

IMPROVEMENTS TO A SUGARCANE ROAD TRANSPORTATION SYSTEM

By

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Abstract

AMONG the costs of the whole cane sugar and ethanol production system, the activities covered by harvesting (manual and mechanical), road transportation and cane unloading are the most expensive category of operations. A comprehensive study of the cane transport system, that covers topics from system logistics to cane bin design, is being undertaken for the Colombian sugar industry. Models for predicting fuel consumption have been developed and tested using techniques like GPS, pull load and direct fuel flow measurements for the complete operational cycles. Sensitivity trials have also been performed to analyse the influence of bin weight on fuel consumption in the complete cycle and FEA modelling has been applied to the design and construction of new equipment. Results show that reductions of 5% of fuel costs are achieved with the 10% structural weight reduction achieved.

Introduction

Cane supply management represents a real challenge for achieving overall efficiencies in the production processes to obtain sugar, ethanol and exportable electricity.

The huge variety of resources and activities involved simultaneously in field, harvesting (batch processes) and factory (mostly continuous processes) requires modern techniques and tools with a systems approach to assess and influence the processes continuously.

The risk of losing competitiveness because of high production costs, low prices of final products and devaluation of the national currency are threats for Colombia's sugar industry and it is necessary to look for new and better production systems, especially in the harvesting, transport and delivery of the cane.

These operations constitute, on average, one third of the sugar production costs of which transport is 37% of this figure (Ramirez, 2006).

Currently 80% of the cane is cut manually but some individual mills are approaching 60% mechanical harvesting.

Cane is transported by road using three different size bins with 12, 20 and 30 tonnes capacity of chopped cane.

The 12 and 20 tonne bins are loaded directly with chopped cane from the harvester or from the loader in the case of manual harvesting.

Figure 1 show a typical train composed of four 20 tonne wagons.

At the mill yard, cane is unloaded by lifting cranes tipping on to feeding tables from where the cane is fed controlled to the main carrier. Severe damage and compaction happens in the fields, particularly in the rainy seasons, so the industry is returning to the use of tipping wagons of 7.5 and 10 tonne nominal capacity.

Cenicana is currently running a research project on cane supply operations, aiming to reduce production costs by improving the complete cane supply system. The project includes field design,

private road circuits for neighbouring factories, logistics strengthening and equipment design, as well as redesigning together with equipment suppliers.



Fig. 1—Typical train composed of four 20 ton wagons.

Logistic analysis

A simulation computer program based on Excel and linked with Crystal Ball® has been developed for the analysis of complete cane supply operations. It covers resources configuration and operational strategies evaluation, applying stochastic simulation. Statistical variation of input variables and equations were defined with real time information taken from a pilot mill and also from historical data. Cycle time, number of cycles, number of hauling units and the different logistic indices are obtained as program output.

A logistics benchmark was established and a first opportunity for improvement was found in the mill yard. Some results on improvement of spent time in the mill yard by transport equipment are presented in Figure 2. As a consequence of this improvement, equipment availability was improved.

