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A Study of the Costs and Benefits of Smart City Projects Including the Scenario of Public-Private Partnerships

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***Abstract*—**A smart city project embraces benefits and costs which can be classified under direct and indirect categories. Externalities come into the picture, but they are often difficult to quantify. Despite this barrier, policy makers need to carry out cost-benefit analysis to justify the huge investments needed to make a city smart. The recent trend is towards the engagement of the private sector to utilize their resources and expertise, especially in the Information and Communication Technology (ICT) areas, where innovations blossom. This study focuses on the identification of costs (on a life cycle basis) and benefits associated with smart city project developments based on a comprehensive literature review and case studies, where public-private partnerships would warrant consideration, the related costs and benefits are highlighted. The findings will be useful for policy makers of cities.

***Keywords*—**Costs and benefits, identification, public-private partnerships, smart city projects.

I. Introduction

SMART city development is on the rise globally. Different meanings of "Smart City" prevail, but the basic premise is that people's well-being will be enhanced thereby. ICT is the main thrust in providing efficient services to citizens and visitors, apart from green and physical infrastructure improvements. Despite this good intention backed by technology-push and demand-pull [1], the benefit and cost justifications from the economic and social perspectives of implemented projects are often questionable, as manifested in a number of hastily decided cases. Integration of smart city projects within the same locality is often lacking, not to mention the potential IT hazards and data security breaches. For example, it has been estimated that one-hour of downtime would cost over US$100,000 for 95 percent of enterprises [2], and the average cost of cyber-crime has reached US$12.69 million in the US [3].

For hefty investments in smart cities to be justified (to guard against "White Elephants"), especially in the public sector, it is imperative to carry out a proper cost-benefit analysis (CBA). With the plethora of emerging smart cities and the proliferation of smart technologies, it is necessary to group the various systems into their respective domains for the purpose of identifying relevant cost and benefits, which is the first objective of this paper. Hence, smart city systems are categorized into (i) Transport; (ii) Telecommunication; (iii) Environment (including waste management); (iv) E-government; (v) Business and Finance; (vi) Health care; (vii) Utilities (including power, water and gas); (viii) Crime prevention; (ix) Disaster prevention/warning; and (x) Culture/ entertainment.

Since some categories of smart city projects above may have commercial values, burden on the public coffers may be lessened by tapping into private sector resources, whilst efficiency may be enhanced. Therefore, the second objective of this paper is to focus on the possible modification of costs and benefits when public-private partnerships take place in smart city projects.

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II. Literature Review

Traditional CBA is an evaluation technique with a firm grounding on the theories of welfare and public economics [4]. It entails a thorough analysis of pertinent benefits and costs for a number of policy or project alternatives, comparing the externalities and distributional (or spill over) effects of each alternative. Even if no alternative exists, the net benefits (or costs) for the 'with project' and 'without project' scenarios can be compared. Monetizing benefits and costs (including 'shadow pricing' of intangibles) is the main tool, taking care of the time effect of money through discounting with a carefully determined discount rate and avoiding double-counting. Willing-to-Pay (WTP) for benefits and Willing-to-Accept (WTA) for undesirables are key evaluation measures [5].

A. Benefits of Smart City Projects

At a broad level, smart cities may provide benefits such as [6]:

- Better and more convenient citizen services;
- Better governance of cities;
- Better environment;
- Up-to-date industry, being greener and more people-friendly;
- More intelligent and smarter infrastructure; and
- An innovative and vibrant economy

At a detail level, more succinct benefits may accrue to specific systems, as exemplified in the following [7]:

Smart government: ICT leads to increases of safety and security; digital presence leads to improvements and transparency in policies; open communication leads to real time quick services.

Smart utility: smart grid engenders cleaner, healthier, and greener cities, as well as uninterrupted power, especially with the use of renewable energy; reduced waste and green environment provide clean water; 24-hour utility supplies ensure services availability; city waste and sanitation management improves life quality.

