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SIMULATION OF EFFICIENCY IN AVAILABILITY FOR DIFFERENT SUGARCANE (*Saccharum* spp.) TRANSPORT EQUIPMENT

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KEYWORDS

agricultural mechanization, logistics, planning and management, computational model, truck and trailers, tractor and semi-trailers.

ABSTRACT

Brazil is the world's largest sugarcane producer destined for mills producing alcohol, sugar, and electricity cogeneration. Sugarcane transport to the mills is carried out by trucks with trailers and tractors with semi-trailers, which transport the raw material harvested in the field to the mill. The modal road system of sugarcane transport uses this equipment to meet the continuous demand of the harveste draw material, with punctuality in the transport execution and generating a minimum cost. This study aimed to analyze the influence of availability efficiency on the operational and economic performance of different sugarcane transport equipment. A computational model called *TransporteCana* was developed in a spreadsheet due to the difficulty in meeting the objective under field conditions. The model was checked for possible routine errors, validated, and used in the analysis of variables and generation of results. The results showed that increasing availability efficiency reduces the operational cost of producing the equipment. Large managerial investments for the means of execution are required for high availability efficiencies.

INTRODUCTION

The estimated area cultivated with sugarcane in Brazil reached 8.42 million hectares and a total production forecast of 628.10 million tons in the 2021/2022 growing season (CONAB, 2021).

The road transport system is essential to meet the demand for raw material harvested in the field and deliver sugarcane to the mill on time to avoid direct and indirect damage to the raw material quality. According to Santos et al. (2014b), the demand for the production of processed raw materials depends on the operational performance of the mechanized system. In this sense, operational performance comprises the managerial conditions for the equipment to operate and considers, among the various means of execution, the operational times of service (Santos et al., 2014a).

According to Mialhe (1974), operational times occur through setup, interruption, and production time. Setup time refers to the preparation of the equipment to operate. Interruption time stems from the work of the equipment in operation, such as adjustments and refueling. Production time is exclusively for productive work, that is, when the equipment is effectively performing the agricultural operation. In this context, according to Alizadeh (2011), Araldi et al. (2013), Griffel et al. (2020), Grisso et al. (2002), Linhares et al. (2012), Mohamed et al. (2011), Oduma et al. (2019), Pitla et al. (2014), Santos et al. (2018b), Shamshiri & Ismail (2013), and Zhou et al. (2015), the operational times of service result in the field efficiency (Eff), which corresponds, in this study, to the availability efficiency (Efa) of the equipment of the sugarcane transport system. Efa comprises the worked hours that the equipment effectively performs its productive function, the auxiliary hours that are required according to the operation that the equipment necessarily needs for its full use (Banchi & Lopez, 2007). Furthermore, according to these authors, the lost hours correspond to the period that the equipment is ready to operate but is not used due to managerial or climate conditions,which are independent of the equipment, and maintenance hours, which correspond to the time taken to carry out the routine maintenance that the operation requires.

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The operational performance of equipment in the management of mechanized agricultural systems has a direct influence on economic performance (Santos, 2018a). According to Santos (2019), it occurs because the operational and economic performance variables are systemically interrelated. Thus, this study aimed to analyze the availability efficiency in the operational and economic performance of different sugarcane transport equipment.

MATERIAL AND METHODS

Amill, called Hypothetical Mill, with its sugarcane transport system (truck with trailers and tractor with semi-trailers), was considered in this study. The predominance of the operation of the transport system in this study, as in any mill in Brazil, occurs with the equipment going to the field and back from the field to it, thus completing the entire loading and unloading cycle, with no restrictions on the form of coupling/uncoupling during the cycle between the truck with trailers and the tractor with semi-trailers.

The Hypothetical Mill has distant plots with an average radius that varies from 10 to 50 km and will be covered by the equipment during the loading and unloading cycle. An Elaborated Scenario, which comprises the description of the economic, technical, managerial, and operational characteristics of the equipment was created to generate the results (Table 1).

TABLE 1. Economic, technical, managerial, and operational variables of equipment for the Elaborated Scenario.