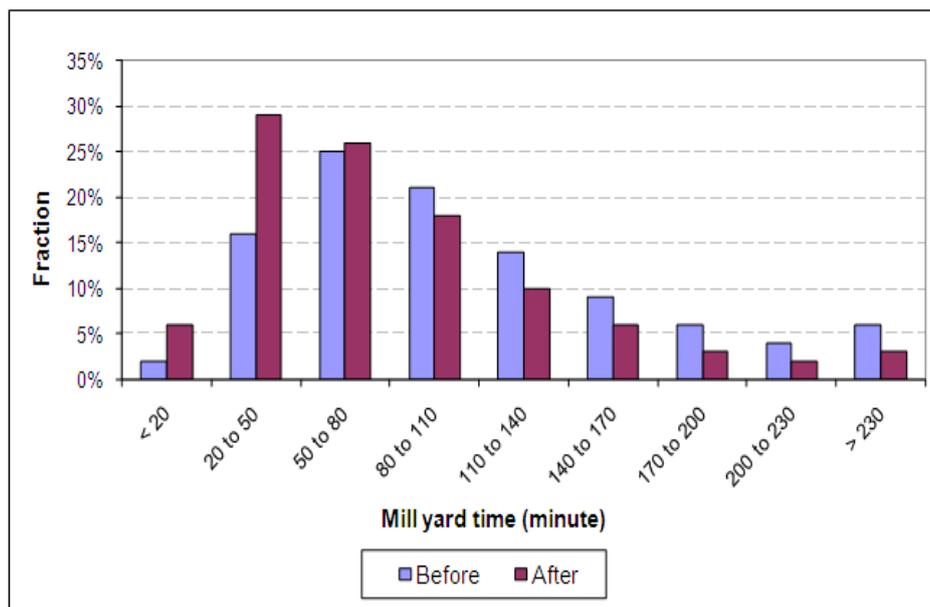


Fig. 2—Mill yard time before and after applying logistics improvements.

So far it has been possible to reduce up to 15% of resources in the pilot mill with better coordination in cane loading, transport and unloading. Quality and opportunity of factory and harvesting personnel communication is a key logistic factor (Amú *et al.*, 2007).

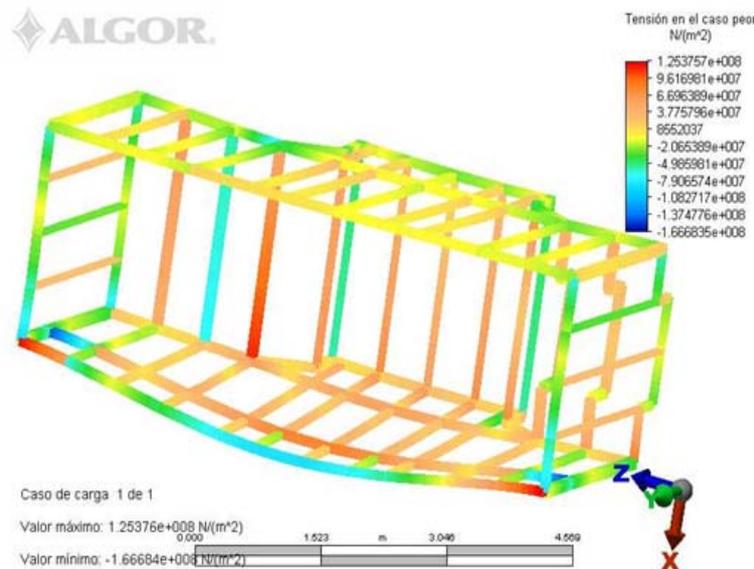
Transport equipment analysis

Recently, Santarossa *et al.* (2007), using finite element analysis, developed a new bin design (10 tonne railroad wagon) and achieved important structural weight savings while keeping good strength performance.

From the inventory of wagons in the Colombian industry, the 12 tonne type is the most extensively used unit, comprising 40.03% of the total industry fleet. It was chosen for structural integrity and maintenance costs analysis.

The most maintenance demanding zones in the chassis and bin were determined and compared with Finite Elements Analysis (FEA) predictions. A close agreement between predicted critical points and reported failure zones was found. Upper corners on the unloading side of the bin and the transition between the chassis central member and the neck were found to be the highest stressed zones. Figure 3 shows FEA outputs for the bin and chassis during cane unloading.

a)



b)

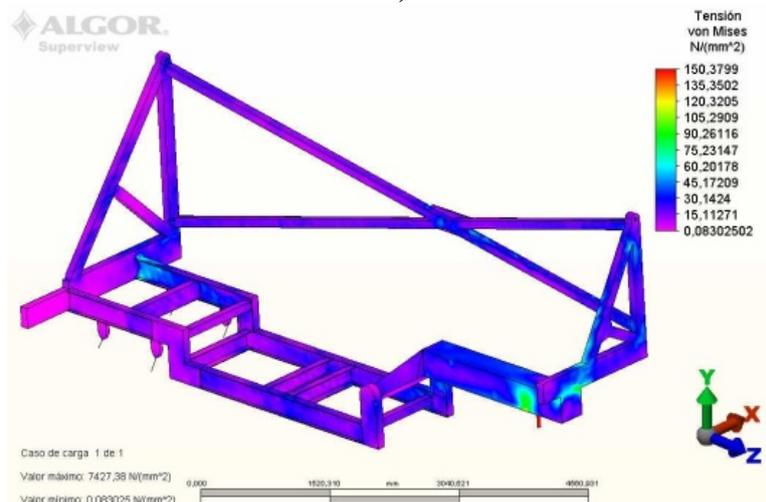


Fig. 3—Stresses during cane unloading a) bin b) chassis.