Smart economy: new revenue models and financial hub increase GDP and per capita income; international and local investments provide more employment opportunities; competitive pricing fosters partnership between public and private sectors.

Smart mobility: intelligent transport system promotes the use of clean energy such as hybrid technology; real time data capture results in cleaner and efficient fuel; big data analytics as well as the Internet of Things (IoT) enable efficient and elegant designs.

Smart environment: in addition to the above, smart homes and buildings reduce waste generation.

Smart living: intelligent devices increase safety; automated systems improve health; education facilities increase life expectancy; Wi-Fi and internet connectivity promote education.

The above benefits may be broadly summarized into sustainability, health, safety and knowledge. The intertwining thread is data, which is transmitted via a system of networks. Ubiquitous, high-speed network connections can have a major impact on sectors including health, education, transportation, and power by improving efficiency and engendering innovations across these and all other sectors of the economy. On one hand, the spill-over effects have prompted governments in OECD countries to increase investment in enhancing broadband connectivity, whereas previous efforts were mainly made from the private sector [8]. On the other hand, the huge demand for better ICT services in some places has made government bring in private partners to bridge funding and efficiency gaps [9].

From a technology standpoint [6], ubiquitous computing enables public sector information re-use and utilization of open data, producing a paradigm shift which impacts on public administration. Easy comparability and comprehensibility through metadata and data standardization can be achieved. Networking will enable democratization, resulting in reasonable cost for high quality service. Congestion and time wasting will be reduced. The provision of open data for public access and use enhances machine readability, adding insight to the performance of key areas such as transport, energy, health and environment. Big data techniques may be used to identify business trends, prevent diseases, combat crime, and determine real-time traffic conditions, amongst other uses. GIS systems allow city managers and individuals to make interactive enquiries, analyze spatial information, handle map data and ease presentations. Cloud computing, if standardized, assures transparent and reliable interfaces to middleware, enabling interoperability between commodities and services across various domains. Service-oriented architecture changes the previous IT models of branded systems to a flexible, shared model, leaving room for scalable and incremental growth. E-government integrating wireless networks increases transparency and the efficiency of public service delivery. IoT comprising sensors and RFID, when complemented with augmented reality, is expected to lead to automation and location-aware applications.

Intangible positive externalities exist in smart cities where citizens enjoy increased convenience, better environment, health and safety [10]. The additional leisure and rest time result in higher productivity. Family bonds are also fostered, for example, due to the use of video conferencing, thereby reducing business travelling.

Fig. 1 summarizes the direct and indirect benefits which may accrue to various types of smart city projects. The upper part of the diagram relates to the situation when investment is carried out by the public sector alone.

B. Costs of Smart City Projects

As with any major investment on a city scale, smart projects entail substantial inputs of financial and human capital, which are needed for production and diffusion of technology [11]. At the technology level, the first consideration in implementing a smart ICT plan for any city manager is to foster the development of a broadband environment which supports digital application for ensuring connectivity and availability to all citizens [12]. The deployment of cables, optical fibers, wireless networks, smart grid, sensors, etc. is an essential pre-requisite. The capital cost of such installations depends on the size of the population, its dispersity, and the existing conditions of the city's infrastructure. For example, the Canadian government spent CAD 1.9 billion implementing smart metering across Ontario [13]. Data centers acting as the hub of ICT networks are expensive to build, operate, and maintain. The first cost of green and sustainable buildings is sometimes (but not always) dearer than the traditional way of construction [14], not to mention the cost of cleaning the city environment. Whilst developing countries may find it easier to start smart cities from scratch due to no existing constraint (such as Qianhai in Shenzhen of China), funding support is often needed from multi-lateral development agencies [9].

