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A system dynamics model to evaluate effects of source separation of municipal solid waste management: A case of Bangkok, Thailand

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ABSTRACT

Municipal solid waste has been considered as one of the most immediate and serious problems confronting urban government in most developing and transitional economies. Providing solid waste performance highly depends on the effectiveness of waste collection and transportation process. Generally, this process involves a large amount of expenditures and has very complex and dynamic operational problems. Source separation has a major impact on effectiveness of waste management system as it causes significant changes in quantity and quality of waste reaching final disposal. To evaluate the impact of effective source separation on waste collection and transportation, this study adopts a decision support tool to comprehend cause-and-effect interactions of different variables in waste management system. A system dynamics model that envisages the relationships of source separation and effectiveness of waste management in Bangkok, Thailand is presented. Influential factors that affect waste separation attitudes are addressed; and the result of change in perception on waste separation is explained. The impacts of different separation rates on effectiveness of provided collection service are compared in six scenarios. 'Scenario 5' gives the most promising opportunities as 40% of residents are willing to conduct organic and recyclable waste separation. The results show that better service of waste collection and transportation, less monthly expense, extended landfill life, and satisfactory efficiency of the provided service at 60.48% will be achieved at the end of the simulation period. Implications of how to get public involved and conducted source separation are proposed.

1. Introduction

Municipal solid waste (MSW) is regarded as unwanted materials to be disposed of. MSW relates to a broad array of issues, such as social, economic, environmental, technological, and legislative. It has been considered to be one of the most immediate and serious problems confronting urban city in most developing and transitional economies (UN Habitat, 2010). Currently, the world approximately generates 1.3 billion tonnes of MSW a year and is expected to increase to 2.2 billion tonnes by 2025 (World Bank, 2012).

Municipal solid waste management (MSWM) is one of the municipal services that should be effectively and equally provided to all residents to make them reach adequate well-being. Having been considered as a serious problem confronting urban government, provided solid waste performance highly depends on the effectiveness of waste collection and transportation process, a contact point between waste generators and waste management systems. The process is one of the costliest urban services in developing countries, where local authorities spend 20–50% of their budget on this service (UN Habitat, 2010).

Waste separation at source is subjectively done by individuals collecting recyclable or compostable materials from commingle and placing them at the disposal locations at their household for collection. The main purposes of source separation are recycling, reusing, and reducing environmental as well as economic burdens to the MSWM systems (Lardinois and Furedy, 1999). The major impact on effectiveness of MSWM system comes from the separation of waste causing essential changes in the quantity and quality of waste reaching final management process or waste treatment and disposal (World Bank, 2012).

Waste separation is considered as human attitudinal ambivalence on MSWM. It is subjective expressing by evaluation of a

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specific entity with different degree of favor or disfavor (Eagly and Chaiken, 1993). Factors that affect human attitudes are habit, attitudes toward target, punishment or reward, social norms, and self-identified outcomes. Perception of waste separation is influenced by many factors, among many of them, incentive based (i.e. cash, vouchers, discount coupons, and goods) and knowledge based (i.e. types of recyclables, importance of effective MSWM system, public benefits, and environmental education) factors are the potential ones (OECD, 2012; Shirahada and Fisk, 2014).

A great deal of research in recent years has evolved to adopt decision support tools to design management systems. Optimization models have widely been used as supporting tools offering a static optimization for selecting the best system. Najm and El-Fadel (2004) emphasized the importance of optimization models for waste management by assessing the importance of user-friendly software tools.

System dynamics (SD) modeling is one of the optimization supporting tools offering a useful modeling approach as it can comprehensively model the dynamic behavior of all processes among all involved variables. In MSWM, SD models can be used for assessing real situation, which simulation is a technique used to study cause-and-effect interactions of different variables on the performance of a closed-loop chain (Ilgin and Gupta, 2010). SD features allow modelers to model feedback loops, time delays, and both linear and non-linear interactions of variables in all processes in the integrated waste management in the real world situation. Over the past decades, the applications of SD have been prevalent in studies covering a wide array of disciplines, such as MSWM systems in the Netherlands and India (Yücel et al., 2008); business system (Sterman, 2000), environmental sustainability (Kunsch and Springael, 2008), strategic management (Warren, 2005), decision-making systems (Nail et al., 1992), and environmental impact assessment (Vizayakumar and Mohapatra, 1993).

