Efficiency Assessments for a Biomass Harvesting and Handling System

Anna Orfanou[1], Dimitrios Pavlou[2], Dionysis Bochtis[3]

[1]Department of Engineering, Aarhus University, Denmark, e-mail: annaorf@yahoo.gr
[2]Department of Engineering, Aarhus University, Denmark, e-mail: dmpavlou@gmail.com
[3]Department of Engineering, Aarhus University, Denmark, e-mail: dionysis.bochtis@eng.au.dk

Abstract. A simulation model, which depicts the harvesting operation of biomass supply chain, is presented in this paper. ExtendSim8 simulation software was used for the development of the model. There are a number of sequential operations, i.e. mowing, drying, baling, picking-up, loading, and transporting, for harvesting biomass until the final product arrives at bio-energy generation plant. Different scenarios, in terms of the operational system configuration, are analyzed in order to show how the operational time and cost are affected.

Keywords: Biomass supply chain, harvesting operations, simulation model, optimisation.

1 Introduction

The interest in new and renewable energy has been increased over the years because of the limited fossil fuel resources and the related caused environmental problems, such as atmospheric pollution. (Goldenberg, 2000; Richardson and Verwijst, 2007) Biomass utilization is important for energy production (McKendry, 2001; Veringa, 2006), such as electricity, heat and biofuels. The use of biomass is expected to be significantly increased in the future (Berndes et al., 2003; Yamamoto, 2001; Jager-Waldau and Ossenbrink, 2004), which is a great opportunity for agriculture, although there should be efficient ways for retrieving it from the field in order to maintain the operational cost at reasonable level (Sambra et al., 2008). Improvements in biomass supply chain should be done for minimizing not only the cost but also the time consumption. The demand and the use of biomass can be increased by several ways, such as new conversion technologies, better planning and handling systems etc. (Sambra et al., 2009).

New and improved ways are required for increasing the operational efficiency of agricultural operations especially in complicated production systems (Sørensen and Bochtis, 2010). Advanced management models, such as fleet management tools for operations of multiple machines in multiple fields are required in order to analyse these processes (Sørensen and Bochtis, 2010; Orfanou et al., 2011). Simulation

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models of a biomass supply chain are important for making the process more efficient by examine different parameters that can affect the process.

This paper refers to a simulation model of biomass supply chain, which consists of the operations of mowing, drying, balling, picking up, loading, traveling and unloading as it is shown in Fig. 1. The purpose of building the simulation model was for demonstrating the process of biomass supply chain and showing how different parameters can affect the whole process in terms of time and cost.