Apart from the need for talents (human capital), smart cities often entail ingenious solutions in the form of IT applications, which may carry intellectual property cost, or licensing fees [15]. Added to this, IT equipment is usually used only up to 60 – 70 percent of its design life (meaning a higher depreciation rate). That explains the reason why data processing equipment is given a 30 per cent annual depreciation allowance in Hong Kong [16]. Consumption of energy (data centre consumes 100 -200 times the electricity used by a typical office building), maintenance, upgrading, expansion and transfer volume – dependent expenses all add to the cost.

Negative externalities of smart cities include the frustration of citizens brought about by dis-integrated data platforms and digital-divide [17]. Loss of privacy is a major growing concern of citizens living in smart cities [18].

Summing up, the direct and indirect costs of smart cities are depicted in Fig. 2, showing relevance to different types of smart city projects by generic groups. Again, the upper part relates to

the scenario of public sector investment.

Source of Investment	Benefits	
	Direct Benefit	Indirect Benefit
PUBLIC SECTOR ONLY	User Charge (if applicable) as public revenue	Saving of scarce resources (alleviate manpower shortage)
	Time saved due to increased convenience , less travelling time and queuing time	Property value / wage increase due to smart installation
	Increased spending (e.g. online purchases, booking, etc.)	Multiplier effect on local economy
	Life saved from accident reduction/disaster prevention	General happiness of users
	Medical cost saving	More timely treatment of illness (less suffering)
	Higher productivity	More resting time/reduced stress
	Reduced pollution (e.g. noise, air, water) abatement	More family union time
	Increased tourism income	Fame and prestige of city
	Street crime reduction	Reduced penal & rehab cost/crime investigation cost
		Birth rate increase alleviates manpower shortage
PUBLIC BENEFITS IN CASE OF PRIVATE INVOLVEMENT	Private sector skills made available	Technology transfer
	Improved efficiency	Competition leads to improved service quality, better technological innovation development and lower price
	Finance availability	Public funds can be channeled for other uses
	Risk transfer	Increase export opportunities (if systems have market)
	Increase local/foreign investment	
	Reduce public sector establishment size	

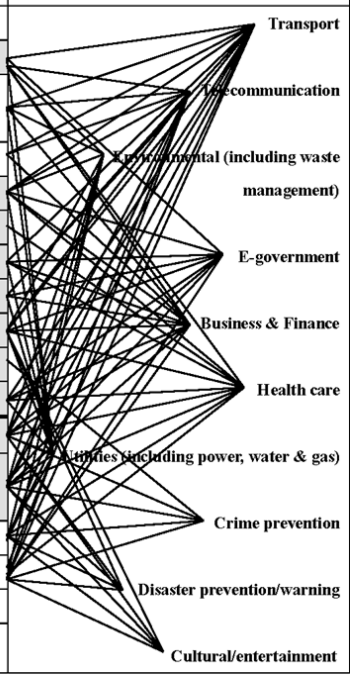

Fig. 1 Examples of Benefits of Smart City Projects (shaded box indicating the lack of direct measures; straight lines indicating relevance of indirect benefits to specific systems)

Source of Investment		Costs		Smart City Projects
		Direct Cost	Indirect Cost	
PUBLIC SECTOR ONLY	Part or all of these costs transferrable to Private Sector in PPPs	Prelim study + Public Engagement	Privacy breach	
		Design + Research & Development	Confidentiality breach	
		Installation + Backup system	Cyber Attack	
		Operation: Data collection & management	Downtime loss (including loss of opportunities, loss of market value, etc.)	
		Operation: License fees for software		
		Equipment maintenance	Non-availability leads to substitution by manual methods (if still exist)	
		Soft & equipment update/replacement	Chaos caused by network congestion/failure	
		Date center building & maintenance (if needed)	Failed system rectification	
		Help desk services	Unhappiness caused to users due to system failure	
			Widened "Digital Divide" btw. users & non-users	
			Forced redundancy payment to severed manual workers	
			Anti-social behaviours	
PUBLIC COST IN CASE OF PRIVATE INVOLVEMENT		Tender / Output Specifications / Negotiation	Monopoly price-setting	
		Legal fees in contract preparation	Poor service quality	
		Performance monitoring	Delay (forced use of alternative)	
		Loss of user charges as government revenue	Dispute resolution	
		Subsidies / Tax reduction as incentives	Polarity btw. payers (for private good) and non-payers (for public good)/Allegation of favoritism/Gov't image damage	

