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The operation of mechanical sugarcane harvesters and the competence of operators: an ergonomic approach

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The mechanisation of sugarcane harvesting in Brazil has experienced significant growth. Mechanical sugarcane harvesters have been rapidly improving to meet the demands of the industry. Operating a harvester machine requires knowledge and competence. This article aims to demonstrate the role of the operator competence in carrying out their task and in the quality of their performance. By applying the Ergonomic Work Analysis (EWA), the activity in an actual work situation was described, and the basic competencies required for satisfactory operation were identified. The primary operator competencies consist of performing the adjustment of the machine; operating the machine on a slope and on uneven ground; harvesting different types of cane; operating at night; avoiding damage, diagnosing problems and performing repairs on the machine; and performing multiple tasks.

Key words: Ergonomics, competence, harvester machine, mechanical harvesting, sugarcane.

INTRODUCTION

Brazil is the world's leading producer of sugarcane (Brasil, 2013). The sugarcane sector plays an important role in the national economy and has shown significant growth due to increasing demand for sugar and ethanol. As a result, investment in greater efficiencies and better technology throughout the country has been encouraged (Magalhães et al., 2008).

In recent years, the reason for the efficiency and expansion of production has been the mechanisation of harvesting. Unlike countries such as Australia, where harvesting is fully mechanised (Renouf et al., 2010), Brazil's mechanised harvesting in São Paulo State reached almost 85% in 2014, with prospects of consolidation due to environmental, social and economic demands (Alves, 2009; IEA, 2015). Since their initial development, harvester machines have been steadily improving. However, merely having the best equipment and conditions in the industry is insufficient if the workers are unqualified. Therefore, the position advocated in this work is that the competence of sugarcane harvester machine operators is essential in the harvesting mechanisation process, both in production and in operator safety.

From the standpoint of ergonomics, competencies are "stabilised sets of knowledge and know-how, standard conducts, standard procedures, and types of reasoning that can be implemented without resorting to new learning and that are grounded in the structure and acquisitions of professional history; they allow the anticipation of phenomena and are implicit in instructions and the variability of the task" (Montmollin, 1984).

Yet according to Montmollin (1990), the concept of competencies consists of the articulation of acquirements (declarative and procedural), representations, reasoning

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and cognitive strategies that the individual builds and modifies in the course of activity. They characterise the way in which the activity is performed and underlie representations and strategies employed by the operators to face working situations (Weill-Fassina and Pastré, 2004).

The identification of competencies not only allows the understanding of human action but also allows the explanation of how the operator avoids mistakes, anticipates failures and corrects them, prioritises task, handles unexpected events, detects and diagnoses problems and organises his actions in both normal and critical circumstances. Thus, considering the advance of mechanical harvesting in São Paulo State, the present paper aims to analyse the role of the competence of the harvester machine operator in the execution of their tasks through the application of an Ergonomic Work Analysis (EWA).

METHODS

In order to analyse the competencies acquired by operators of sugarcane harvester machines and the role in managing their health and the variable activities, we used EWA. This methodological approach of intervention was proposed by Ahonen et al. (1989) and it is capable of obtaining the complex relationship between man and work by placing the actual activity of workers at the centre of the analysis.

EWA consists of a 'bottom up' approach prioritizing the real activity instead of hypothesis previously formulated (Wisner, 1995). Although the methods and techniques employed within an EWA depend on each studied situation, the approach is based on two basic principles: the participation of the worker in the analysis process and the field study of the real situation. Therefore, the present study comprises a qualitative research based on two cases. We studied two sugar mills (referred to as A and B) that agreed to make part of the study. They are located in the Piracicaba, São Paulo State – Brazil, region that is undergoing a mechanisation process. Sugar Mill A is a small, family-owned business that adopted mechanical harvesting in 2006. The machinery for the two fronts of mechanical harvesting is all owned by the sugar mill–a total of five harvester machines.