Variable	Abbreviation	Unit	Truck	Trailer	Tractor	Semi-trailer
Initial value	IV	US$	140,196	16,667	116,667	37,255
Rated engine power	REP	kW/CV	368/500	-	368/500	-
Body load	BL	Mg	20	18	-	35
Number of bodies	NB	Number	-	3	-	2
Number of tires	NT	Number	12	24	10	24
Working time	WT	h	24			
Availability efficiency	Efa	Decimal	0.70			
Average working speed	AWS	km h^{-1}	40		40	
New tire service life	NTSL	km	80,000		80,000	
Retread tire service life	RTSL	km	75,000		75,000	
Number of tire retreads	NTR	km	2		2	
Average distance radius	ADR	km	30		30	
Loading time	LT	min	55		50	
Unloading time	UT	min	55		50	

Efa,which determines the useful life, in kilometers, of the equipment, agreed with Banchi & Lopes (2007). The loading and unloading time values were based on data from the study conducted by Carreira (2010).

A computational model, called *TransporteCana*, which enables the basic characteristics of the sugarcane transport system in the Brazilian mills, was developed to meet the study objective. The model is based on the flowchart shown in Figure 1, prepared according to the features proposed by Oakland (2007).

TransporteCana was developed in an *Excel*® spreadsheet. The model starts its operation (1)[4] with the entry of data referring to the crop (2), such as the sugarcane production to be transported and the price of the ton of sugarcane delivered to the mill. Item (3) refers to the climate data entry: number of days to conduct the transport, number of Sundays and holidays, and number of inappropriate working days for transport to define the available time in days.

[4]The numbers in parentheses refer to the flowchart in Figure 1.

