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Algorithmic Efficiency Analysis of Harvest and Transport of Biomass

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Abstract: Since its energy density is low, an intensive use of biomass for the production of energy goes along, with high transport volumes. With modern biogas plants growing fast, logistic systems that master the large upcoming mass flows are getting more and more complex. Reliable planning tools do not yet exist. Therefore the organization of transport chains is usually based on empirical knowledge. As a consequence the efficiency in biomass logistics is often low. To be able to rate the systems that are used in practice with regard to their efficiency a method to evaluate the regarded systems has been developed at the chair of Agricultural Systems Engineering at the Technische Universität München (TUM). The underlying algorithm connects data of different machines and assigns specific jobs to certain periods of time. The results of this efficiency analysis can be used as input data to simulate agricultural transportation systems and form the basis of a systematic optimization of biomass logistics.
Key words: Agricultural logistics, efficiency analysis, mathematical modeling

INTRODUCTION

The use of biomass as resource for the production of energy is increasing all over the world. In Germany about 5 % of the demand for electric power is covered by renewable resources (Nickel, 2010). The electric power of German biogas plants is estimated at 2.5 GW for 2011 (Fachverband Biogas e.V., 2010). The supply of these biogas plants with biomass entails a significant logistical effort. This is especially true for the harvest of energy maize for the production of biogas, because enormous transport volumes have to be managed in a limited period of time. Due to the many factors of influence, which can hardly be estimated, the efficiency in biomass logistics is often low. Optimization approaches from commercial freight transports or sugar beet logistics can barely be adapted to the transport of biomass for energy production, because the underlying circumstances differ substantially. Thereby the main difference is caused by the fact that transport vehicles in biomass logistics are not loaded at stationary stocks but by an interaction of several machines.

To improve the economic and energetic efficiency in biomass logistics, the critical points in the systems have to be detected and analyzed. For this purpose an algorithmic evaluation method has been developed at the chair of Agricultural Systems Engineering at the Technische Universität München (TUM). It is based on GPS data of harvesting and transporting machines, combined with geographic information of the harvested fields and transport routes.

The recorded data are evaluated in a way that a specific job is assigned to each machine at each time step. The algorithm distinguishes between *on road, waiting, loading, unloading* and *interruption.* Thereby the position data of all machines of a harvesting process chain and geographic information about harvested fields and transport routes are combined by causal relationships. The degree of utilization of each machine can be visualized as a histogram that contains the relative time slices of the assigned jobs. A Gantt-Chart outlines the chronologic process of harvesting day. Furthermore it is possible to find out characteristic values and typical machine parameters of the regarded harvesting system such as average interruption rates or working and transporting speeds of the used vehicles. These parameters can be used as input parameters of optimization methods that are based on simulation algorithms.

MATERIALS and METHOD

The data basis of the developed method is formed by data recorded during the silage maize harvest 2010. On totally nine harvesting days measurement data were collected on three different Bavarian dairy farms and one biogas plant with an electric power of 500 kW. In the course of this all machines that participated in the harvest were equipped with GPS-data logger. The following data were recorded with a frequency of 1 Hz:

- GPS-time
- Current position (latitude and longitude)
- Altitude
- Velocity

It is an important component of the developed analysis method that real harvest process chains can be analyzed with an adequate technical effort and exposure of time. The decision to structure the metrology rather simple was made consciously in order to ensure as much flexibility as possible during the data logging. It is a basic aim of this method to be able to run measurements in practical field tests as plug and play systems. Because of that we did not install extra sensors e.g. in the braking system of a transporting unit to find out the loading level or connect our data loggers to the CAN-Bus system of the forage harvester. So the setup time for the data recording could be reduced to a minimum.

The data analysis is performed in three steps. First, the GPS coordinates have to be converted from WGS 84 into Gauss-Krueger. In this process, latitude and longitude are projected into a two-dimensional plane and thus transformed into an orthogonal coordinate system. Gauss-Krueger coordinates display the distance of a point to the origin of the selected zone in meters. Followings steps can be done much easier with Gauss-Krueger coordinates.

In the second step of the data analysis, the plausibility of the recorded data is reviewed. Control algorithms test the continuity of the recorded time steps and extract datasets that assign different positions to one single point of time. Furthermore, data sets that contain unrealistic position data as a result of irregularities in the GPS signals are filtered out.