Sugar Mill B is part of a group comprised of five units, being the only one of the group located in São Paulo State. The sugar mill implemented mechanical harvesting in 2010 and has only one mechanised front, manually harvesting the other six fronts. Because mechanised harvesting in Sugar Mill B is a recent development, much of the front harvesting machinery is outsourced; of the four harvester machines, only two are owned by the sugar mill.

To understand the prescribed work and the tasks entrusted to operators, we conducted interviews with those in charge of all the cutting fronts of the sugar mills and the leader from Sugar Mill B. For the analysis of the activity, nine operators were studied through observations, filming and photography during the performance of their work. The visits were performed on different days of the week and at different times of the day: morning, afternoon and evening/night. The observations primarily occurred inside the cabins of the harvester machines, but activity was also observed in the field within a certain distance of the machines in operation. During the observations, we asked questions such as "what," "how," and "why" to understand determinant aspects of the activity.

Individual and collective interviews were conducted with the operators. The majority of the individual interviews took place during the operation. The first interview with each operator sought to collect basic data such as age, education, time in the profession and access to professional training courses. Subsequent interviews did not have a well-structured script of questions; they were based on the observations and analyses already performed.

The collective interviews took place at moments when it was possible to gather the front cutting operators, such as during meal times and pauses due to machinery breakdowns and the lack of trucks. To understand the collective work, six tractor drivers were also interviewed individually and collectively, primarily with other tractor drivers and machine operators. The data obtained through interviews, filming and recording was transcribed and keywords were selected to perform the interpretation and description.

To validate the results, self-confrontation was used, which consisted of relaying to operators a description of their activities in order to understand what caused them to act in a certain way (Wisner, 1995). This self-confrontation occurred both during the operation and in the group. This brought together three operators and was conducted during the off-season and off-work situations. Prompted by film viewing, playback of phrases and using keywords, operators were questioned about various aspects of their work, and they complemented and corrected the description of their activities. All workers participating in the study were informed about the research goals, and a commitment was given to preserve complete anonymity of images and information disclosure.

SUGARCANE HARVESTER MACHINE

The sugarcane harvester machines (also called combines) perform the basal cutting, promote the cleaning of sugarcane through gravity (by the action of fans and/or blowers), and chop the stalks into 15 to 40 cm billets (on average), unloading them onto a transport unit for transshipment. Inside of the machine, the sugarcane passes through various stages from the moment of basal cutting to the loading into the transportation vehicle. During the harvesting operation, the machine (Figure 1) is positioned in the sugarcane row and initially cuts the sugarcane pointers with the crop topper. The crop dividers, the knock down and feeding rollers constitute the power supply system that guides the sugarcane bundle to be chopped by the base cutter, composed by two rotating disk blades. The gathering and lifting of the sugarcane bundle is initiated by an elevator roller. The sugarcane bundle is then horizontally carried and distributed by the feeding rollers. Then, the chopper rollers cut the sugarcane into billets that are deposited in the elevator's basket and the primary extractor removes impurities. The billets are then taken by the elevator and at the end, a secondary extractor performs a second clean up before the billets are unloaded into a transportation vehicle.

OPERATOR

All harvester machine operators interviewed were male and despite the initiatives to reallocate workers from manual cutting to new positions generated by the cutting mechanisation, in the studied sugar mills not all of them began their careers as manual sugarcane cutters. They had as previous occupation various jobs either inside or outside sugar and alcohol sector. As for education, six