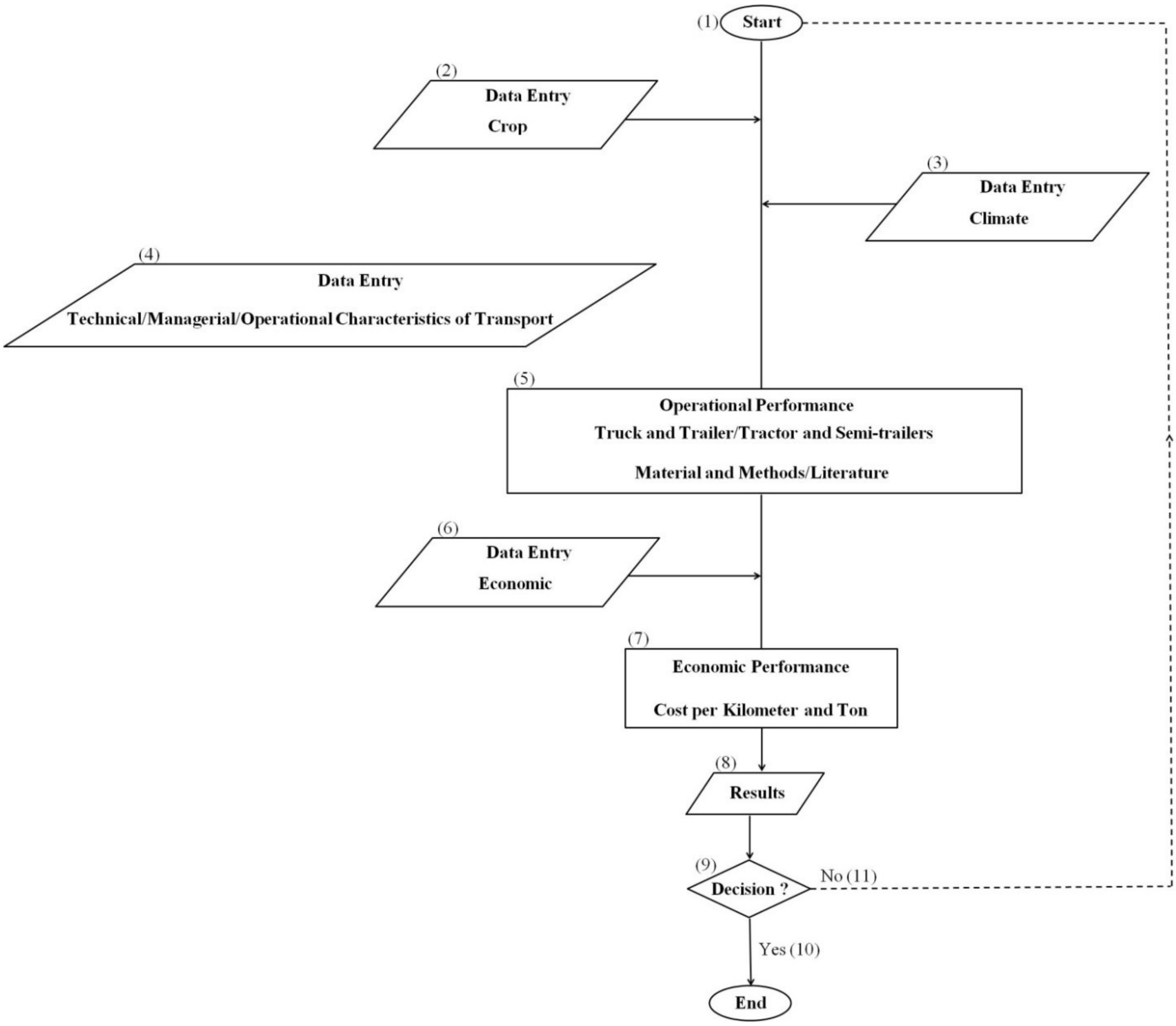

FIGURE 1. General flowchart of the computational model.

Data entry (4) refers to the technical/management/operational characteristics of the transport: rated engine power, body loads, number of bodies, number of tires, average working speed, working time, new tire service life, retread tire service life, number of tire retreads, average distance radius, loading time, and unloading time.

The association between items (2), (3), and (4) determined the operational performance of the truck with trailer and tractor with semi-trailer set (5): total loading and unloading cycle time, number of loading and unloading in the day, month, and growing season, the total load of the set, the total production capacity of the set, production transported in the day, month, and growing season, distance traveled in the day, month, and growing season, operational fuel consumption in the growing season, production rate, and number of required sets.

The results of operational performance associated with the entry of the economic data of machinery (6) initial value, final value, service life in years and hours, interest per year, storage, insurance, and fees (SIF), licensing, fuel consumption, and repair and maintenance determined the calculation of economic performance (7), which refers to the cost of fuel, repair and maintenance, repair and maintenance of the new tire, repair and maintenance of the retreaded tire, per kilometer and ton, and gross and net gain of the mill with the transported production.

The model results (8) allow the user to evaluate the operational and economic performance of the transport and decide (9) as to the feasibility (10) or not. New data must be inserted in the model in case the transport with the considered equipment is not feasible for the user (11) or the user chooses to evaluate another scenario.

Climate

The local climate determines the available time in growing season days (TAd) to transport the harvested raw material, based on Mialhe (1974), with adjustments. The available time in growing season days (TAd) was calculated based on the number of days (Nd), number of Sundays and holidays (Nsh), and number of unsuitable working days for transport (Nuwdt), according to [eq.(1)].

$$TAd = [Nd - (Nsh + Nuwdt)] \quad (1)$$

In which:

TAd is the available time (days);

Nd is the number of days;

Nsh is the number of Sundays and holidays, and

Nuwdt is the number of unsuitable working days for transport.

Operational performance

The total loading and unloading cycle time (TLUCT), the number of loading and unloading in the day (NLUD), production transported in the day (PTD), production transported in the growing season (PTGS), distance traveled in the day (DTD), and distance traveled in the growing season (DTGS) were based on Carreira (2010). This proposal was adopted because it meets the operationalization of the logistic process (transport) of the sugarcane to a Mill.

The total loading and unloading cycle time (TLUCT) was calculated based on the average distance radius (ADR), average working speed (AWS), loading time (LT), and unloading time (UT) (Carreira, 2010), according to [eq.(2)].

$$\text{TLUCT} = \left[\left(\frac{\text{ADR} * 2}{\text{AWS}}\right) + \left(\frac{\text{LT} + \text{UT}}{60}\right)\right] \tag{2}$$

In where:

TLUCT is the total loading and unloading cycle time (h);

ADR is the average distance radius (km);

2 is the constant to determine the round-trip distance traveled in the loading and unloading cycle;

AWS is the average working speed (km h^{-1});

LT is the loading time (min);

UT is the unloading time (min), and

60 is a constant.

The number of loading and unloading in the day (NLUD) was determined based on the working time (WT), total loading and unloading cycle time (TLUCT), and availability efficiency (Efa), based on Carreira (2010).

The number of loading and unloading in the month (NLUM) was defined by the association between the number of loading and unloading in the day (NLUD) and the total number of days in a month (NDM).

The number of loading and unloading in the growing season (NLUGS) was calculated by the association between the number of loading and unloading in the day (NLUD) and the time available in growing season days (TAd).

The total load of the set (TLS) was determined by the association between the body load (BL) and the number of bodies (NB).

The total production capacity of the set (TPCS) was defined by the ratio between the total load of the set (TLS) and the total loading and unloading cycle time (TLUCT).

The production transported in the day (PTD) was calculated by the association between the number of loading and unloading in the day (NLUD) and the total load of the set (TLS), according to Carreira (2010).

