Sugar-cane harvesting machine design “in the field”

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Mechanical sugar cane harvesting machines were first developed by farmers in Australia. In early 1970s the Australian concept of harvester served as inspiration for the production of the first successful machines in Brazil. This research explored the design of these machines in Brazil and in Australia. Task analysis of machine operation, questionnaires and interviews with harvesting teams were undertaken at five sites considering both countries. It was observed that maintenance staffs made several modifications to the machines to improve reliability, operation, productivity, maintenance and safety. It is believed design in use should be taken into account during the design process.

**Practitioner Summary:** the study explores the design of sugar cane harvesting machines and identifies the design modifications undertaken by field maintenance staff to improve several issues of the equipment. It is discussed that designers and workers should participate in the harvesters’ design, according to their diversity and their specificities.

**Keywords:** design-in-use, harvester machine, participative design, ergonomics.

1. **Introduction**

Brazil is the largest sugar cane producer in world and its last season (2013/2014) surpassed 650 million of tonnes (UNICA, 2014). Over the last decade, the country has experienced a process of harvesting mechanisation due to environmental, social and economic demands. Nowadays, around 85% of the whole Brazilian crop is mechanically harvested (CTC, 2012).

The first successful sugar cane harvester was built in Brazil in 1973, adapted from the Australian concept (RIPOLI, VILLANOVA, 1992). Australia led the sugar world in the adoption of labour and cost-saving mechanisation. According to Kerr and Blyth (1993), today’s sophisticated cane harvesting systems are the evolutionary product of more than 100 years of improvisation and adaptation. The pursuit for a successful machine in Australia began in 1890 when the first design was patented and since then, many growers were dedicated to the task of creating a reliable, practical machine suitable for the industry’s needs. Currently, two multi-national equipment manufacturers are the leaders in production of these machines.

Although the machine design is “corporatized” by large manufacturers, as pointed by Béguin (2003), the design of an instrument is far from being finished when the final technical specifications leave the research and design office. The inventiveness and creativity shown by users when faced with technique is a necessary condition for the efficiency of their activity. When users appropriate of artefacts, there is a specific process of construction and reconstruction of uses and devices: in other words, design continues in usage (RABARDEL, BÉGUIN, 2005).

The processes by which the users continue design in usage are called instrumental genesis and consist of instrumentation and instrumentalization (RABARDEL, BÉGUIN, 2005). According to Béguin (2007), instrumentation involves form of actions, i.e., the operator develops new techniques stemming from those he/she already disposes of. Instrumentalization, on the other hand, is related to the artefact’s properties, so the operator adapts, modifies, transforms the devices to mould them to his/her own constructions.

As highlighted by Rabardel and Waern (2003), the existence of instrumental genesis is not an effect of a deficient design, but rather an expression of the concept embodied by the artefact that is in all ways instantiated by the user. Design, thus appears as an activity distributed between designers (design for use) and users (design in use): designers elaborate a proposition in form of artefacts and users may take advantage of these propositions (totally, partially or not at all) in order to develop instruments that fulfil their needs, considering the organisation and the situations.
The aim of this research was to explore the design of sugar cane harvesting machines in Brazil and Australia. The objective was to account for the intelligence manifested by users during their activity and more specifically to identify the continuation of design in usage in both countries.

2. Method

The research was divided in two phases: the first in Brazil and the second in Australia. The first phase was developed from May/2013 to February/2014 at three sites located in the city of Piracicaba, São Paulo State. The second one was undertaken from July/2014 to December/2014 at two sites: in Tweed Heads, New South Wales and in Tully, North Queensland.

Each site had a different machine model therefore, the machines Case 8800, Cameco CH2500 and John Deere 3510, 3520 and 3522 were analysed in the study. In order to perform task analysis, observations and video footage were conducted during the operation, primarily inside the cabins but also in the field within a safe distance from the machines. To access the design of the machines and to identify the design modifications and improvements made by users, interviews and questionnaires were applied with the harvesting team.

In Brazil, the team is composed basically by: team leaders, harvesting machine operators, tractor drivers and mechanical technicians (and their assistants). In Australia, the sugar cane growers own the machinery or they hire a contractor so there are no leaders, neither mechanical technicians, once the operators are responsible themselves for the maintenance. The interviews were conducted individual and collectively with all team members. Individual interviews were carried out during the operation and the collective ones, during moments when it was possible to gather the team such as pauses for refuelling, maintenance, etc.

The questionnaires were applied with the operators and they aimed to detail the workers’ experience and the evaluation of the machines’ design using Likert Scale for nine design features related to ergonomics: cabin access, cabin’s internal space, visibility of cutting, posterior visibility, seat comfort, acoustic comfort, thermal comfort, layout of controls and layout of displays. The questionnaires applied with the mechanical technicians in Brazil aimed to detail their experience, maintenance process, design’s limitations and modifications. The design modifications performed by Brazilian teams were collected during off-season, period in which all harvesting teams are gathered for machinery maintenance and the machines are in process of total disassembling. As the period of research in Australia comprised the season time, the design modifications were collected during pauses in harvesting. For data analysis, filming and recording were transcribed and key words were selected and used to facilitate the interpretation and description of results.