In the third step, one of the jobs *on road, waiting, loading, unloading* and *interruption* is assigned to each machine at each point of time. The measured data are visualized dynamically in an applet that shows the time continuous progress of the harvest and the degree of utilization of each machine.

ALGORITHMS

Through causal connections a multilevel algorithm assigns a specific job to each machine of the harvest process chain at each point of time. Therefore the datasets of all machines are connected as well as additional geographic information is applied.

First the positions of harvested fields and the silo have to be specified with a geographic information system (GIS). For the silo, a central coordinate point is defined. The algorithm calculates the distance of each transporting unit to this central point at each point of time. If the distance of a transporting unit is less than a critical distance d_{crit}, the job *unloading* is assigned to the transporting unit in the relevant period of time. Thereby the value of d_{crit} depends on the vast extend of the silo area and has to be set according to the practical conditions.

To be able to identify the jobs of a machine on a field, as a first step it is decisive to know whether a vehicle is on a field at a specific point of time or not. In a preprocessing progress before the actual evaluation of the data, boundary lines of the harvested fields, which can be exported from a GIS program as polygons, are transferred into an appropriate matrix. Like that, the decision whether a vehicle is located on a specific field at a certain point of time is reduced to a multiplication of the matrix from the preprocessing and the vector with the current position data of the regarded machine.

The identification if or which transporting unit is currently loaded by the forage harvester depends on several aspects. A basic requirement for the loading process is that the forage harvester has to be located on a field, which is then denoted as current field. Furthermore, not more than one transporting unit can be loaded at certain point of time. The currently loaded transporting unit is denoted as current transporting unit. The algorithm has to check in each time step if certain admittance conditions are fulfilled to admit a transporting unit as current transporting unit. After the admittance, as long as this unit fulfills certain duration conditions, no other transporting unit can be considered as currently loaded unit. Then, the algorithm regards the velocity of the forage harvester. If the average speed of the forage harvester in ten seconds is more than 0.3 km/h and a current transporting unit is existing, the concerning period of time is considered as loading time for the forage harvester as well as for the transporting unit. If the average speed is below 0.3 km/h, the algorithm assigns interruption to both machines. The mentioned conditions of admittance and duration for transporting units are also constructed with multiple levels. First, a transporting unit has to be on the same current field as the forage harvester. Then, the algorithm calculates a fifteen seconds average distance between forage harvester and transporting unit. To fulfill the conditions of admittance or duration, the average distance value has to be smaller than a predefined value d_{admit} respectively d_{dur}. The value of d_{admit} is smaller than d_{dur}. The effect of this is that the admittance conditions to admit a transporting unit as currently loaded unit are rather strict. This means that the algorithm does not accept transporting units that temporarily pass by the forage harvester as current transporting units. Otherwise the comparatively weak duration conditions effect that the algorithm does not tend to reject currently loaded transporting units in case of irregularities in the GPS signals or turning operations.

Waiting periods are identified by the algorithm if a transporting unit is on the current field but not admitted as currently loaded transporting unit. The forage harvester is considered to be waiting if it is on field and no transporting unit is admitted as currently loaded transporting unit. Thereby the velocity has no influence on the decision, if a machine is considered to be waiting because in the practical field use, waiting transporting units often follow the forage harvester with low speed. Also the forage harvester does not always stand still while it is waiting. Sometimes the driver of the forage harvester drives to the beginning of the field to be able to start loading the next transporting unit rapidly or harvests single maize plants that have been missed on the worked part of the field.

Especially at the beginning of a new field, transporting units often do not wait on the field but close to it. The algorithm also identifies waiting periods as such if a transporting unit is located in a distance less than 100 meters and the average speed in ten seconds is less than 0.3 km/h.

Periods of time that are not identified as unloading, loading, waiting or interruption time are seen as driving on road. In particular if a vehicle stands still at street crossings or traffic lights, this is not considered as waiting time, but as part of driving on road.

RESULTS

The results obtained by the described algorithmic data analysis can be shown in various forms. A histogram is the appropriate visualization to get an overview of the rate use of each machine during a harvesting day. Figure 1 shows the different jobs of each machine in relation to the total working time. In this example, the forage harvester spends 8 % of the time on the road to get from one field to another. The on field waiting time of the forage harvester, when no transporting unit is available, comes to about 23 %, interruption time is 4 %. So the forage harvester is loading a transporting unit in about 65 % of the time. The transporting units spend between 56 and 62 % of the time on the road. Waiting time is between 10 and 23 %. The percentage of the unloading time for all transporting units is at about 13 %, while the loading time differs strongly with values from 6 to 16 %. This reflects the varying capacities of the used transporting units from 15 m^3 (TU 1) to 40 m^3 (TU 4, TU 4).

