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Functional modeling for green biomass supply chains

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ABSTRACT

The biomass supply chain is a multiple-segment chain characterized by prominent complexity and uncertainty, and as such, it requires increased managerial efforts as compared to the case of a single operation management. This paper deals with the supply chain management of green (e.g. grass) biomass. Specifically, three different supply chain systems, in terms of machinery configurations, were analyzed and evaluated in terms of task times and cost performance. By using a functional modeling methodology, the structural representations of the systems, in terms of activities, actions, processes, and operations, were generated and implemented by the ExtendSim® simulation software. It was shown that the models can identify the bottlenecks of the systems and can be further used as a decision support system by testing various alternatives, in terms of the resources used and their dimensioning. Finally, the models were evaluated against the sensitivity on input parameters which are known with a level of uncertainty, i.e. the expected yield and the expected machinery performance.

1. Introduction

The biomass supply chain is a multiple-segment chain characterized by prominent complexity and uncertainty, and as such, it requires increased managerial efforts as compared to a single operation management. In its full extent, biomass supply chain includes the production of biomass, harvesting and in-field handling, transportation (occasionally, inter-mediate transportation, inter-mediate storage, and additional transportation), pre-treatment, storage, and conversion, while some times the storage and distribution of the generated bioenergy also is connected to the biomass supply chain (An et al., 2011). To that effect, numerous studies have been dedicated to analyze and elaborate planning approaches associated with the different segments of this specialized supply chain, including approaches for the initial network design (e.g. Zhang et al., 2012; Mafakheri and Nasiri, 2014; Rentizelas et al., 2014; Grigoroudis et al., 2014), biomass storage planning (e.g., Rentizelas et al., 2009; Ebadian et al., 2013), and different planning levels such as operational (e.g., Zhang and Hu, 2013), tactical (e.g., Bochtis et al., 2012; Shabani et al., 2014), and strategic levels (e.g., De Meyer et al., 2015).

A specific characteristic of biomass supply chains is that the upstream decisions affect the subsequent links of the chain. On the other hand, the selection of biomass processing technologies, and the size and location of the conversion plant determine the type of all preceding operations (De Meyer et al., 2015). This characteristic is attributed to the fact that the delivered biomass must fulfill specific requirements in terms of timeliness for delivering, quantity, quality, and desired shape and size of the delivered product (Iakovou et al., 2010). Furthermore, the upstream segments should be robust and flexible in order to adapt to the uncertainties inherent in the biomass supply chains (Kim et al., 2011). Consequently, the availability and configuration of different systems and the operational efficiency of field operations (e.g. harvesting and handling of biomass) are key factors within the biomass supply chain.

In order to increase operational efficiency, improved methods and managements tools are required. This requirement is especially important in complex production systems which involve large scale operations. During large scale harvesting, where biomass is used as a bioenergy resource, a number of sequential tasks are executed which depend on different factors, such as the type of biomass (plant residues, grass, or grain), the moisture content, and the final usage of the biomass. The duration of the tasks is based on factors such as machinery and labor availability, machinery capacity, and agronomical factors. Advanced management models are required, such as fleet management tools for operations of multiple machines in multiple fields (Sørensen and Bochtis, 2010; Orfanou et al., 2013; Bochtis et al., 2013), in order to analyze the process and understand the inner working elements and interconnections.

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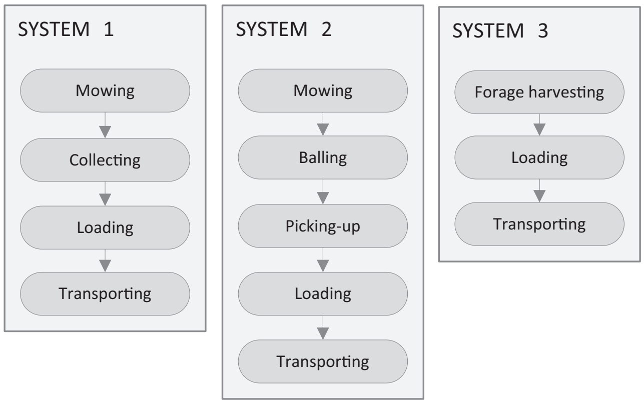

Fig. 1. The three examined biomass supply chain systems and the involved operations.

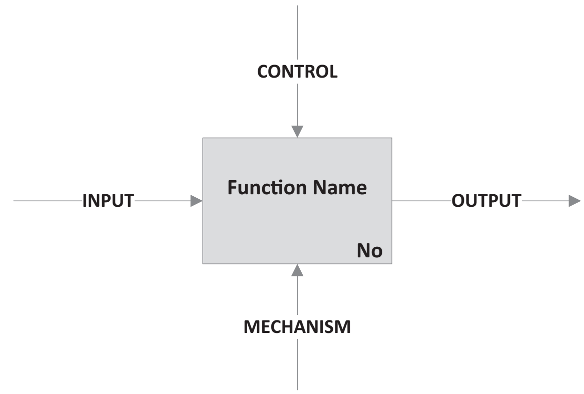

Fig. 2. The basic syntax of an IDEF0 model.