The production transported in the month (PTM) was determined by the association between the production transported in the day (PTD) and the total number of days in a month (NDM).

The production transported in the growing season (PTGS) was defined by the association between the production transported in the day (PTD) and the time available in growing season days (TAd), according to Carreira (2010).

The total distance traveled in the loading and unloading cycle (TDTLUC) was calculated based on the average distance radius (ADR), according to [eq. (3)].

$$\text{TDTLUC} = \text{ADR} * 2 \tag{3}$$

In which:

TDTLUC is the total distance traveled in the loading and unloading cycle (km).

The distance traveled in the day (DTD) was determined based on the total distance traveled in the loading and unloading cycle (TDTLUC) and the number of loading and unloading in the day (NLUD) (Carreira, 2010), according to [eq. (4)].

$$\text{DTD} = \text{TDTLUC} * \text{NLUD} \tag{4}$$

Where:

DTD is the distance traveled in the day (km day^{-1}).

The distance traveled in the month (DTM) was defined by the association between the distance traveled in the day (DTD) and the total number of days in a month (NDM).

The distance traveled in the growing season (DTGS) was calculated by the association between the distance traveled in the day (DTD) and the time available in growing season days (TAd), according to Carreira (2010).

The operational fuel consumption in the growing season (OFCGS) of the set truck with trailer and tractor with semi-trailer was determined based on the distance traveled in the growing season (DTGS), fuel consumption (FC), and production transported in the growing season (PTGS).

The production rate (PR) was defined by the ratio between the mill production in the growing season (MPGS) and the time available in growing season days (TAd).

The number of required sets (NRS) was calculated by the ratio between the production rate (PR) and the production transported in the day (PTD).

Economic performance

The fixed cost (FC) of the equipment was calculated based on the adjusted proposal of ASABE (2011), defined by the ratio between annual depreciation (AD), annual interest (AI), storage, insurance, and fees (SIF), licensing (LIC), and distance traveled in the growing season (DTGS), according to [eq.(5)].

$$\text{FC} = \left|\frac{\left\langle\left\{\text{IV} * \left[\left(\frac{1 - \text{FV}}{\text{ESL}}\right) + \left(\frac{1 + \text{FV}}{2}\right) * \text{i} + \text{SIF}\right]\right\} + \text{LIC}\right\rangle}{\text{DTGS}}\right| \tag{5}$$

In which:

FC is the fixed cost of the equipment (US\$ km^{-1});

IV is the initial value of the equipment (US\$);

FV is the final value of the equipment (decimal);

ESL is the equipment service life (years);

i is the interest rate per year (decimal);

SIF is the storage, insurance, and rates per year (decimal);

LIC is the licensing (US\$ year^{-1}), and

DTGS is the distance traveled in the growing season (km year^{-1}).

The variable cost (VC) of the equipment was defined as the sum of the cost of fuel (CF), cost of repair and maintenance (CRM), cost of repair and maintenance of the new tire (CRMNT), and cost of repair and maintenance of the retreaded tire (CRMRT), based on Mialhe (1974) and Balastreire (1990) with adjustments.

Fuel consumption (FCP) of the truck and tractor can be estimated or averaged. The estimated value must be provided when choosing the estimated consumption. The average consumption option is in accordance with the proposal by Banchi et al. (2008). This proposal provides average values of fuel consumption of sugarcane trucks by the rated power range of the equipment's engine.

The cost of fuel (CF) of the equipment was calculated by the ratio between the price of a liter of fuel (PL) and fuel consumption (FCP). The price of a liter of fuel (PL) was 0.92 US\$ L^{-1}, which was based on the average price of gas stations in the city of Uberaba-MG in 2021.

The cost of repair and maintenance of the truck and tractor (CRMTT) was defined based on ASABE (2011) with adjustments.

The cost of repair and maintenance of the trailer (CRMT) and semi-trailer (CRMST) was calculated according to Banchi et al. (2009).

The cost of repair and maintenance of the new tire (CRMNT) and retreaded tire (CRMRT) of the equipment were based on Goodyear (2017) and Rosa (2017). The cost of repair and maintenance of the new tire (CRMNT) was defined based on the price of a new tire (PNT), number of tires (NT), and the new tire service life (NTSL), according to Goodyear (2017) and Rosa (2017) (Equation 6).

$$\text{CRMNT} = \left(\frac{\text{PNT} * \text{NT}}{\text{NTSL}}\right) \quad (6)$$

Where:

CRMNT is the cost of repair and maintenance of the new tire (US\$ km^{-1});

PNT is the price of a new tire (US\$);

NT is the number of tires, and

NTSL is the new tire service life (km).