The study adhered to the guidelines of the ethical review process of both universities: The University of Queensland and Federal University of São Carlos. All workers participating in the study were informed about the research goals and signed a consent form.

3. Results

3.1 Task analysis

The mechanical sugar cane harvesting principle currently used worldwide gathers the operations of cutting and loading in a single process, therefore, it requires synchronized movement of the harvesting machine and the transhipment vehicle.

As shown in figure 1, the sugar cane passes through various stages in a harvester machine. The crop topper cuts the sugar cane pointers and the crop dividers lift up and separate the sugar cane row to be harvested from the adjacent ones. The knock down bends the stalks and the base cutter cuts the them at the ground level. The sugar cane bundle is then horizontally carried by the feeding rollers and the chopper rollers cut the stalks into billets that are deposited in the elevator’s basket. The primary extractor removes impurities and the billets are then taken by the elevator and at the top, a secondary extractor performs a final cleaning before the billets are unloaded into the transportation vehicle.
All of the machine’s functions are adjusted by the operator inside the cabin, considering the quality requirements and the variability. The quality requirements for harvesting are related to the height of tip cutting (in order to cut only pointers and leaves), the height of base cutting (to get the lower part of stalk which is richer in sucrose) and the cleaning of billets (to eliminate as much as possible straw and other impurities). The variability, on the other hand, are related to the age of the crop, the type of sugar cane (variety), position of the stalks (standing or tangled), characteristics of the plot (soil composition, slopes) and plantation practices (one or two rows).

The task analysis highlighted the need for operator visibility of various areas of the machine to meet harvesting requirements. During the harvesting, operators need good visibility of the front of the machine to verify the crop topper’s height, machine alignment in the sugar cane row and base cutter’s height in order to make the necessary adjustments. The cleaning of the billets is monitored by the visibility the operators have of the back of the machine and rear views. The operators look for alterations in the load such as excess of straw, dust, stalks not chopped or billets flying along with the impurities so they can make the adjustments and/or detect problems.

The questionnaires identified that visibility is a feature that needs improvements according to the operators. The visibility of cutting of Case 8800 was not well evaluated due to restrictions associated with the location of a protective screen that retains the leaves (Figure 2A). The visibility of the back of the machines John Deere 3520 and John Deere 3522 were also evaluated as “satisfactory” and Case 8800 was qualified as “bad”. Concerning Case 8800, this evaluation is related to the position of the radiator, which is more prominent at the right side, blocking the view of the primary extractor (Figure 2B).
Other ergonomic issues identified by the operators were: acoustic comfort, seat comfort, cabin access and internal space. Acoustic comfort of all machines received at least one bad evaluation due to inefficiency in noise isolation: Cameco CH 2500, Case 8800, John Deere 3510, 3520 and 3522. With regard to seat comfort, operators of Case 8800 and John Deere 3522 pointed out the need for better vibration attenuation and considering Case 8800, the backrest dimensions (width and high) should also be improved. Cabin access and internal space were issues identified only in Cameco CH 2500 due to lack of a platform and the restricted space for more than one person, respectively.

3.2 Design modifications

In the cases studied, both maintenance staffs from Brazil and from Australia were primarily concerned with ensuring reliability of the harvesters and aimed to prevent wear and breakdowns. Hard facing of crop dividers, elevator and feeding rollers, chopper rollers and base cutter were found in all five machines studied. The principle is to cover these parts with welding to increase their thickness and consequently, their resistance during use.

The staff in Brazil made numerous modifications to the harvesters. Considering the three sites together, more than 50 modifications were found and they aimed to improve reliability, visibility, productivity, maintenance and safety.

To improve reliability, reinforcements were made in several parts of the machines, like the posterior structure (Figure 3A) and the elevator (Figure 3B). According to the staff, these and many others are necessary due to the places they harvest: “The machine cracks because it can’t bear the job. There are too many bad places to harvest here, sloping, uneven places… So you have to make reinforcements all the time”.

![Figure 3](https://via.placeholder.com/150)

Figure 3. Reinforcement of posterior structure of John Deere 3520 (A) and of the elevator of Case 8800 (B).

With regard to visibility, external lights were added in places where operators need to see during harvesting at night. As shown in Figure 4, additional lights were placed at the back of the machines so the operators can have better visibility of the primary extractor (figure 4A) and the tractor drivers can check the size of stumps for the operators (figure 4B).

One modification related to productivity was the fuel tank of John Deere 3522 machines. The staff increased the tank to eliminate the need to refuel the harvesters at night, considering that this machine is for two rows of sugar cane and fuel consumption is higher. The figure 5 shows the original size and the new part, increasing tank’s capacity in approximately 350 litres. For the machine to bear the new weight of the tank, the staff made reinforcements in the structure of the tank and the in place where it is positioned on the machine.
Figure 4. Superior light at the back of Case 8800 (A) and inferior light at the back of John Deere 3520 (B).