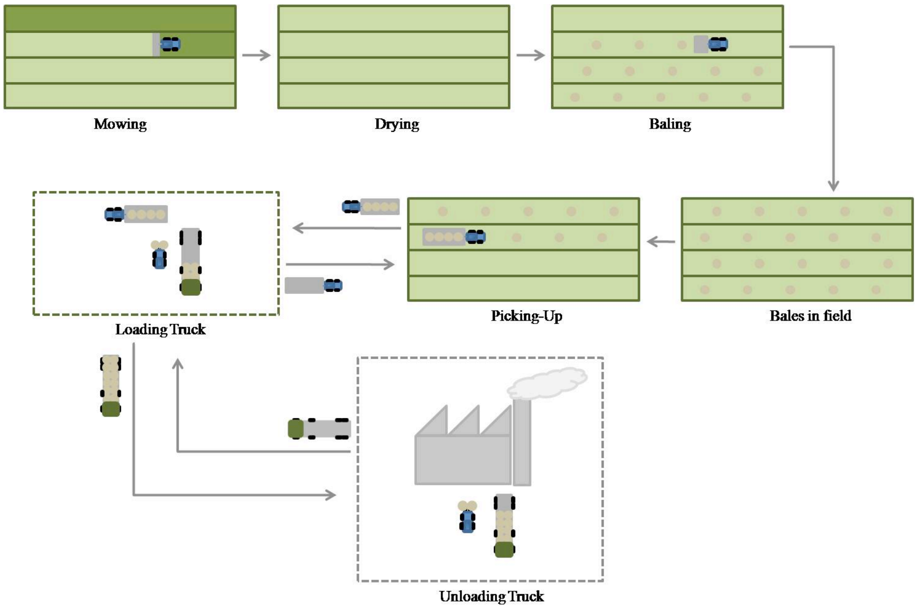


Fig. 1. Graphical representation of the biomass supply chain

2 Materials and Methods

A simulation model was created by using ExtendSim8 simulation software. A number of blocks were utilized for representing biomass supply chain. The activities (i.e. mowing, baling, loading, unloading, transportation) and resources (i.e. machines, labor) are represented by the blocks of *Item* library. The blocks that belong to *Value* library were used for importing data (inputs), making equations and taking decisions (e.g. to start an operation when the previous one is terminated). Furthermore, the blocks from *Plotter* library were used for the graphical representation of the results.

The inputs are separated into field data (e.g. field area, yield, etc.), machinery data (e.g. number and capacity of the machines in each task, etc.), and cost data (labor, fuel cost, etc.). The output of the simulation process provides the total time and the variable cost of the harvesting process according to different operational scenarios and a range of travel distances between the field and the bio-energy generation plant. It shows also the identification of different bottlenecks for pick-up machine and truck in each scenario.

The architecture of the model is presented in Fig. 2. Every box in the diagram represents an activity and the constrain parameters of it. Inputs and outputs are presented by arrows on the left and on the right of each box respectively. The physical aspects of each activity are shown by the arrows at the bottom of each box.

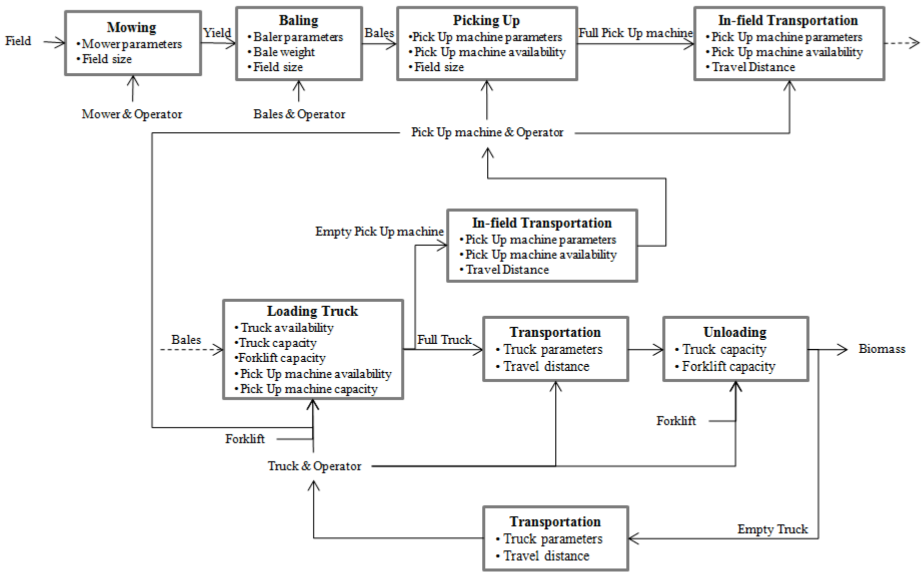


Fig. 2. Architecture of the simulation model

3 Implementation

In the presented case study, it is shown a harvesting process of crops for bio-energy production purposes. Mowing, baling, picking up, loading truck, transporting, and unloading truck, are the sequential operations of the system. Table 1 shows the parameters of the selected machines. In a field of 5 ha, different parameters of distance (5 km, 15 km and 25 km), number of trucks (1 and 2 trucks), and capacity of each truck (34 bales, 48 bales, 62 bales) were examined.

Table 1. Machinery Parameters

Machines	Repair factors[a]		List Price[b] (€)	Fuel Cost (€/h)	Accum .Use (h/y)	Productivity (min/ha)	Capacity	Travel speed (km/h)
	RF1	RF2						
Tractor (150 hp)	0.003	2.0	60,000	-	1,000	-	-	-
Mower	0.44	2.0	15,000	11.89	400	42.00	-	-
Round Baler	0.43	1.8	32,000	14.18	400	65.00	-	-
Pick-Up	0.16	1.6	34,000	13.03	400	62.00	18	15.0
Forklift	0.40	1.7	9,000	8.46	400	17.86	2	
Truck	0.003	2.0	110,000	Full: 17.92 Empty: 12,46	1,750	-	48	51.5