The chronological progress of the harvesting process can be visualized as Gantt-Chart (Figure 2). Different jobs are shown in different colors, referring to a time axis. Like that, for example the sequence of transporting units at the silo can be reconstructed visually. Especially in case of an interruption, a Gantt-Chart is helpful. The algorithm identifies an interruption in the system, if a transporting unit is located close to the forage harvester on a field, but the velocity of the forage harvester is close to zero. Without additional information, it is not possible to decide within an algorithm, whether the interruption is caused by the transporting unit or the forage harvester. Thus time periods are counted as interruption for both machines. The Gantt-Chart shows, which machines are involved in the interruption. As the case may be, one can see if one transporting unit is more often involved in interruptions than other.

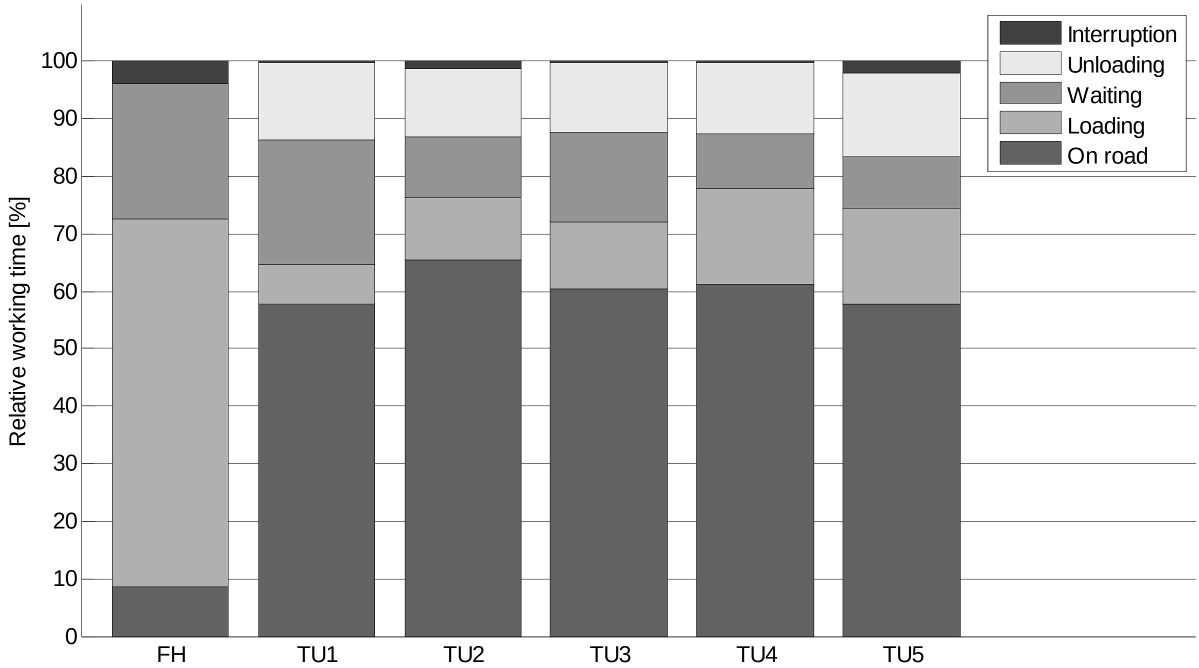

Figure 1. Relative working time proportions of a harvesting process chain with a forage harvester (FH) fife transporting units (TU1 ... TU5), silage maize harvest 2010