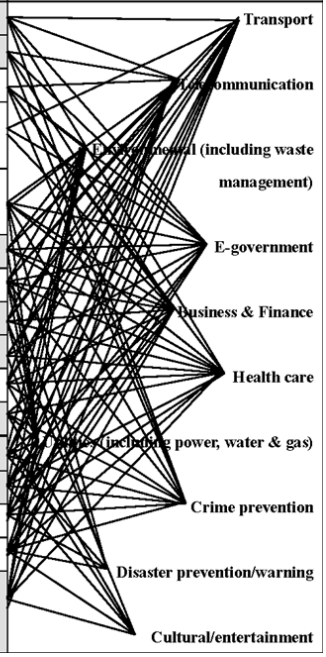

Fig.2: Examples of Costs of Smart City Projects (shaded box indicating the lack of direct measures; straight lines indicating relevance of indirect cost to specific systems)

III. Case Studies

Being a proven research method for illustration of principles and theory [19], five case studies are carried out on smart city projects in this research. The projects are chosen to highlight their costs and benefits based on the grouping rationale as mentioned earlier, in order to lay the foundation for the use of CBA in smart city project development.

A. Brazil

Rio de Janeiro, the capital city having a population of 6.5 million over an area of 1.2 million square kilometers, features an Operations Centre called COR. It is resourced to act as an integrated urban management centre capable of real-time analysis and responses for major events happening in the city daily.

Its weather radars, surveillance cameras and GIS systems track traffic, movements, assets and the weather (including triggering alarms for landslides. Journalists are present to follow its operation, making it transparent and intelligent. Citizens contribute their messages on things happening in the city (e.g., accidents, traffic jams, etc.) via an integrated platform called Waze, which allows users' reports to be tracked in a geo-referenced platform to enable shift action by the city managers. About 50,000 reports are received each day, totaling 1.5 million per month [20].

B. Japan

As one of the world's leading exporting nations of consumer electronics, Japan spares no efforts in its smart city campaign, especially in major cities such as Tokyo. Being prone to earthquake, many attempts are being made to move away from nuclear energy, paying much more attention to other forms of renewable as a substitute, amidst other strong drives to excel in energy efficiency.

Tokyo, as the capital city, has a highly dense population of 37.8 million on a land mass of 2,189 square kilometers. Although still being highly innovative and cohesive in terms of citizen bond, recent drops in scores by IESE Insight (published by the University of Navarra in Spain) on mobility, urban planning, governance and public management see rooms for improvement [21].

One particular characteristic of Japan's smart city initiative is the building of 'smart towns' as assemblies of numerous solutions put together at the community level. Examples are seen in Fujisawa and the Kashiwanoha sites around Tokyo. Houses are built using local renewable energy with battery storage, and drivers charge their vehicles from grid, which is connected to a community energy management system capable of monitoring individual household's use of energy. Large technology companies from conglomerates lead these projects, jointly with smaller suppliers of hardware and services, on the basis of public-private partnerships [22].

C. Korea

Songdo, being located at the southwestern part of Incheon Metropolitan City, has an area of 54 square kilometers and a planned population of 260,000 by 2022. An investment of KRW 165 billion has been earmarked to establish a smart city. Apart from a fully integrated real-time system monitoring traffic, illegal parking, crime, emergency situations, etc. through video images, abnormal sound such as screaming is also captured. Energy management is enabled through the use of smart phones, which can control the temperature and lighting of residences remotely.