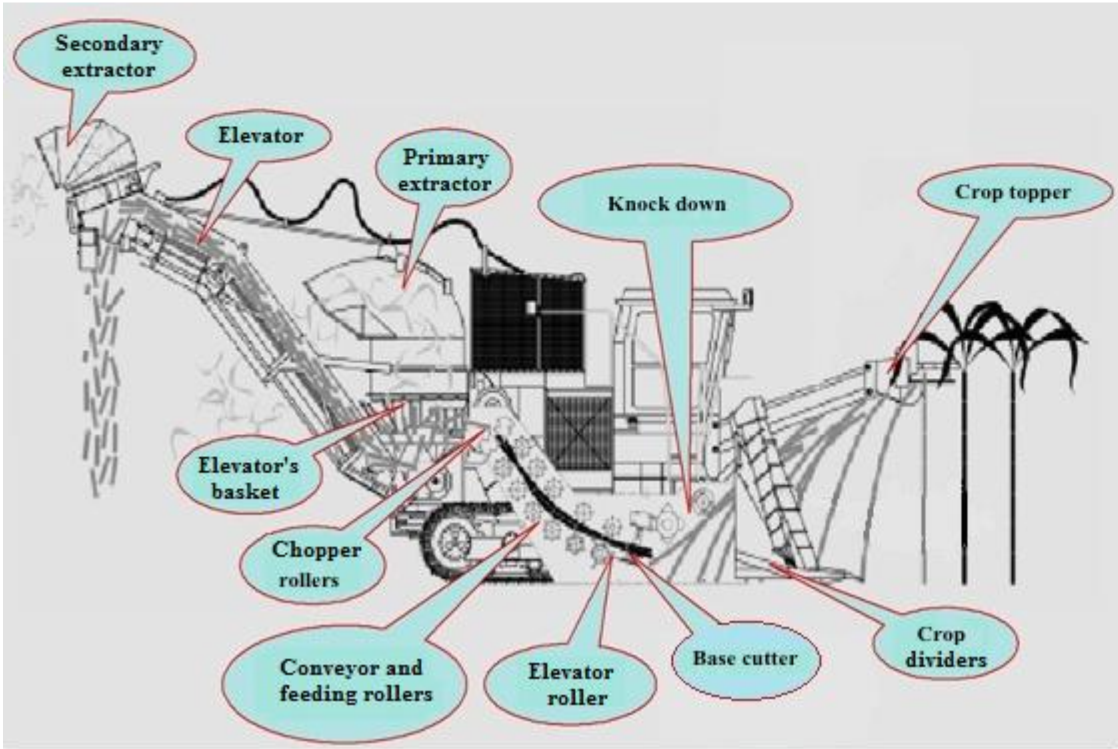

Figure 1. Schematic view of the primary functions of a sugarcane.

operators had incomplete elementary education, three had attended high school, but only one had completed it. Concerning qualification courses for harvester machine operators, only three of the studied operators had access to training:

"When the machines came, they said: 'let's try this one to see how it goes.' I learned by myself. The beginning was complicated; you see, in the first areas that we harvested, no sugarcane was even grown ... it would sink very close to the base and would cut everything off!"

OPERATION

Work organisation

Harvesting machines are allocated in mechanised cutting fronts, which are typically located in nearby areas where the sugarcane is apt to be cropped in the same period. In each cutting front there are usually four or five harvester machines and other supporting vehicles such as:

(i) A truck-convoy for supplying fuel and lube oil,
(ii) A workshop-truck for performing necessary repairs,
(iii) A water-truck in case of fire,
(iv) Trans-shipments for loading the harvested sugarcane,
(v) A caterpillar-truck for eventual machine towing,
(vii) A truck with two or more trailers or hp-motor for transportation to the sugar mill,
(viii) A loader for arranging the sugarcane for transport.

As Ripoli and Ripoli (2004) noted, the harvesting period in Brazil implies a *"war operation"* for the synchronised mobilisation of all front cutting machines to ensure adequate supplies for a constant flow (24 h per day) of raw material production. The operator workload, which is typically a 5x1 type (5 working days per 1 rest day), can be 8 hours with three shifts or 12 h with two shifts (12x2 was the practice used at the sugar mills examined in this study). Depending on the work organisation, these shifts can be either be exchanged every 7, 15 or 30 days or remain fixed during the entire harvesting period.

The operator is assigned to operate the same machine throughout the harvesting period (except for the person that covers the days off) and his prescribed duties consist of cleaning and inspecting the machine at the beginning and end of the operation, cataloguing the breakdowns/stops and reasons, preventing damage to the machine, preventing loss or damage to the harvested raw material, and assisting in any repairs.