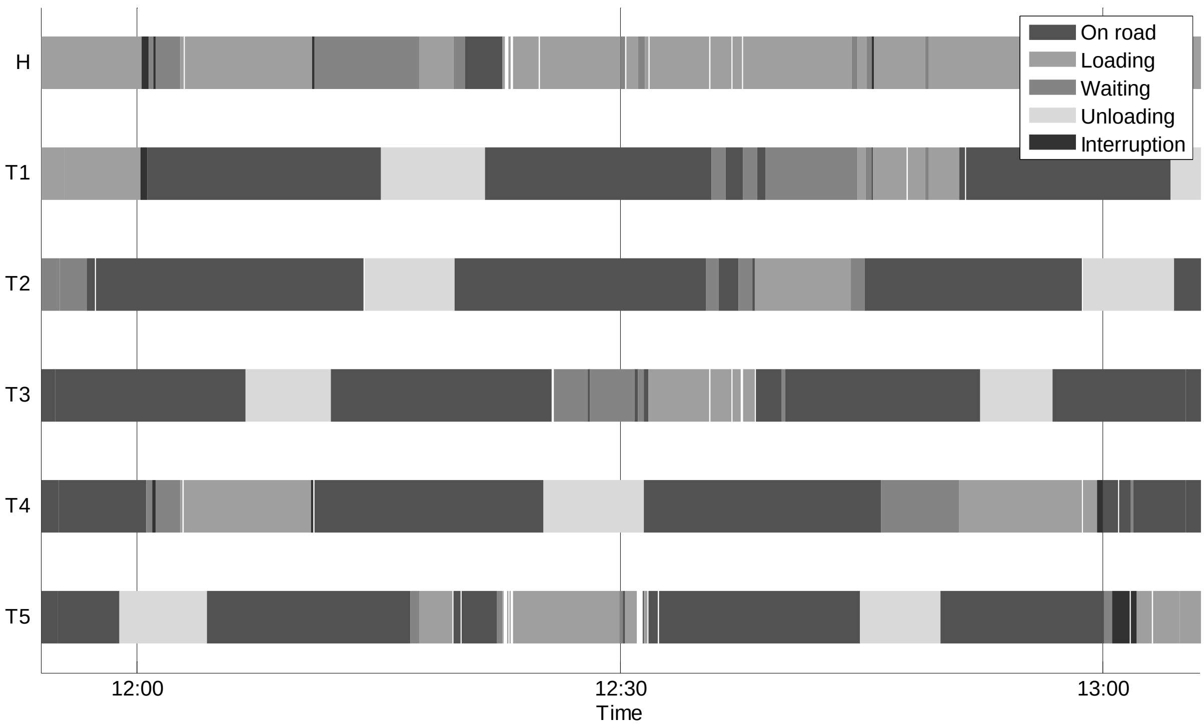

Figure 2. Gantt-chart of a harvesting process chain with a forage harvester and five transporting units, silage maize harvest 2010

Simulation based decision support systems, like the model developed by Johannes Sonnen (Sonnen, 2009), require input data about the regarded harvesting system to be able to analyze and optimize them. With the shown analysis method, it is possible to find out specific system parameters algorithmically, e.g. transport speed depending on the loading status of transporting units, working velocity on field or average interruption rates of a machine. This is based on the assignment of different jobs to each machine at each point of time.

DISCUSSION

An algorithmic analysis of a real process chain, as presented here, is based on a modeling that transfers real events to an analytic model, which makes decisions by logical causal conditions. By definition, modeling is a purposeful, simplified replication of a real system, which approaches it sufficiently (Sauerbier, 1999). Within the revision of the significance of the model, two different aspects have to be considered: for the purpose of the verification it has to be checked how far the conceptional modeling assumptions are implemented correctly in the algorithm.

The validation of the model examines, if the model assumptions reflect the real system sufficiently (Sauerbier, 1999).

As harvesting chains describe a complex real system, certain simplifications in the modeling process have to be accepted. Thus some jobs can not be assigned correctly by the algorithm. E.g. the analysis method identifies an interruption as such, if the forage harvester stands still on a field and a transporting unit is available. Interruptions that do not occur on a field or interruptions of a transporting unit that appear independently of the loading process can not be detected correctly. Under certain conditions, transporting units wait at the silo after unloading to get instructions for their next destination. Such waiting periods are seen as additional unloading time with this analysis method.

For the rating of this method, it is decisive how far real processes are assigned correctly by the algorithm. Therefore, the assignment of the jobs was carried out manually for the forage harvester and one transporting unit. The assignments of the algorithms were compared to the manual generated jobs at each point of time. The job assignments agreed with 93 % for transporting units and 91 % for the forage harvester. To extract the influence of human perception, it is planned to record data with the application of additional sensors during the silage maize harvest 2011. Then, the operating state of the machines can be identified by sensors. So, the analysis method can be verified again by the comparison of the algorithmic job assignments and the sensor data.

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