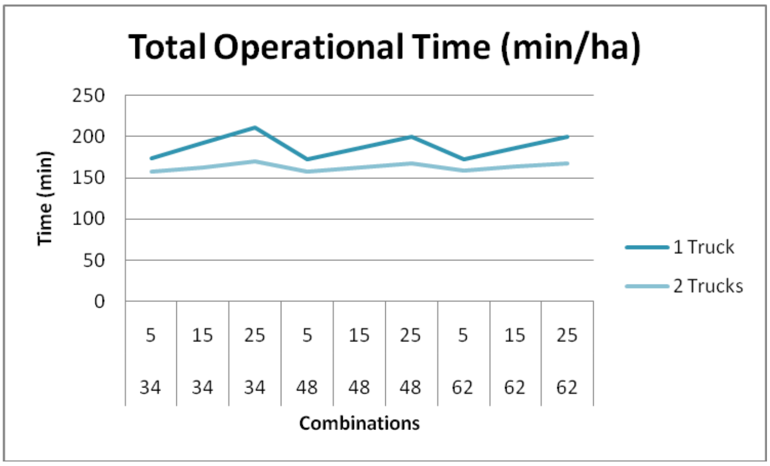
a: ASAE D497.5 (2006), b: DAAS (2011)

Table 2. Tested Scenarios for biomass supply chain

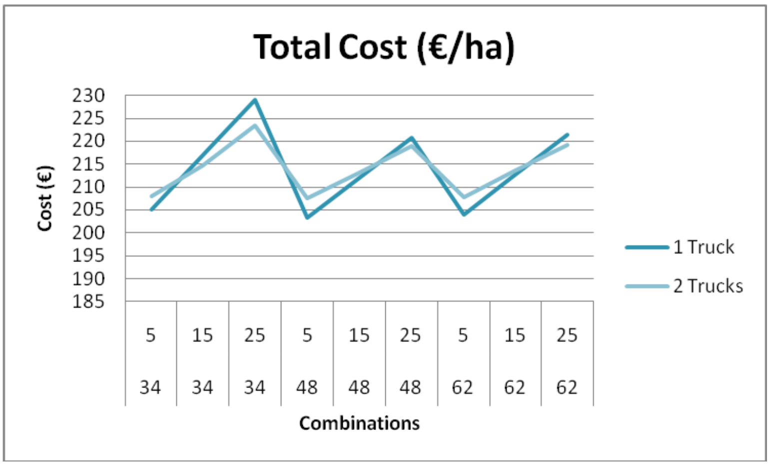
Number of Trucks	Capacity of each Truck (bales)	Travel Distance (km)
		5
	34	15
		25
		5
1	48	15
		25
		5
	62	15
		25
		5
	34	15
		25
		5
2	48	15
		25
		5
	62	15
		25

4 Results

Fig. 3 shows (a) the total operational time per ha and (b) the total cost per ha for the selected scenarios presented on Table 2. At the x axis (Combinations), the first row refers to the travel distances between field and bio-energy generation plant, while the second row shows the capacity of each truck.



(a)



(b)

Fig. 3. (a) Total operational time and (b) total cost of biomass supply chain

Table 3 lists the results of total dead time (bottleneck) of pick up machine and truck, total operating time and cost of the biomass supply chain, regarding specific scenarios (1-34, 1-48, 1-62, etc) in a field of 5 ha and travel distance between field and bio-energy plant of 15 km. The first number of the combination (1, 2) represents the number of trucks used in the process. The second number (34, 48, or 62) refers to the capacity (bales) of the truck. Fig. 4 shows graphically the total dead time of pick up machine and truck during the process for each combination.

Dead time is a stage in a process that causes a part of the process or the whole process to slow down or stop. The dead time of pick up machine is created when there is no available truck and the pick up machine waits for being unloaded. The dead time of the truck is created when the pick up machine collects bales from the field and the truck waits for being loaded.