Once the cut is running simultaneous to the loading, this operator is also assigned to work with the same trans-shipment person, also called a tractor driver because the unit that typically tows the trans-shipments is a tractor. In the sugar mills examined in this study, this relationship can be between pairs, an operator and a tractor driver, or trios, one operator and two tractor drivers. In the two studied sugar mills, the salary of the harvester operator was solely based on worked hours. However, the most common payment practice used by sugar mills is divided between fixed and variable instalments according to productivity.

ACTIVITY

Because the competencies are invisible, their existence can only be indirectly inferred through external signs (Stroobants, 2006). Therefore, the activity analysis is presented by highlighting the knowledge and strategies employed in the operation. These strategies are important for ensuring the highest production quality and managing the operator workload.

Regulation of the machine

Before beginning the operation, the operator performs adjustments to the mechanisms of the machine already inside the sugarcane row (or “street”) to be harvested. This occurs when there is a transfer of the plot (or even blocks) or in cases where the age of the planted sugarcane varies. He adjusts the inclination and height of the crop dividers to enable the lifting of tangled or tumbled sugarcane in such a way that the dividers just barely touch the ground. He also adjusts the crop topper’s height so that only the sugarcane leaves are cut (preserving the maximum amount of stalk) and adjusts the height of the base cutter with the suspension system in front of the machine. The latter is critical because the part of the stalk closest to the ground is the richest in sucrose. Therefore, the cutting should preferably be performed as close to the ground as possible.

To determine if the cutting height is ideal, the operator relies on a numbered ruler that displays the elevation level at the front of the machine. After determining the proper cutting height, there may be irregularities in the ground requiring the operator to adjust the height during harvesting, lifting and lowering the machine so that the base cutter follows the undulations. This is because if in a moment of upslope the operator does not lift the machine it can pull out the stumps with the root, leaving flaws on the plot that will damage the next harvest, and if in a moment of downslope he does not lower the machine it will leave a very high stump, wasting the best part of the sugarcane. Therefore, paying attention to the cutting height is crucial part the operation. This can be facilitated with a ground copier, which is an automated system for the height control of the base cutter. However, this device is not always available because it is an accessory in some harvester models, and it cannot always be used. On grounds that are not prepared for mechanical harvesting, with holes, ditches, slopes, rocks, or flaws on the sugarcane rows, it is not possible to use the system because it will not recognize these variables on the ground and damage the machine. For these reasons, operators eventually develop operational methods that help them in the task of manually regulating the cutting height during harvesting, such as detecting differences in noise of the machine:

“...over time, just by the noise of the machine, you know that you have to lift the machine. It swallows the rumble, and the base cutter pointer stops up there. Then, you know you're picking up ground and you have to lift it, then it eases up....”

Variability of the ground

As previously mentioned, any ground that is unprepared to receive mechanical harvesting (with considerable declivity) poses a risk of tipping the harvester machine. Although in theory one cannot place a mechanised front on ground with slopes greater than 12%, in practice what was observed is that the sugar mills in this study (with their recent mechanisation process) still allocated machines to these grounds and cut where possible. Thus, operators are instructed to harvest the sugarcane up to where the machine still has access. The strategy adopted by the operators on the sloping grounds was to balance the machine with the elevator: they always position the elevator against the declivity and attempt to rotate the elevator approximately 180° during the manoeuvres.

Variability of sugarcane

In addition to the slope and pedological attributes (such as holes, rocks and gullies), there are often variations on the ground that are inherent to the maturation process of the raw material to be harvested. Sugarcane rows are planted inside a sulcus, spaced from each other by 1.5 m. In newly planted sugarcane, the sulcus is located at a greater depth than the spacing if they are not levelled during the planting. As more cuttings are made, the stump roots become increasingly superficial. This is called "high stump" by the operators, that is, it is located higher than the ground between the rows. Both conditions have a direct impact on the operator’s work.

“There are places which are nearly 1 inch of stump because you cannot lower the machine. Working with high stumps is also bad because with high stumps, there is a limit for you to lower the machine not to rip off stumps”.