In order to calibrate the FEA models for the bin and chassis, experimental stress analysis was performed using strain gauges bonded at critical points in the wagon structure (Figure 4).

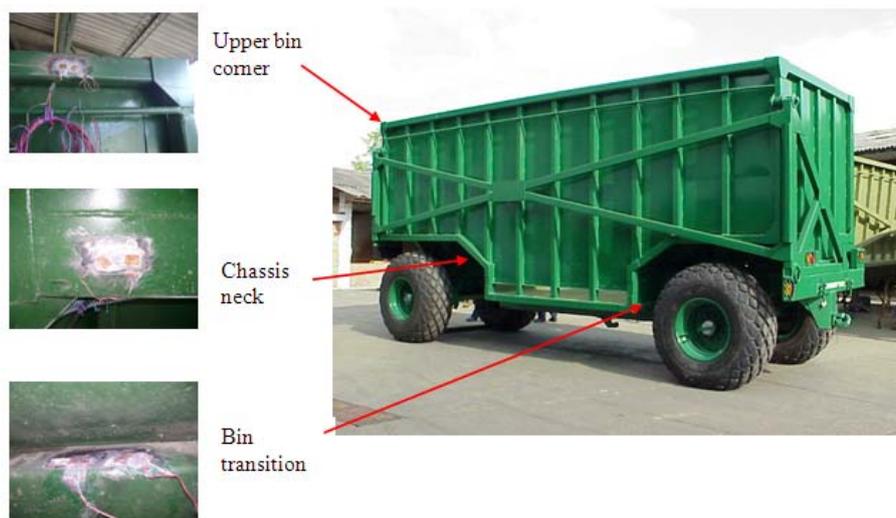


Fig. 4—Strain gauge locations in a HD-12000 wagon.

Stress levels were determined during field loading, while travelling on paved and unpaved roads and while unloading at the feeding table. A static loaded wagon condition was established as Service Factor = 1 and different factors were determined for other conditions (Table 1).

The critical condition for the loaded wagon chassis occurred when travelling in the field (factor 2.92). For the bin, the worst scenario was the unloading operation (factor 2.41). For off-road travel, a bigger factor was found than the factor of 1.8 reported by Moreno *et al.* (2000). Table 2 shows a comparison between FEA predicted stresses and experimental measurements.

Table 1—Service factors for cane transport. Static and level loaded wagon considered as a reference.

		Chassis	Bin
Empty wagon	Unpaved road	1.46	0.69
	Unpaved road-turning	1.76	0.7
Loading and movement in the field		2.92	2.17
Loaded wagon	Unpaved road	2.04	1.3
	Paved road	1.32	1.17
	Static	1	1
Unloading		2.37	2.41

Table 2—Measured vs. FEA predicted stresses.

Condition	Measured point	Stress (MPa)	FEA prediction (MPa)	% Error
Static and level loaded	Bin transition	14.26	15.99	10.80%
	Upper bin corner	99	108.77	8.90%
	Chassis Neck	15.21	15.46	1.60%
Unloading	Bin transition	34.4	38.01	9.50%
	Upper bin corner	110.04	113.33	2.90%
	Chassis Neck	40.95	42.34	3.20%

Using the same equipment for receiving the cane from loaders and harvesters and also to transport the cane to the yard for being unloaded by cranes leads to substantially heavier equipment with high impact on the fuel and maintenance costs. A significant number of mills, therefore, are returning to the practice of using smaller tipping wagons to receive the cane inside the field and deliver it to the specialised bigger road wagons for transport to the factory.

Different approaches and activities have been adopted to develop a new transport wagon design with a better cane load to wagon tare relation, without compromising the equipment reliability:

- Load exerted by cane on the side walls of a wagon bin has been modelled and experimentally confirmed (Cobo *et al.*, 2008).
- Pull loads have been assessed using experimental stress analysis.
- FEA modelling of welded connections of thin walled structural members has been performed together with experimental evaluations (Castro *et al.*, 2009).
- New unloading systems, less demanding of wagon strength, have been documented.
- A prototype of a 12 tonne side dumping wagon was developed and tested, with both mechanically harvested and hand cut cane (Figure 5).