This paper deals with the operations management within the supply chain of green (e.g. grass) biomass. Specifically, three different supply chain systems, in terms of machinery configuration, are analyzed and evaluated in terms of task times and cost performance. By using a function modeling methodology, the structural representations of the systems, in terms of activities, actions, processes, and operations, are generated. Based on this modeling approach, three individual simulation models are built and implemented by the ExtendSim® (Imagine That Corporation, San Jose, CA, USA) simulation software. Finally, a sensitivity analysis is performed in order to assess the impact of the uncertainty of the yield and machinery productivity on the simulation models output.

2. Methodology

2.1. Systems description

The three examined systems of biomass supply chain are shown in Fig. 1. Systems 1 and 2 regard chains where the cut biomass is subjected to in-field and physically drying prior to its transportation to the process facility (bio-energy generation plant or any intermediate storage facility). System 3 regards a supply chain system of wet biomass where the biomass is cut and transported directly to the designated location with high moisture content without any prior in-field drying.

2.2. Modeling of the work process

For modeling the process of the tasks and operations in the previously described three systems, the IDEF0 (Integrated Computer Aided Manufacturing definition for Function Modeling) modeling scheme was implemented. IDEF0 is a function modeling technique for the analysis of manufacturing functions and the description of the workflows as an ordered sequence of events and involved objects. IDEF0 has been implemented to describe processes in supply chains of agricultural products, such as grain supply chains (Thakur and Hurburgh, 2009; Busato, 2015) and vegetable supply chains (Hu et al., 2012), and processes in agricultural production systems (van ‘t Ooster et al., 2013). The IDEF0 diagram follows a

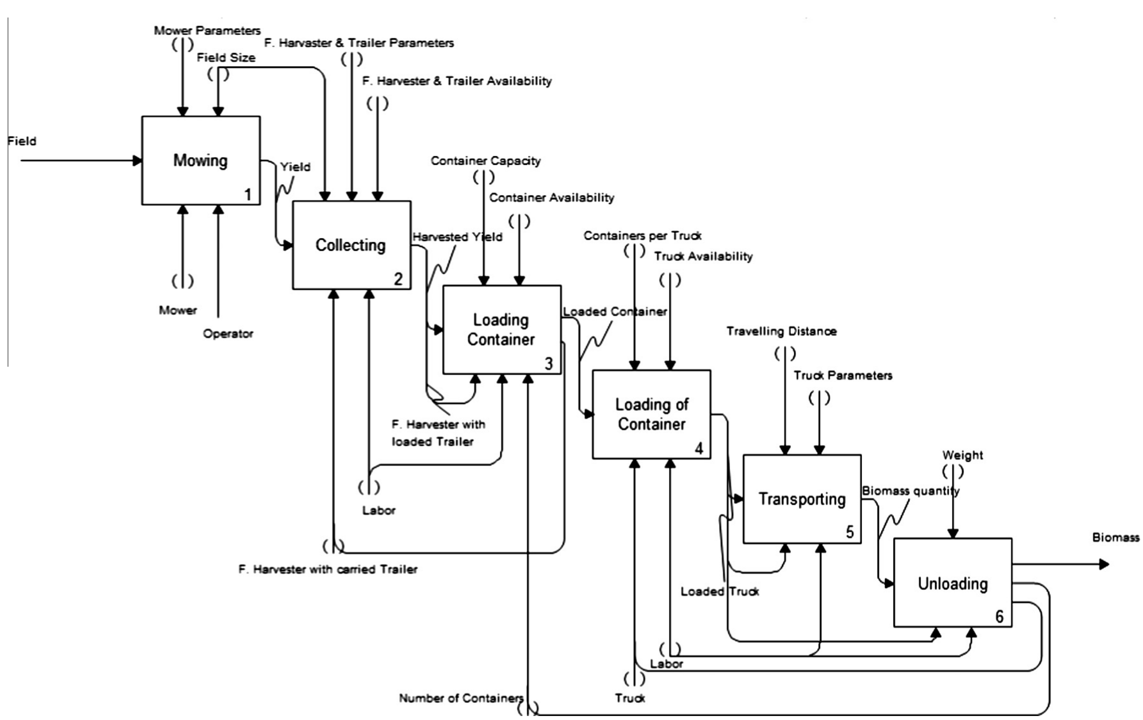

Fig. 3. The IDEF0 architecture of a system 1.