold Medal of the 45th International Exhibition of Inventions of Geneva, 2014 APEC Science Prize for Innovation, Research and Education, 2018 Hong Kong Green Innovations Award, CIC Innovation Award 2015, HKIHT Highways and Transportation Excellence Award 2015 and three Paper Awards by the team members.
S2. Letter of corroboration from the Highways Department of the Hong Kong SAR Government.
S3. Letters of corroboration from K. Wah Asphalt Limited to corroborate the associated research method to reduce harmful effects of working with asphalt on construction site operatives, and the changes in practices in resurfacing the pavement friction course.
S4. Letter of corroboration from Hong Kong Asphalt (Green) Limited to corroborate the impacts of the new "green" pavement material incorporated with waste tyre rubber.
S5. Consultation document on a new Producer Responsibility Scheme (PRS) on glass beverage containers, Environmental Protection Department of the Hong Kong SAR Government, https://www.epd.gov.hk/epd/bottles_consult/files/ENG/Environmental_condoc_ENG_chapter1.pdf
S6. Letter of corroboration from the Chief Executive Officer of Autotoll Limited. To corroborate that the developed solution algorithms have been adopted in various ITS projects for the Transport Department of the Hong Kong SAR Government together with the merits of the algorithms.
S7. Letter of corroboration from the Transport Department of the Hong Kong SAR Government.
S8. Letter of corroboration from the Department of Highways of Thailand.
S9. News releases by the Asia Pacific Economic Cooperation (APEC) for the winner of the 2014 APEC Science Prize for Innovation, Research and Education (ASPIRE Prize), https://www.apec.org/Press/News-Releases/2014/0917_Aspire_Winner
S10. Letter of corroboration from Qinghai Qingtie Railway Technology Co., Ltd.
S11. Letter of corroboration from China SWJTU Railway Development Co., Ltd.