Fig. 5—Prototype of 12 tonne side dumping wagon.

Fuel consumption in cane transport

A theoretical model for a train of cane transport wagons was developed to predict pulling force and power and fuel consumption (Ascuntar, 2008). Figure 6 shows a simplified vehicle forces scheme. The model was confirmed with field experiments. The importance of weight reduction on the wagon structure was determined.

A complete cycle of cane supply operations was considered which consists of four main activities:

1. Empty wagons transported to the field.
2. Cane loading operations.
3. Loaded wagons transported to the factory.
4. Mill yard operations (weighing, sampling, unloading).

Typical fractions of time spent on each activity and average speeds of the main activities are shown in Table 3 for a train of six 12 tonne wagons pulled by a STX 275 tractor.

Table 3—Operational parameters during a cycle of cane supply for a train of six 12 tonne wagons pulled by a STX 275 tractor.

Cycle activity	Average speed (km/h)	Fraction of time
1	20	0.19
2	3.5	0.30
3	15	0.24
4	2	0.27

Field experiments were conducted on very fine Tepic Haplustert soils with 200 mm per year of precipitation and medium to high permeability. A CASE IH 9230 tractor (280 kW) was used together with a pull dynamometer developed by Cenicaña with a modified Holland hitch point (Figure 7, Gómez and Bejarano, 2007), a GPS and a fuel flow meter (Figure 8). Tractor position, speed, pull force and on-line fuel flow were recorded.

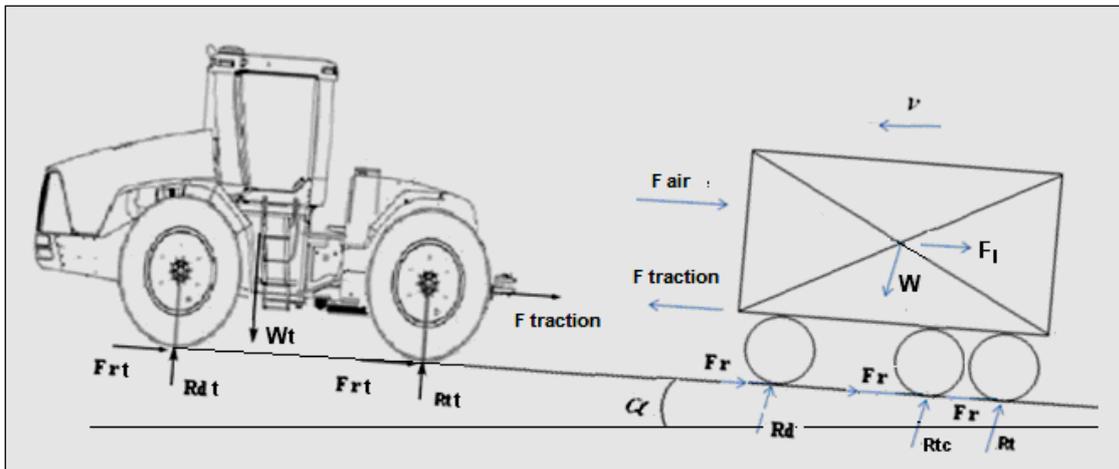


Fig. 6—Forces involved in a power consumption model for a towed system.

With:

- Wt: Tractor weight
- V: Vehicle speed
- W: Total weight (tare+cane)
- α = Road slope
- FI: Inertia force
- Fair: Air resistance
- Frt: Tractive force
- Rdt: Reactive force of terrain, tractor’s front axis
- Rtt: Reactive force of terrain, tractor’s rear axis
- Rd: Reactive force of terrain, wagon’s front axis
- Rtc: Reactive force of terrain, wagon’s first rear axis
- Rt: Reactive force of terrain, wagon’s second rear axis

