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Synthesis of multiple biomass corridor via decomposition approach: a P-graph application

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ABSTRACT

The increase of the global population has a negative impact to the environment due to the direct correlation between the amount of solid waste generated and the population growth. In order to create a more sustainable future, an adequate waste management system is necessary. Utilisation of biomass that have potential to be converted into various forms of valuable products (i.e. energy, biochemical and value-added products) is a promising way to deal with the increasing amount of agriculture residues. Therefore, it is suggested to develop a multi-biomass corridor in order to promote a global sustainable development of renewable energy. However, this large-scale problem normally consists of a huge number of variables (large set of possible locations of processing hub, large set of operating units and large set of material involved). This will lead to a longer computational duration due to the high complexity of the network. In order to address this issue, a novel "Decomposition Approach" which integrates P-graph framework and conventional mathematical modelling is proposed in this paper. The presented approach is demonstrated via an actual case study in Johor. In this paper, the correlated cost function for the four main biomass in Johor (i.e. palm oil biomass, sugarcane bagasse, pineapple residue and paddy biomass) is formulated. On top of that, a multiple biomass supply chain which integrates three underutilised biomass into the palm oil biomass supply chain in Johor is synthesised successfully and efficiently as well. The result shows that about 82% of the overall variables in this case study are removed from the model after applying the proposed approach, causing a 50% reduction in the computational time. This indicates that the proposed approach is useful for real-world applications. However, regular revision on the model is recommended in order to assure the reliability of the result. In addition, this paper also outlines several potential extension works that can be conducted in future.

1. Introduction

The increase of the global population has a negative impact to the environment due to the direct correlation between the amount of waste generated and the population growth. Thus, a suitable waste management system is necessary in order to build a sustainable future. Agriculture residues (e.g. palm kernel shell, rice husk, sugarcane bagasse, etc.) are one of the major sources of biomass. Usually, biomass have the potential to be further converted into valuable products. Besides, biomass is also one of the most significant renewable energy sources (Duić et al., 2011). To date, there are many investigations on integrating supply chain networks have been conducted. However, only few have considered underutilized biomass (Duić, 2014). Therefore, it is suggested to develop a multiple biomass corridor which integrates underutilized biomass into the existing biomass supply chain in order to promote a global sustainable development of renewable energy. This multiple biomass corridor concept is firstly introduced by Ng et al. (2012). It is defined as "*a conceptual zone which connects the facilities from biomass harvesting stage to the product delivery stage*". In other words, it involves the systematic of green supply chain (GSC) network refers to a predefined zones that consist of sources of different biomass (supply), processing hubs where biomass are converted into other value-added products and also the final destinations (demand) where the products should be sold to. Unlike other countries which the biomass industries are well-developed,

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distributed and unlikely to be repositioned, the biomass industry in Malaysia is still at the initial level. Hence, the concept of biomass corridor may act as a management and planning guideline for the Malaysia biomass industry (Ng et al., 2012).

Malaysia is the world second largest producer of palm oil around the world. It contributed 39% of the world production and 44% of world oil export (MPOC, 2014). With such amount of palm oil production, the amount of palm oil biomass is also tremendous. It was estimated that for each kg of palm oil generated, approximately 4 kg of waste residue produced (Abdullah and Sulaiman, 2013). The palm oil biomass includes empty fruit brunch (EFB), palm kernel shell (PKS), fronds, trunks, etc. Currently, the wastes are commonly used as fuel stock in palm oil mill operations. Apart from that, these biomass wastes can be used as fermentation feedstock to produce several value-added products or energy sources, e.g. ethanol from empty fruit bunch (Sudiyani et al., 2013), bio-gas from oil palm frond (Srimachai et al., 2014), acetone from palm oil mill effluent (POME) (Al-Shorgani et al., 2012), energy pack from palm kernel shells (Ng et al., 2014), etc. Besides, paddy is another commodity in Malaysia as rice is an important dietary carbohydrate. According to the Department of Agriculture Malaysia, paddy planted area throughout Malaysia is estimated to be 674,332 ha while the average paddy yield is around 3.879 ton per hectare (DOA, 2014). The cultivation of rice results in two types of residues, i.e. paddy straw and rice husk. Both have attractive potential in term of energy due to their high energy content, i.e. 15.09 MJ/kg and 15.84 MJ/kg respectively (Lim et al., 2012). Besides, the silica ashes derived from rice husk (Kartini, 2011) and paddy straw (Munshi et al., 2013) can be used as renewable pozzolanic additive in cement paste. However, there is still limited commercial building systems have been developed using these materials on large-scales. Instead, these paddy wastes are commonly used in mineral mix for composting (Theeba et al., 2012). Other than that, sugarcane is another important agriculture crops in Malaysia. The production of sugar from sugarcane yields vast amount of biomass in the form of molasses, vinasse and bagasse. In the past decades, the lignocelluloses residues (e.g. bagasse) are converted into furfural as renewable substitute for synthetic resins (Uppal et al., 2008). Recently, sugarcane wastes can be converted into second generation ethanol (Cardona et al., 2010), paper paste (Pattra et al., 2008), etc. Furthermore, pineapple wastes are another potential biomass which can be converted into value-added product. Occasionally, these wastes are utilised as fertiliser or animal feed (Lim and Matu, 2015). The recent research has proven that dehydrated pineapple by-products will increase the digestibility of animals which eventually lead to an increment in the animals' weight (Costa et al., 2007). In short, the increase interest in biomass waste utilization not only reduces the environmental impact and also creates more business opportunity in Malaysia (Lam et al., 2010).