Thus, in cases where the sulcus is deeper, the operators base their depth on the manometer that indicates the pressure of the base cutter, maintaining a certain range. If the pressure rises or falls too much, they adjust the height of the machine. It is also possible to use the pressure manometer to determine the cutting height and then rely on the corresponding level indicated by the ruler. In cases where the stumps are high, they pay attention to evidence showing that the stumps are being ripped: the presence of too much dust during cutting and “wigs” (stumps with the root) being thrown into the trans-shipment.

The sugarcane still presents other variations. As the plantation ages, productivity falls. Sugarcane that initially presents large thick stalks with many leaves is called “strong sugarcane.” With successive cuts, it becomes “weak sugarcane” with smaller stalks and fewer leaves. This characteristic has a significant impact on the operator’s harvesting approach because it can determine the speed of the machine, the rotation of the primary extractor and infers how much cane to cut without turning on the elevator. The visibility is considerably reduced when harvesting “strong sugarcane:” This “Strong sugarcane” also influences the speed of the machine, which must be slower.

Likewise, the type of sugarcane affects the rotation of the primary extractor fan, allowing a higher or lower speed. “Strong sugarcane,” being larger, presents heavier billets, which allows an increased fan speed without the billets flying together with the straw. “Weak sugarcane” requires a lower speed. This is checked by the operators through rear view mirrors that can show the primary extractor and any billets thrown to the ground.

The type of sugarcane can also influence whether the operators accumulate billets of sugarcane in the elevator’s basket without turning on the conveyor. While operators adjust the cutting height, they accumulate the chopped sugarcane in the basket and do not turn on the conveyor of the elevator, either to save time or because the trans-shipment vehicle is not in position to receive the billets. However, the rear view mirrors do not show the basket, so calculating the amount of sugarcane to be cut without clogging the basket is acquired by experience. This knowledge is also useful in the harvesting of short sugarcane rows, where the trans-shipment stays still to save manoeuvres and the machine harvests the entire row, unloading only at the end.

When the stalks are lying over other rows of sugarcane in a diffused way it is difficult to identify the sugarcane row, which is essential for good alignment between the base cutter’s discs and the lower portion of the stalk. To avoid the stalk from becoming chipped, operators adopt strategies to identify the sugarcane row. They can take as a reference the previous row that has already been cut by aligning the crop dividers of the machine. They can use the sprouts of sugarcane, when they are present.

Variables of the harvester machine

In addition to the adaptations in facing the existing variables, another important feature of the operator activity is the ability to identify problems in the machine. Among these are blunt or broken base cutters, blunt chopper rollers, and obstructions/blockages, or “straw tamp.”

Base cutter’s blades wear out during harvesting - a natural process that can be accelerated if the operator lowers the machine too much. When the blades are dull, the operator observes chipped stumps or entire sugarcanes smashed by the machine in the previous sugarcane row. When the chopper roller’s blades become dull, the operators become aware of the problem through signs observed in their rear view mirrors such as entire stalks being thrown on the trans-shipment vehicle and the presence of excess straw in the secondary extractor.

Clogs can occur in the base cutter, the chopper roller and the elevator’s basket. When clogging occurs in the first two, the respective manometers indicate the problem with a sudden rise in oscillation during the cutting; operators detect this and perform a “reversal,” changing the cutting direction with a button. When the blockage occurs in the elevator’s basket due to the accumulation of billets without turning on the elevator (or from harvesting “strong sugarcane”), operators notice the problem through the rear view mirrors, which show a decrease in the amount of straw that comes out of the primary extractor.

When the basket is clogged, the chopper roller has nowhere to deposit the billets and they end up passing behind the roller and falling onto the ground instead of going through the elevator. In this type of clogging, the operator needs to turn off the machine, go down and release the clogged billets with a piece of sugarcane or with some type of metal hook that is made by the operators and mechanics. Meanwhile, it may be necessary to climb on the machine and enter the opening of the primary extractor and trample on the clogged billets, forcing them downward.