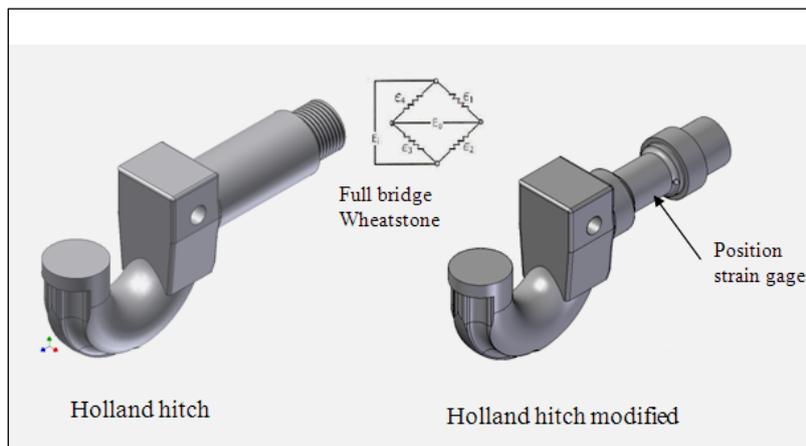


Fig. 7—Holland hitch modified and fitted with strain gauges for pull force measurements.



Fig. 8—AIC-888 Instruktor Fuel flow meter, on a 9230 tractor.

Figure 9 compares available fuel energy (measured on-line) to energy dedicated to move the loaded vehicle, as calculated from pull force and train velocity. Results show that 76.8% of the fuel available energy is spent in the thermal and mechanical conversion including mechanical losses and motor vehicle displacement, indicating a very inefficient process.

Figure 10 presents fuel consumption for a tractor pulling five different train configurations over the same terrain, during a 500 s period and Table 4 shows the results of integrating the power vs. time curve to determine the total energy for each configuration. Figure 11 presents fuel consumption vs. towed weight for different towing speeds.

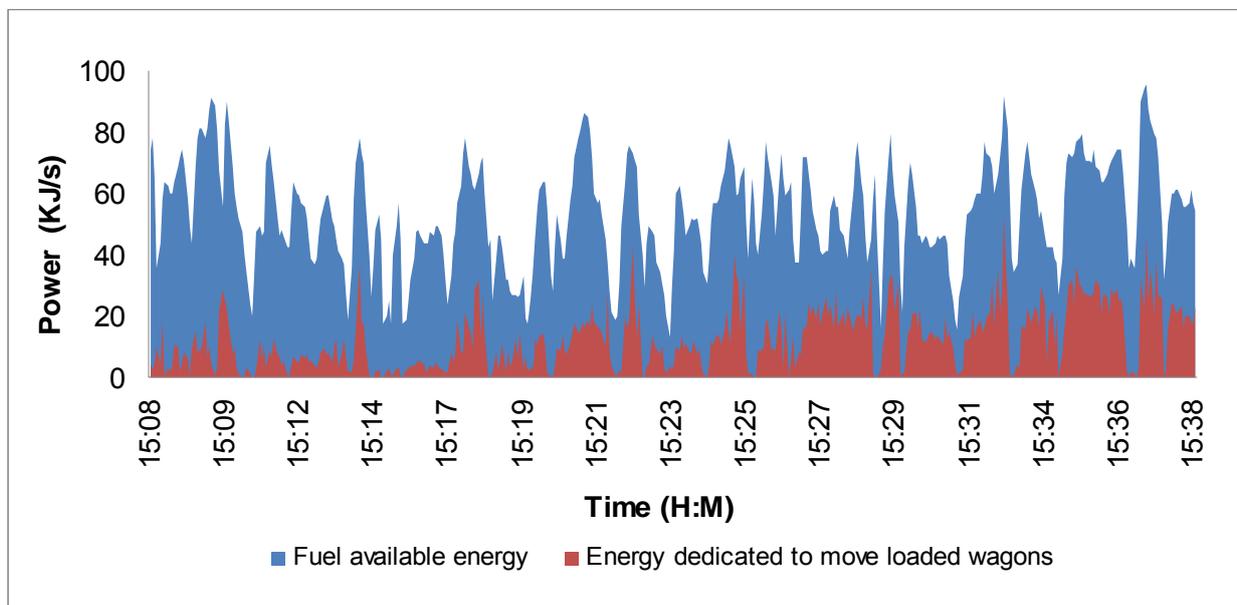


Fig. 9—Fuel available energy vs. energy dedicated to move loaded wagons.