Table 3. Dead Time, Total Operational Time and Total Cost

No Trucks-Capacity	Dead Time PU (min)	Dead Time Truck (min)	Total Time (min)	Total Cost (€)
1-34	153	139	964	1085
1-48	116	139	930	1060
1-62	130	139	930	1063
2-34	0	169	811	1074
2-48	0	173	814	1066
2-62	0	180	817	1067

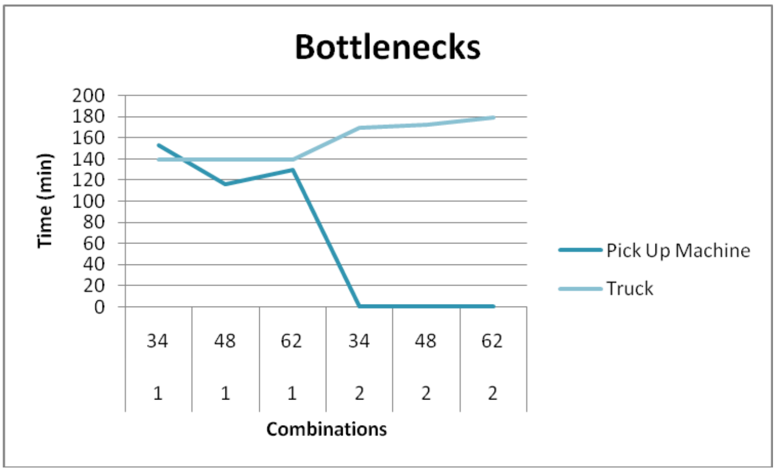


Fig. 4. Total dead time of Pick Up Machine and Truck by changing the number and/ or the capacity of the truck

5 Discussion

Fig. 3(a) shows that more time is consumed for biomass supply chain when one truck is used instead of two. This difference is greater in long distances (25 km) than in short distances (5 km). For stable travel distances, the increase of capacity after a certain point does not reduce the total operating time because even if the number of transportations is less, the loading and unloading time is increased. A solution could be more forklifts in use in both locations (field and bio-energy plant). Also, the capacity and/ or the number of pick up machines could affect the total operating time. It should be noticed that when two trucks of low capacity (34 bales) are used, less time is needed than in the case of one truck of high capacity (62 bales) for same travel distances. The period of absence of a low capacity truck is less than a high capacity truck, while at the same period the second truck continues the operation making the entire process faster.

As it is shown in Fig. 3(b), the total cost is higher in long distances (25 km) than short distances (5 km) for both cases. The biomass supply chain costs less in short distances when one truck is used and in long distances when two trucks are used. The cost is reduced when the capacity is increased, but when the capacity overcomes the optimal, then the cost is not reduced anymore (e.g. 62 bales capacity).

As it is presented in Table 3 and Fig. 4, in the case of one truck in use, the dead time of pick up machine is reduced as the capacity of the truck is increased from 34 bales to 48 bales. Although, when the capacity is increased to 64 bales the dead time is greater than the case of 48 bales capacity, because the truck of 64 bales capacity needs more time to be unloaded when it arrives to bio-energy generation plant delaying the activity of pick up machine. This implies that truck with high capacity does not always minimise the bottlenecks of an activity due to the interaction that capacity has to other parameters, such as unloading time.

By using two trucks in the process, the dead time of pick up machine reaches zero because there is always an available truck. However, the dead time of the truck is getting higher in comparison with the case of one truck because the second truck is always waiting for the first to be loaded and leave. As the capacity of the trucks becomes higher, the dead time of the trucks is increased because the second truck waits longer. For minimizing the dead time of a truck, increased number and/ or capacity of pick up machines should be used. Also, the total number of forklifts in use should be considered in both locations (field and bio-energy plant) in order the bottlenecks of the truck to be reduced.

By analysing Table 3, it occurs that higher dead time of a machine does not necessarily mean higher total operating time or cost. For long travel distances between the field and the bio-energy plant, when low capacity trucks are used, the process is more expensive because of the increased number of transportations.

6 Conclusion

A simulation model for biomass supply chain including the operations of mowing, baling, picking up, loading, transporting and unloading was created. Different scenarios concerning how the number and/or the capacity of the truck(s) can affect the process in terms of time, cost and bottlenecks were examined. The increased number and/or capacity of trucks make the process less time consuming but not always less cost consuming. Factors like the area of the field and travel distance should be considered for the best choice of number and capacity of the truck. However, the biomass supply chain can be more optimized in terms of time, cost and bottlenecks, if the number and capacity of pick up machine as well as the number of forklifts are taken into consideration.

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