It is worth mentioning that when operators detect a problem they perform a diagnostic to determine where the problem is, based on the available information and their competencies, and immediately begin the repair process. Repairs are responsible for much of the physical effort expended by operators and are the primary reason for complaints related to breakdowns of machines.

Risk of accidents

In addition to the risk of accidents and injuries resulting from performing repairs, operators also live with a major accident risk inherent to the operation of the machines. This is because the junction of the cutting and loading operations requires the simultaneous movements of the harvester machine and the trans-shipment vehicle within a distance of just three meters. Factoring in the lack of ground preparation for mechanised harvesting (pedological

(pedological accidents and slopes) and the limited visibility for harvesting during the night, the risk of accidents and collisions is very high. Night work, in addition to reducing the visibility over long distances, leads to chronic fatigue and reduced alertness, further increasing the risk of accidents. An operator clearly explains the fatigue and the risk of accidents due to the shift work:

"At night the danger is falling asleep... You must rest well during the day."

It is important to consider that fatigue due to shift work (and therefore the risk of accidents) is aggravated by the length of the workday, which in this study was 12 h, excluding the displacement time for the operators.

In addition, mechanised harvesting is subject to weather, such as rainfall. When it rains, it is necessary to stop the cutting for two reasons: the trans-shipment is difficult to moving around, and the wet ground is subject to greater compacting and damages the ratoon. However, harvesting may be performed in the rain depending on the conditions of the plot (that is, if reforming is scheduled, if the ground has no slope, if the type of ground allows it). Harvesting in the rain leaves the area that has already been harvested smoother, presenting a hazard for the tractor operator with the trans-shipment.

Variability of tasks

Several operators had other duties such as being an operator and in charge of the front at the same time, or covering the shift the mechanic or the tractor driver. And although there are mechanics in the cutting fronts, it is common that they assist in machine repair; therefore, over the time they know how to fix it as well.

Moreover, the scope of work of the harvesting machine operator occupies the offseason period, during which the operators perform various activities such as operating machinery for soil treatment (disking, sub-soiling, planting, fertilising), assisting mechanics in complete maintenance of the harvesters and even collecting rocks and stumps present in sugarcane fields that can break the machines.

DISCUSSION

Competence – Device relationship

Harvesting is considered the most complex stage and the most important operational cycle of sugarcane because it determines the quality of the product delivered to the sugar mills (Magalhães et al., 2008). The activity analysis provided evidence that the set of competencies held by a harvesting machine operator is a key component in determining this quality. The obtained results show that the primary professional competencies of the sugarcane harvester machine operator are: performing the regulating of implements of the machine (crop dividers, crop topper, base cutter); operating the machine on sloping and rugged ground; harvesting different types of sugarcane; harvesting at night; avoiding damage to the machine; diagnosing machine problems; performing necessary repairs; performing other off-season tasks; and if necessary, performing other tasks concomitantly with the operation.

The competencies for operators in regulating and operating the machine at night and on different types of ground and sugarcane highlight the conclusions of Abrahão (2000) on the capacities relevance with the regulation capacity of the operators, that is, the ability to manage variables according to the situations. According to Daniellou (2002), in any work activity there are always numerous variables that lead to a detachment regarding the expected situations, and production only achieves quantity or quality because operators resort to strategies to compensate for the variables. To meet the demands of a given work situation, operators are constantly undergoing a process of internal regulation (Abrahão, 2000). Operators regulate the activity by managing the external and internal changing conditions of the activity and taking into account the effects of the activity (Tersac and Maggi, 1996).

According to Abrahão (2000), it is only when confronting the variables of the activity, the tools, the object and the organisation of the task that the intelligence of the operator manifests itself. Hence Le Boterf (2000) states that to be competent means to have the capacity to act and react in different contexts , to request and combine the necessary and relevant resources to accomplish the task, to understand it and to succeed in its execution. The greater the capacities of the operator, the greater the possibility of dealing with the uncertainties present in the activity (Vasconcelos et al., 2008). In examining the harvester machine operation, it was observed that operators handle several variables (many unpredictable) and risky situations. Therefore, the multidimensional and multifunctional capacities are those that sustain the different aspects of professional activities (Weill-Fassina and Pastré, 2004).