The cost of repair and maintenance of the retreaded tire (CRMRT) of the equipment was determined based on the price of the retreaded tire (PRT), number of tire retreads (NTR), number of tires (NT), and retread tire service life (RTSL), according to Goodyear (2017) and Rosa (2017) (Equation 7).

$$\text{CRMRT} = \left(\frac{\text{PRT} * \text{NTR} * \text{NT}}{\text{RTSL}}\right) \quad (7)$$

Where:

CRMRT is the cost of repair and maintenance of the retreaded tire (US\$km^{-1}),

PRT is the price of the retreaded tire (US\$),

NTR is the number of tire retreads, number of tires (NT), and

RTSL is theretread tire service life (km).

The equipment operational cost (EOC) was calculated by the sum between the fixed cost (FC) and variable cost (VC), based on Mialhe (1974) and Balastreire (1990) with adjustments.

The operational cost of the truck and trailer set (OCTTS) was determined by the sum between the operational cost of the truck (OCTk) and the operational cost of the trailer (OCTr).

The operational cost of the tractor and semi-trailer set (OCTSTS) was defined by the sum between the operational cost of the tractor (OCT) and the operational cost of the semi-trailer (OCST).

The operational cost of production of the truck and tractor (OCPTT) was calculated based on the equipment operational cost (EOC), distance traveled in the growing season (DTGS), and production transported in the growing season (PTGS), based on Carreira (2010) and Rosa (2017) with adjustments, according to [eq.(8)].

$$\text{OCPTT} = \left[\text{EOC} * \left(\frac{\text{DTGS}}{\text{PTGS}}\right)\right] \quad (8)$$

in which:

OCPTT is the operational cost of production of the truck and tractor (US\$ t^{-1});

EOC is the equipment operational cost (US\$ km^{-1});

DTGS is the distance traveled in the growing season (km year^{-1}), and

PTGS is the production transported in the growing season (Mg year^{-1}).

The operational cost of production of the trailer and semi-trailer (OCPTST) was determined similarly to the operational cost of production of the truck and tractor (OCPTT), according to Carreira (2010) and Rosa (2017) with adjustments. The operational cost of production of the truck and trailer set (OCPTTS) was defined by the sum between the operational cost of production of the truck (OCPTk) and the operational cost of production of the trailer (OCPTr). The operational cost of production of the tractor and semi-trailer set (OCPTSTS) was calculated by the sum between the operational cost of production of the tractor (OCPT) and the operational cost of production of the semi-trailer (OCPST). The total cost of the set (TCS) was determined by the sum of the operational cost of production of the set (OCPS) and production transported in the growing season (PTGS).

Economic gains of the mill

The mill gross (MGGPTGS) and net (MNGPTGS) gain with the production transported in the growing season were based on Santos et al. (2014a), Santos et al. (2015), and Santos et al. (2017), with modifications. In this case, the mill gross gain with the production transported in the growing season (MGGPTGS) was calculated by the association between the estimated price per ton of sugarcane delivered to the mill (PTSDM) and the production transported in the growing season (PTGS). In contrast, the mill net gain with the production transported in the growing season (MNGPTGS) was determined by the difference between the mill gross gain with the production transported in the growing season (MGGPTGS) and the total cost of the set (TCS). The estimated price per ton of sugarcane delivered to the mill was 14.69 US$ Mg^{-1}, according to UDOP (2019).

Validation

TransporteCana was validated by comparing simulation results with data from the literature (secondary data). Validation, sensitivity analysis, and consistency of the computational model were performed using the operational cost of production.

RESULTS AND DISCUSSION

The climate planning of the Elaborated Scenario of the Hypothetical Mill considered the pluviometric conditions of the Triângulo Mineiro region, in the State of Minas Gerais, between 1980 and 2010, according to the pluviometric data presented by Roldão & Assunção (2012) *apud* ANA (2012), and clayey soil. The climate planning of the considered region resulted in atime available in growing season days (TAd) of 235.

Availability efficiency (Efa) is a management variable that represents the time worked, adjustments, and equipment availability. Figure 2 shows the operational cost of production of the sets under two management conditions of availability efficiency, that is, 70 (Elaborated Scenario) and 100%, as a function of the average distance radius between the mill and the production plot. Increasing the average distance radius results in linear growth in cost but higher availability efficiency reduces the cost of the sets. The cost of the truck and trailer set within a radius of 10 km with efficiencies of 70 and 100% was 0.70 and 0.62 US$ Mg^{-1}, respectively, while the tractor and semi-trailer set had a cost of 0.67 and 0.60 US$ Mg^{-1}, respectively.