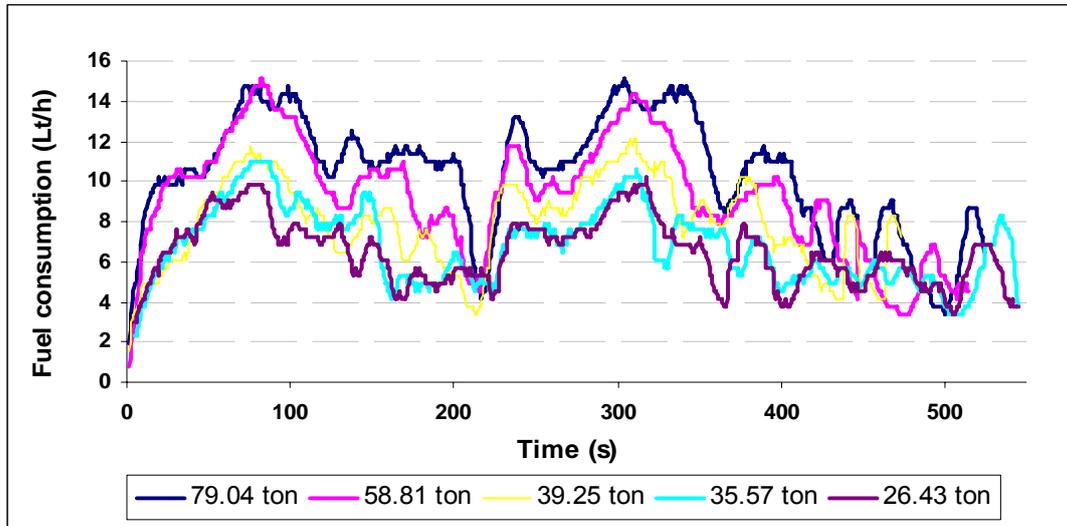


Fig. 10—Fuel consumption for five different load configurations.

Table 4—Tractive energy and fuel consumption for different transported weights.

Transported weight (tonne)	Tractive energy (kJ)	Fuel consumption (l)
26.43	9016	0.96
35.57	9488	0.98
39.25	9632	1.06
58.81	12686	1.32
79.04	17628	1.55

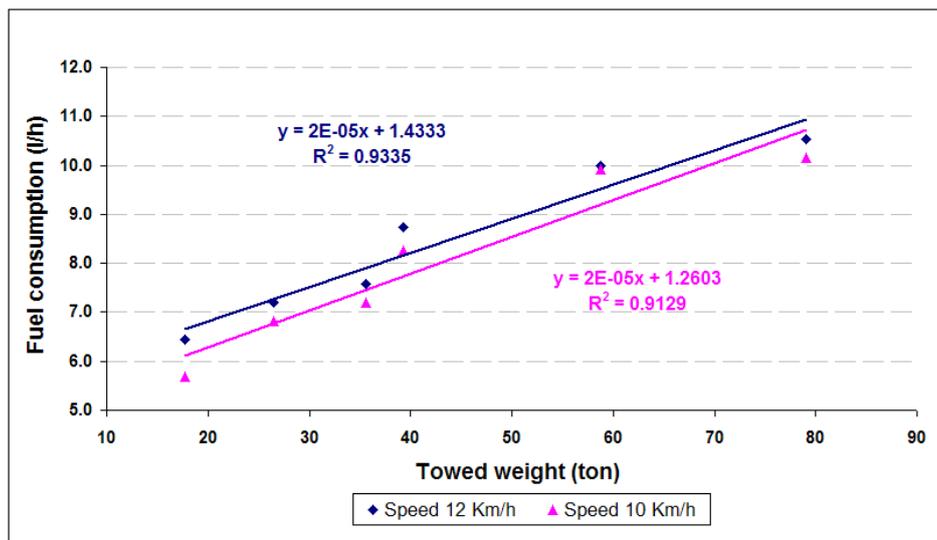


Fig. 11—Fuel consumption vs towed weight for different towing speeds.

The model predicted a 5.3% fuel consumption reduction for a 10% decrease in wagon weight. For the same condition, experimental measurements so far show fuel consumption reductions of 5.6% at 10 km/h and 5.2% at 12 km/h (Figure 12).

More experiments are in progress to identify the influence of other variables such as tyre type, inflation pressure, and speed.