The prediction of municipal solid waste generation plays an important role in MSWM. In Mashayekhi (1993), SD models consisted of qualitative aspects on waste generation and separation of recyclable waste at source to analyze the impacts of transition from landfill to other methods of waste disposal. The models have been used as a basis for forecasting MSW generation and planning sustainable MSWM in developing countries (Hao et al., 2007). Wang (2001) developed a model to deal with integrated waste management system focusing on MSW generation, collection and transportation system and its associated economic and environmental impacts. Dyson and Chang (2005) simulated five different models presenting useful results for associated MSWM system planning with future generated quantities of MSW, site selection, cost assessment, and capacity planning of MSW. The prediction of MSW generation model of Sufian and Bala (2007) showed potential to be used in the assessment of treatment facilities to achieve a desired environmental quality improvement. Apart from being used as a tool to support MSWM policy analysis, by means of SD, the results have shown that MSWM models provide a better understanding of dynamic interactions and interdependencies of key concerns of MSWM processes.

This study is, therefore, carried out to develop a comprehensive model that envisages the dynamic relationships between source separation and effectiveness of MSWM in Bangkok by applying the SD approach. The detailed objective of the study is to identify essential variables for MSW collection and transportation that would support the management system toward a more effective and efficient municipal service. The study also aims to compare impacts of source separation on effectiveness of waste collection and transportation service provided by the Bangkok Metropolitan Administration (BMA) in different scenarios.

2. Literature review

2.1. Source separation of MSWM

Source separation of waste is subjectively done by individuals collecting recyclable or compostable materials from commingle, sorting them into types at the place where the waste is generated, and putting them into different containers for collection (Rousta et al., 2015). The main purposes of source separation are recycling, reusing, and enhancing MSWM service (Lardinois and Furedy, 1999). It has become a successful front-end waste management method that leads to increase in collected recyclable waste and decrease in the amount of waste to landfill. Not only does a large amount of sorted waste will be recycled, but also a substantial amount of landfilled household waste can be recovered in various forms such as energy recovery or compost.

Public participation plays a major role in source separation process as the participation simplifies further management processes, namely collection, transportation, treatment, and disposal. For MSW source separation, sustainable public participation is the profound of successful MSWM (Dhokhikah et al., 2015). However, public participation in conducting waste separation is considered as human attitudinal ambivalence on MSWM, which is subjectively expressed by evaluation of a specific entity with different degree of favor or disfavor (Eagly and Chaiken, 1993).

Government authorities around the world aim to achieve an increase in correctly sorted recyclables and a decrease in missed-sorted waste. Accordingly, factors that affect quantification and qualification of sorted waste at source are needed investigation. Previous researches show that influential factors are recycling behaviors of residents (Hornik et al., 1995); socio-demographic issues (Barr et al., 2003); environmental concerns (Miafodzyeva and Brandt, 2013); and convenience (Bernstad, 2014).

Researches have proved that source separation is an effective waste management method that enhances waste reduction to landfill and increases recyclables amount (Boonrod et al., 2015). It has been widely used in developed countries to strive for sustainable MSWM (Rousta et al., 2015; Tai et al., 2011). Developing countries have applied the method as an element of integrated waste management system in pilot source separation programs in potential cities (Tai et al., 2011). However, cities in developing countries find that a low volume of incoming sorted waste is caused by a lack of public participation and understanding of the importance of waste separation at source (World Bank, 2012; Boonrod et al., 2015), outdated laws and regulations and unavailability of facilities and infrastructures (Sukholthaman et al., 2015), a lack of market for recyclables (Belton et al., 1994), and inconsistent of waste separation campaigns (Miller Associates, 1999).

Therefore, to evaluate the impact of source separation on waste collection and transportation, this study adopts a decision support tool to comprehend cause-and-effect interactions of different variables in MSWM system. As a result, the relationships of source separation and effectiveness of MSWM are envisaged.

2.2. Municipal solid waste management (MSWM) in Bangkok

Bangkok is the capital city of Thailand and one of the world's megacities. The city's features as being institutional and financial center for both private and public sectors have attracted people to come and earn their living temporarily or permanently. The city is the 69th largest province among all 77 provinces of the country (NSO, 2014). However, including non-registered population, Bangkok has about 8,937,000 people living in (Bangkok Statistics Report, 2014; CPD, 2015). In terms of land area, the city of Bangkok