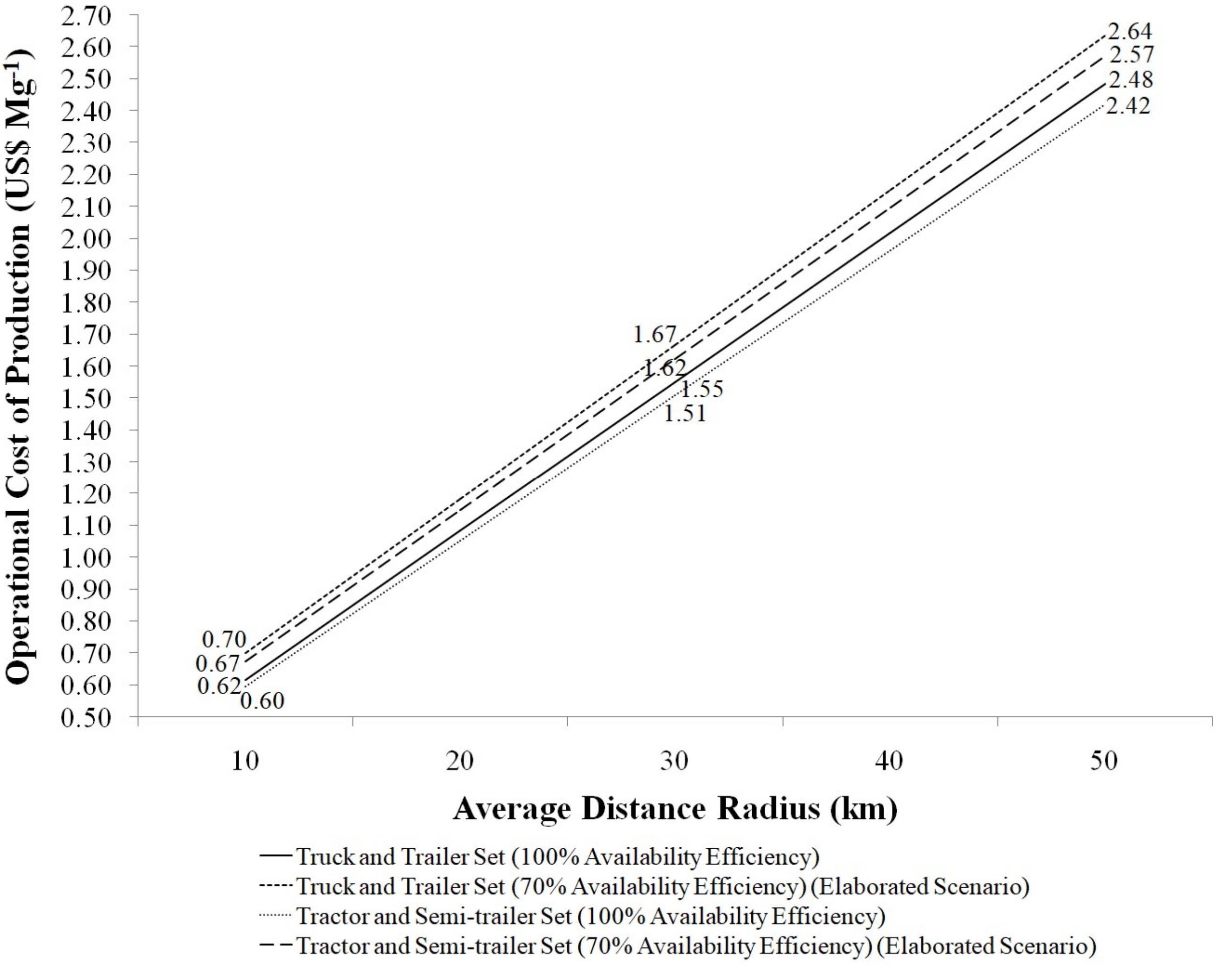

FIGURE 2. Operational cost of production and availability efficiency as a function of the average distance radius.

The cost of the truck and trailer set within a radius of 30 km (Elaborated Scenario) was 1.67 and 1.55 US$ Mg^{-1} with efficiencies of 70 and 100%, respectively. Moreover, the tractor and semi-trailer set reached the cost of 1.62 and 1.51 US$ Mg^{-1} for these efficiencies, respectively.