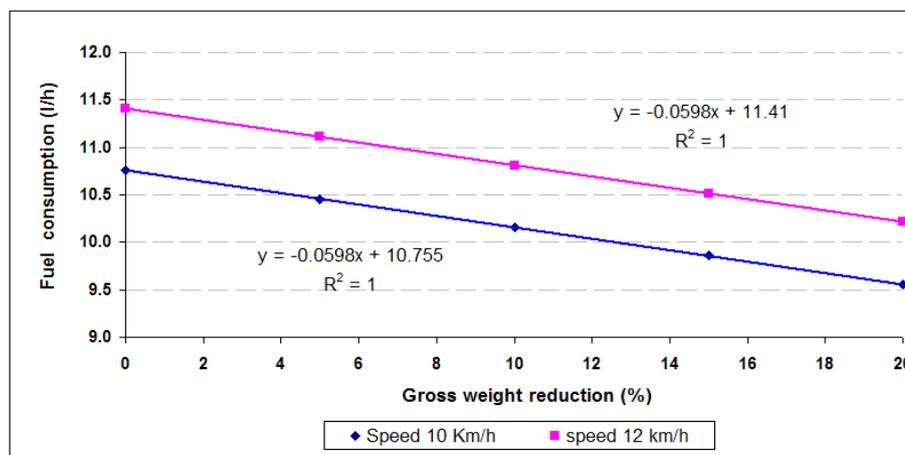


Fig. 12—Weight reduction and fuel consumption.

Conclusions

There was good agreement between FEA predicted stresses for wagon structures and experimental measurements. FEA modelling of welded connections of thin walled structural members can be used safely for design purposes.

Logistics analysis is an important tool for cost reduction. It has been possible to reduce up to 15% of resources in a mill with better coordination in cane loading, transport and unloading. Quality and opportunity of factory and harvesting personnel communication is a key logistic factor.

Also a good agreement was achieved between fuel consumption model predictions and experimental measurements. So far a 10% wagon tare reduction indicates around 5% saving of fuel in road transport for the complete cycle.

The developed dynamometer proved to be a useful tool for determining forces affecting wagon structures and energy consumption measurements. It can also be used to assess the impact of other variables such as tyre type and inflation pressure.

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AMELIORATIONS POUR LE TRANSPORT ROUTIER DE LA CANNE A SUCRE

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**MOTS-CLEFS: Transport de la Canne,
Consommation de Carburant, Modelage FEA.**

Résumé

LE TRANSPORT routier, la récolte manuelle ou mécanique et le déchargement de la canne à sucre sont les opérations les plus coûteuses pour l'industrie de la canne a sucre et de l'éthanol. Une étude complète du système de transport de canne, comprenant la logistique et la conception des caissons pour la canne, a été entreprise pour l'industrie sucrière colombienne. Des modèles pour prédire la consommation de carburant ont été développés et testés à l'aide de techniques comme le GPS et les mesures directes de débit de carburant pour les cycles opérationnelles complets. L'influence du poids des caissons sur la consommation de carburant a été étudiée pour le cycle complet et on a utilisé le model FEA pour la conception et la construction des équipements. Les résultats montrent que des réductions de 5 % de frais de carburant sont obtenues avec une réduction de 10 % du poids structurel.

MEJORAS A UN SISTEMA DE TRANSPORTE DE CAÑA POR CARRETERA

Por

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**PALABRAS CLAVE: Transporte de Caña,
Consumo de Combustible, Elementos Finitos.**

Resumen

DE LOS costos del sistema global de producción de azúcar y etanol, los relacionados con las actividades de cosecha (manual y mecanizada), transporte por carretera y descarga de caña son los mas significativos. Se desarrolla para la industria azucarera colombiana un estudio integral del aprovisionamiento de caña a las fábricas, que incluye desde la logística del sistema hasta el diseño de vagones. Se han desarrollado y probado modelos para predicción del consumo de combustible, usando técnicas como sistemas de posicionamiento global (GPS), medición de fuerza de tiro y de consumo directo de combustible para el ciclo completo de las operaciones. Se han efectuado análisis de sensibilidad para determinar la influencia del peso de los vagones en el consumo de combustible durante el ciclo completo y se ha usado modelamiento por Elementos finitos para el diseño y construcción de nuevo equipo. Los resultados muestran reducciones del 5% en el costo de combustible cuando se logra disminuir en un 10% el peso estructural de los vagones.