Figure 5. Fuel tank of John Deere 3522 increased.

The hydraulic oil tank also suffered alteration to its oil level warning system. As shown in figure 6A, the original design has the sensor way below the oil level, which led to great oil losses until the system could detect the oil leak. The maintenance staff designed an additional tank, with capacity of 20 litres, containing the sensor and connected to the main tank. According to the mechanical technician: “We used to lose 40, 60, 100 litres of oil. Now it’s only 4 or 5 litres before the machine beeps”.

Figure 6. Hydraulic oil tank of John Deeres 3520 and 3522. Figure A shows the original design and figure B shows the modification, with the additional tank.
Concerning maintenance, a pulley system was created (figure 7) by one of the staff due to difficulty to move the three radiators (for water, oil and intercooler) located at the top of the machine. A mechanical technician explained: “When the radiators break, we have to take them off and put them on the ground to make the repairs. It’s 5 metres from up there and they are heavy, around 60kg and there is no grip. We used to do it by hand, with 3 or 4 people to help”.

![Figure 7. Pulley being used. One operator controls the pulley and the other directs the radiator.](image)

To improve safety, a steel cable was added to hold the elevator in position once the original strap (Figure 8A) was not enough to contain the elevator’s weight. According to the operator of Case 8800: “The strap breaks very often and elevator falls down. It can’t bear the weight. And it’s dangerous if it falls over the transhipment or someone…”.

![Figure 8. Steel cable detached from its connexion (A). Steel cable connected (B).](image)

In Australia it was observed that the modifications to the equipment were mainly focused on prevention of wear, with hard facing of parts consisting of the main alterations practiced. Nonetheless, at one site, the Cameco CH 2500 (a 16 year old machine) had its cabin lifted up (figure 9A) in order to improve the operator’s visibility of cutting. With the new height, an additional step was placed to facilitate the access of
operator (figure 9B). As pointed by the operator: “We lifted it up and you can see the cane better, see where you're going…”.

Figure 9. Cameco CH 2500. Cabin lifted up (A) and the additional step to access the cabin (B).

4. Discussion

The obtained results show that sugar cane harvester is a complex machine and its successful job demands besides skilled operators, modifications and adjustments. As observed, maintenance staff has a central role to elaborate and perform the necessary improvements in design. These modifications were specially developed to solve specific problems of each type of machine and they aimed to improve reliability, operation, productivity, maintenance and safety. Traditionally, design process is established by the classical engineering approach as something rational rather than a construction (see HUBKA and EDER, 1996; PAHL and BEITZ, 1996). According to Horestein (2010), the design cycle has a sequence of events leading from the idea to the finished product for the end user.

However, no matter how the subject’s activity is anticipated before the design process, user will develop the resources of his/her own activity (BÉGUIN, 2003). This is because during work users cope with unforeseen situations and full anticipation of future use remains limited (FOLCHER, 2003) and also because as pointed by Kaptelinin and Nardi (2006), technological creativity is rooted in our primate past. With continuing design-in-use, subjects encounter new needs and they lead to further design. Therefore, design seems to be a cyclical process, without any real beginning or end (RABARDEL and BÉGUIN, 2005).

The results show that design of sugar cane harvester is not completed with the finished product. In situations studied, new lights, additional reinforcements, better warning system, higher cabin and etc. were found necessary and were performed by the staffs.

To account for users’ contribution to design process, a participative approach is proposed by Béguin (2003). According to the author, there are exchanges of activity between designers during the design process (due to interdependence of their tasks and need for integration) and these exchanges should also be extended to those between users and designers. The idea is to favour a dialogical process, where the user can learn from temporary result of the designer’s work and symmetrically, the designer can carry out new apprenticeships resulting from the user’s “responses” (BÉGUIN, 2007). These “responses”, as previously presented, consist of instrumentation and instrumentalization process. Therefore, within this approach, users are assumed to be designers in a very real sense of this word (KAPTELININ, 2003).

Considering design as a collective process, as stated by Béguin (2007), besides the identification of worker’s task, anticipation of future activity and support the design of flexible devices, the ergonomist has the role of organizing and facilitating dialogues between designer and user. As highlighted by task analysis and questionnaires, the design of sugar cane harvester could benefit from the staffs’ participation, not only because they improved several aspects of the machine but also because there are some issues out of their reach. As shown, the position of specific parts (as the radiator) and cabin’s features (acoustic isolation, seat
comfort, cabin access and internal space) were found as needing improvements and the staffs were not capable of acting on.

5. Conclusion

The observations indicate that the design of the sugar cane harvester is not completed during the design stage of the life-cycle of a sugar cane harvesting machine. Rather, the maintenance staff, composed of operators and mechanics of the equipment has valuable insights and innovations to share with designers. The design of equipment could be enhanced if these insights were able to be harnessed in a participative design process.

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