The cost of the truck and trailer set was 2.64 and 2.48 US$ Mg^{-1} within a radius of 50 km with efficiencies of 70 and 100%, respectively, while the tractor and semi-trailer set reached the cost of 2.57 and 2.42 US$ Mg^{-1}, respectively.

The difference between the costs of the truck and trailer set regarding the radius of 10 km and a 70% efficiency showed an increase of 0.97 and 1.94 US$ Mg^{-1} or 138.55 and 277.11% compared to radii of 30 and 50 km, respectively. The 100% efficiency led to an increase of 0.93 and 1.87 US$ Mg^{-1} or 151.27 and 302.54%, respectively. In contrast, the difference in cost for the tractor and semi-trailer set relative to the 10 km radius with an efficiency of 70% showed an increase of 0.95 and

1.90 US$ Mg^{-1} or 140.47 and 280.94% compared to radii of 30 and 50 km, respectively. The 100% efficiency led to an increase of 0.91 and 1.82 US$ Mg^{-1} or 152.86 and 305.71%, respectively.

Therefore, it is recommended to transport the sugarcane from production plots located up to, on average, a radius of 30 km from the mill, otherwise, the operational cost of production of the equipment will be very high, thus reducing the gains of the mill.

CONCLUSIONS

The increase in availability efficiency is advantageous for the operational cost of production of the equipment.

The tractor and semi-trailer set is more advantageous than the truck and trailer set.

Mills should adopt an excellent management method to facilitate the means of conducting the operation and, therefore, achieve high availability efficiency with the equipment.

REFERENCES

Alizadeh MR (2011) Field performance evaluation of mechanical weeders in the paddy field. Scientific Research and Essays 6(25):5427-5434. DOI: http://dx.doi.org/10.5897/SRE11.1412.

ANA - Agência Nacional de Águas (2012) ANA. Available: www.ana.gov.br. Accessed Jan, 2012.

Araldi PF, Schlosser JF, Frantz UG, Ribas RL, Santos PM dos (2013) Eficiência operacional na colheita mecanizada em lavouras de arroz irrigado. Ciência Rural 43(3):445-451. DOI: http://dx.doi.org/10.1590/S0103-84782013000300011.

ASABE - American Society of Agricultural and Biological Engineers (2011) Agricultural machinery management data ASAE D497.7. St. Joseph, American Society of Agricultural and Biological, 8p.

Balastreire LA (1990) Máquinas agrícolas. São Paulo, Manole, 307p.

Banchi AD, Barreto Junior EA, Lopes JR (2009) Implementos I: custos de reparo e manutenção dos implementos rodoviários. Revista Agrimotor (41):8-11.

Banchi, AD, Lopes JR (2007) Custos com reparo e manutenção no transporte de cana-de-açúcar. Revista Agrimotor (26):28-29.

Banchi AD, Lopez JR (2007) Gestão das operações agrícolas I. Revista Agrimotor (21):12-14.

Banchi AD, Lopez JR, Rocco GC (2008) Uso anual e consumo de combustível em frotas agrícolas. Revista Agrimotor (39):8-10.

Carreira ML (2010) Desempenho operacional, econômico e energético do transporte de cana-de-açúcar: um estudo de caso. Mestrado Dissertação, Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz".

CONAB - Companhia Nacional de Abastecimento (2021) Acompanhamento da safra brasileira: cana-de-açúcar, primeiro levantamento (área cultivada e produção). CONAB. Available: https://www.conab.gov.br/component/k2/item/download/37153_e0cf6a2e665c14f322a731f6f0f98551. Accessed Ago 02, 2021.

GOODYEAR (2017) Cálculo de custo por km. GOODYEAR. Available: https://caminhao.goodyear.com.br/mais-informacoes/custo/. Accessed Abr 24, 2020.

Griffel LM, Vazhnik V, Hartley DS, Hansen JK, Roni M (2020) Agricultural field shape descriptors as predictors of field efficiency for perennial grass harvesting: An empirical proof. Computers and Electronics in Agriculture 168:1-8. DOI: https://doi.org/10.1016/j.compag.2019.105088.

Grisso RD, Jasa PJ, Rolofson DE (2002) Analysis of traffic patterns and yield monitor data for field efficiency determination. Applied Engineering in Agriculture 18(2):171-178. DOI: http://dx.doi.org/10.13031/2013.7782.