An interesting feature of Songdo is that the investment in smart city is achieved through public-private partnership, in that the city of Incheon owns 28.6 percent of the share, with private companies owning the rest. The perceived success of this business model has attracted world's attention, and the Incheon U-City Corporation has been engaged as consultants for other countries aspiring to establish their smart cities. Minor hiccups, however, occurred in replacing single-purpose cameras detecting illegal parking to enable functioning as crime prevention as well. Duplications in sensor installation were also mitigated to rationalize between environmental and weather monitoring locations [23].

D. Singapore

As a city state occupying only 719 square kilometers, having a population of around 5.6 million comprising over 39 percent of non-citizen residents, Singapore pays particular attention to maintaining security and social harmony. The installation of surveillance cameras across the city has helped to reduce urban crime rate. It was reported by the media that since 2012, more than 430 cases were solved in public housing estates where the cameras are installed, and crucial information was provided for 890 crime investigation cases [24].

Singapore's e-government portal has also earned good reputation by having 9 out of 10 citizens being satisfied with the quality of e-government services, with intention to recommend them to others, according to a survey report [25].

E. Spain

Since 2009, Barcelona has begun its plan for establishing an intelligent city, which was later reinforced by the mobility, e-government, smart city, systems of information and innovation (MESS) strategy in pursuance of the Europe 2020 direction.

As a city of 101 square kilometers housing 1.6 million people, Barcelona is now connected by over 375 km of internet cables and covered by countless wireless sensors making its urban management an efficient task. Uses range from trash collecting resources allocation for optimizing routes and frequency to smart irrigation. In terms of green infrastructure, Barcelona has become one of the most densely installed photovoltaic cities in Europe since 2006. Electric vehicles can now be charged throughout the city. With the use of thousands of LED-lit street lamp furniture, the municipal energy consumption was reduced by one-third.

Although the city has been hailed as one of the most prominent exemplars of smart cities, its city management does not regard it a testing ground for trial of new equipment and gadgets. Instead, they are proud of the city progressing on the smart city frontier step by step, starting from small projects and

moving towards bigger goals according to plans aiming at long-term operability [26].

IV. The Scenario of Public-Private Partnerships (PPP)

Some of the above cases feature the joint efforts made by the government and private companies in the establishment and/or operation of smart cities to a varying extent. Since governments are used to providing standard public services from the use of taxpayers' money, often they are constrained in spending extras on innovations or taking additional risks to bring pilot schemes to operation at scale, especially if the improved services entail some cost on the part of public users. Private sector entities have more diverse funding channels and they are more willing to take on commercial risks with an expectation of sufficient returns on their investment. They may also have better access to market trend information and can adopt more flexible approaches in management. Hence, synergy may result in public-private partnerships, which often are not available by the public sector going about smart city development on its own.

In most developed countries, the existing ICT market is usually led by private corporations and they are eager to promote their new technologies and eye on the public sector market. In the situations of developing economies, public sector funding sources may be limited, whilst the adoption of ICT will almost certainly accelerate the economic development of the countries seeking growth. For smart city applications which often involve the capturing of public users' data, monitoring by participating authorities adds to the users' confidence.

From the users' cost and benefit perspectives, private sector involvement would change the balance of values, which need to be carefully evaluated right at the inception stage of smart city projects. For example, whilst risk and technology transfers are enabled, price setting and competition are sensitive issues to avoid the pitfalls of perceived monopoly and collusion. The lower parts of Figs. 1 and 2 show the possible factors in terms of direct and indirect costs/benefits to be considered before engaging in public-private partnerships. Based on the possibility of commercial value creation, links to different groups of smart city projects are also depicted to demonstrate PPP applicability.

V. Conclusion

This paper sets out the costs and benefits associated with smart city projects as grouped by their nature. Through five carefully selected case studies, these attributes have been illustrated and classified as direct and indirect as to their effects. Whilst direct costs and benefits are measurable, indirect ones are often intangible, making CBA a challenging art in economic studies.

The case studies also illustrate the common use of public-private partnerships, which change the cost/benefit balance but often result in synergy if properly planned and implemented.

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