The determination of optimal structure in supply chain (including transportation design, process facilities selection, process hubs location and biomass allocation) is referred to the process network synthesis (PNS). Recently, many techniques and approaches have been proposed and applied in order to solve these kind of complex combinatorial problems. Generally, it can be classified into three types, i.e. mathematical modelling, multi-agent technology and heuristic algorithm. In mathematical modelling, the problem will be represented by a mixed-integer programming (MIP) or mixed-integer linear programming (MILP). The main benefit of using traditional mathematic programming is that the optimum solution can always be found. Several researchers have implemented this technique in solving the supply chain problem. For instance, Petrovic et al. (1998) proposes a supply chain fuzzy model to analyse the behaviour of a serial supply chain in an uncertain environment; Yan et al. (2003) proposes a strategic production-distribution model to solve the supply chain design problem; Chen and Lee (2004) proposes a multi-product, multi-stage and multi-period scheduling model to solve the multi-echelon supply chain synthesis problem; Liang (2006) develops an interactive fuzzy multi-objective linear programming method to solve the transportation problem in supply chain; Seifert et al. (2012) introduces a mathematical model which able to solve the three-echelon supply chain problem; and Ng et al. (2013a,b) develops a mathematical model to solve the synthesis problem of a rubber seed supply chain. However, these methods usually applicable for problems of relatively small or moderate size due to the huge computational time. Therefore, it is less capable to solve the real-time optimisation of large-scale problem (Turan et al., 2012). Multi-agent technology is another common technique which firstly introduced by Swaminathan et al. (1998). By using this technique, supply chain is structured as a library of structural elements (i.e. production and transportation) and control elements (i.e. flow, inventory, supply and demand). All of them are represented by agents that interact with each other in order to determine the optimal configuration. The major strength of this technique over the conventional mathematical modelling is its flexibility. It is able to interpret new information from time to time, allows information exchange between agents (Ahn et al., 2003). The researchers who applied this technique to supply chain synthesis problem include: Guillén et al. (2005) applies an agent-oriented simulation system to model each entity in supply chain as an independent agent; Zhang et al. (2006) proposes an agent-based approach to integrate, optimise, simulate, restructure and control the supply chain dynamically and cost effectively; Hanafizadeh and Sherkat (2009) develops a multi-agent based model to tackle the distribution and allocation problems in supply chain; and Fu and Fu (2015) introduces an adaptive multi-agent system to improve the cost collaborative management in supply chain. In spite of the aforementioned benefit, finding an appropriate methodology to coordinate the agents is still a major challenge. In order to overcome the coordination problem faced by multi-agent technology, several heuristic algorithms have been developed, e.g. genetic algorithm (GA), ant colony optimisation (ACO) algorithm, bees algorithm (BA), etc. To date, researchers have implemented these techniques to solve the single-objective and multi-objective optimisation problem in production and operational management which are NP-hard. For instances, Gen and Syarif (2005) proposes a spanning tree-based GA to solve the production and distribution problem in supply chain with the aim of minimising the cost; Pasandideh et al. (2015) introduces two modified GA (non-dominated sorting GA and non-dominated ranking GA) to solve the multi-product, multi-period three echelon supply chain problem; Wang (2009) proposes a two-phase ACO to solve the multi-echelon defective supply chain network design; Cheng et al. (2015) develops a modified ACO to solve the scheduling problem for the production in supply chain; Mastrocinque et al. (2013) introduces BA to solve the multi-objective supply chain model with the aims of minimising the total cost and total lead time; and Yuce et al. (2014) develops an enhanced BA with adaptive neighbourhood search and site abandonment strategy to solve the multi-objective supply chain model. However, a heuristic solution can be very far from the global optimum due to the nature of approaches (Heckl et al., 2015).

In early 1990s, Friedler et al. (1992a,b) introduced P-graph framework for PNS problems. It has been implemented in the systematic optimal design, including industrial processes synthesis and supply chain network synthesis. Generally, P-graphs are bipartite graphs which have nodes for materials, nodes for operating units and arcs that describe if a material is an input or output of a given operating unit. The framework has to satisfy five axioms, i.e. (i) every demand is represented in the structure; (ii) a material