Linhares M, Sette Júnior CR, Campos F, Yamaji FM (2012) Eficiência e desempenho operacional de máquinas harvester e forwarder na colheita florestal. Pesquisa Agropecuária Tropical 42(2):212-219. DOI: http://dx.doi.org/10.1590/S1983-40632012000200007.

Mohamed HI, Gabir SIMN, Omer MAA, Abbas OM (2011) A program for predicting performance of agricultural machinery in visual basic. Research Journal of Agriculture and Biological Sciences 7(1):32-41.

Mialhe LG (1974) Manual de mecanização agrícola. São Paulo, Agronômica Ceres, 301p.

Oakland J (2007) Gerenciamento da qualidade total tqm. São Paulo, Nobel, 459p.

Oduma O, Oluka SI, Nwakuba NR, Ntunde DI (2019) Agricultural field machinery selection and utilization for improved farm operations in south-east nigeria: a review. Scientific Journal of Agricultural Engineering (3):44-58. DOI: http://dx.doi.org/10.5937/PoljTeh1903044O.

Pitla SK, Lin N, Shearer SA, Luck JD (2014) Use of controller area network (can) data to determine field efficiencies of agricultural machinery. Applied Engineering in Agriculture 30(6):829-839. DOI: http://dx.doi.org/10.13031/aea.30.10618.

Roldão A de F, Assunção WL (2012) Caracterização e duração das estações seca e chuvosa no Triângulo Mineiro - MG. Revista Geonorte 2 3(8):428-440.

Rosa JHM (2017) Dimensionamento operacional e econômico da colheita mecanizada de cana-de-açúcar (*Saccharumssp*): modelo computacional como ferramenta de apoio a tomadas de decisão. Doutorado Tese, Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz".

Santos NB, Cavalcante DS, Fernandes HC, Gadanha Júnior CD (2014a) Simulação da eficiência de campo da colheita mecanizada de cana-de-açúcar (*Saccharum* spp.). Revista Energia na Agricultura 29(1):09-13. DOI: http://dx.doi.org/10.17224/EnergAgric.2014v29n1p09-13.

Santos NB dos, Silva RP da, Gadanha Júnior CD (2014b) Economic analysis for sizing of sugarcane (*Saccharum*spp.) mechanized harvesting. Engenharia Agrícola 34(5):945-954. DOI: https://doi.org/10.1590/S0100-69162014000500013.

Santos NB dos, Fernandes HC, Gadanha Júnior CD (2015) Economic impact of sugarcane (*Saccharum* spp.) loss in mechanical harvesting. Científica 43(1):16-21. DOI: http://dx.doi.org/10.15361/1984-5529.2015v43n1p16-21.

Santos NB dos, Teixeira MM, Fernandes HC, Gadanha Júnior CD (2017) Estimated repair and maintenance cost of sugarcane (*Saccharum* spp.) harvester. Científica 45(3):214-217. DOI: http://dx.doi.org/10.15361/1984-5529.2017v45n3p214-217.

Santos NB dos (2018a) Simulation of distance between field and replenishment pump in mechanized spraying of sugarcane (*Saccharum* spp.). EngenhariaAgrícola 38(5):805-812. DOI: http://dx.doi.org/10.1590/1809-4430-eng.agric.v38n5p805-812/2018.

Santos NB dos, Teixeira MM, Fernandes HC, Gadanha Júnior CD (2018b) Analysis of times and efficiencies of the mechanized harvest of sugarcane (*Saccharum* spp.). Nucleus 15(1):181-188. DOI: http://dx.doi.org/10.3738/1982.2278.2794.

Santos NB dos (2019) Economic analysis of different hydraulic sprayers used in sugarcane (*Saccharum* spp.). Engenharia Agrícola 39(2):225-233. DOI: http://dx.doi.org/10.1590/1809-4430-eng.agric.v39n2p225-233/2019.

Shamshiri R, Ismail WIW (2013) Exploring gps data for operational analysis of farm machinery. Research Journal of Applied Sciences, Engineering and Technology 5(12):3281-3286. DOI: http://dx.doi.org/10.19026/rjaset.5.4568.

UDOP - União dos Produtores de Bioenergia (2019) Preço cana campo (São Paulo). UDOP. Available: https://www.udop.com.br/cana/tabela_consecana_saopaulo.pdf. Accessed Jan 13, 2019.

Zhou K, Jensen AL, Bochtis DD, Sørensen CG (2015) Performance of machinery in potato production in one growing season. Spanish Journal of Agricultural Research 13(4):1-12. DOI: http://dx.doi.org/10.5424/sjar/2015134-7448.