These capacities, as well as the abilities and experiences, are acquired through the practice of an occupation (Christol and Mazeau, 1996). As they acquire capacity and experience, operators manage to integrate more dimensions or concepts into the management of the situation (Weill-Fassina and Pastré, 2004). For Hubault (1996), the question of competence focuses on the "and" thematic, an implicit order that causes the operator to work well "and" quickly, "and" with quality, "and" low cost "and" safely. As shown in the activity analysis, the machine operators of sugarcane harvesters perform the appropriate cutting, ensure good cleaning, avoid damaging the machine, ensure the production even on adverse grounds, and take into account their safety and health status.

This practice also allows the operators to increase their abilities and easily master increasingly complex professional situations (Christol and Mazeau, 1996). Therefore, the concept of competence is linked to the complexity of the task (Leplat, 1996). The operator is able with practice to develop the capacity to detect problems in the machine, perform repairs, perform other activities during the offseason and take on other tasks concurrently. The latter was a commonly observed practice in one of the studied sugar mills, where some cutting fronts lacked a well-defined hierarchical structure, delegating to harvester machine operators the task of the person in charge of the front, the tractor driver and the mechanic.

Two other points in this study are worth mentioning. The first concerns the lack of ground preparation at the sugar mills for receiving mechanised harvesting, requiring exceptional competence from the operators to operate the machinery on such challenging terrain. Despite the existence of a current ground copier and a GPS autopilot, it is clear the role that human activity played in these situations. This is because human behaviour presents the particular dynamics of flexibility, adaptability, development and improvement of forms of regulation.

The second major point focuses on the lack of professional training courses for the operators. Although most operators interviewed never attend any course, all of them held the necessary competencies to operate a harvester machine to some degree. An explanation for this finding lies in the fact that the transformation of knowledge into competence occurs from the combination of many forms of learning: reading, communication, practice, situation analysis, and observation (Fleury and Fleury, 2001). Moreover, as shown by Weill-Fassina and Pastré (2004), competencies are built through the knowledge of an outcome against the obstacles to achieving the goal, and not through the repetition of gestures and actions. Thus, the development of competencies combines learning by action and learning by the analysis of the action; the articulation between these two moments is the characteristic of the construction of professional experience (Weill-Fassina and Pastré, 2004).

Conclusion

This paper specifically emphasised a very important characteristic that involves the operation of sugarcane harvester machines: the competence of the operators. Although this paper has the limitation of being a case study, the EWA method allows for the generalisation of results in two specific situations. It enabled an analysis of the operator competencies required for the task, as well as the competencies are operationalised based on the actual work. The sugarcane harvester is a large and highly complex machine, requiring a certain degree of operator competence to operate it. In addition, the presence of variables in the activity demands additional competence to obtain a satisfactory operation from the point of view of productivity and safety. According to the obtained results, we can affirm that the competencies attained by the operators were the key to obtaining a quality harvest in the sugar mills examined in this study. They enabled the execution of multiple tasks and managing the different variables of the activity while considering the concomitant risk of accidents and impacts on health.

Furthermore, these competencies overcame the lack of ground preparation for the mechanisation of the cut and the technical limitations of the harvesting machine. While the machine has its role and its contribution, without the competence of the operator it would be worth nothing.

Obviously, the effort put forth by the operator in getting the best performance out of the machine can lead to a physical and mental overload, e.g., the physical effort during machinery repairs and fatigue due to shift work and the length of the workday. Due to the limitations of this paper, aspects that influence the workload of operators such as work sitting, shift work, payment by production and the cooperative relationship with the tractor driver could not be deeply addressed and require further studies. Additionally, knowledge about the activity of the operator and the necessary competence for the operation must be deepened. Other relevant contributions from future research will address the cognitive processes that engender the mental load of these operators.

Conflict of Interest

The authors have not declared any conflict of interest.

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