Identification of key sugarcane harvester features using the Analytic Hierarchy Process

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Abstract. The Philippine sugarcane industry is worth roughly 88 billion pesos and employs around 700,000 Filipinos. However, the competitiveness of the local industry ($0.17 per lb sugar) is currently under threat from international producers ($0.14 per lb sugar) because of the upcoming ASEAN 2015 integration. One of the major blockages to cost effectiveness is the low productivity of the local industry. This may be addressed with the use of a semi-automated mechanical harvester. As a preliminary study, the present work captures the expert preferences of various stakeholders in the selection of a semi-automated mechanical harvester. This is done using the Analytic Hierarchy Process (AHP) surveying tool. The study assumes the following important factors: a) Ease of use, b) Productivity, c) Adaptability to different terrains, d) with Lifter, and e) with Topper. Using a survey with a series of pairwise comparison questions, it is able to quantify even qualitative factors affecting decision making. The priorities of the surveyed stakeholders are averaged and discussed in the results section. Widely used in policy making and planning, the paper introduces the use of the AHP tool to commercial machinery design. The model may be expanded and improved to consider other key factors.

1. Introduction
The Philippine Sugarcane Industry is now facing a dilemma which has big opportunities and challenges ahead. Sugarcane is the fourth largest crop in the Philippines (after coconut, corn, and rice). It easily gives employment to around 700,000 Filipinos. The sugarcane industry contributes no less than P70 billion annually to Philippine economy [1]. In the Philippines, sugarcane is planted in about 422,500 hectares with a labor force of 62,000 farmers. The archipelago has 23 sugar producing provinces. As of Crop Year 2009-2010, 29 mills are operational and divided as follows: 6 mills in Luzon, 13 mills in Negros, 4 mills in Panay, 3 mills in Eastern Visayas and 3 mills in Mindanao [2]. In terms of the farm sizes, 75% of farms have sizes less than 5 hectares and another 11% have sizes of 5 to 10 hectares. Among the remaining farms, 11% have sizes 10 to 50 hectares, a mere 2% have sizes of 50 to 100 hectares, while only 1% has a size of over 100 hectares.
The problem arises during the harvesting season since most of the mechanical harvesters that are available are not suitable to the terrains in our country. Most of the advance designed harvesters are basically suited to developed countries which have wide and flat farm areas. In the Philippines manual harvesting of sugarcane is still very much in practice because of the adaptability issue. Manual harvesting is very tedious and labor-intensive. Because of this, the cost of production for sugarcane becomes high. The efficiency in the harvesting industry is measured by the number of crops one manages to harvest within a given span of time. An increase in efficiency in the harvesting process will lead to lower production costs which will eventually lead to a bigger profit margin. Aside from the harvesting problem, the Philippine Sugar Industry is also facing another challenge because tariff on imported sugar under ASEAN Trade in Goods Agreement (ATIGA) is now at 28% [1]. The ASEAN Free Trade Area (AFTA) will basically eliminate the tariff, making imported sugar cheaper compared to locally produced sugar. Because the cost of production in the Philippines is a little higher compared to the neighbouring competitors, possible entry of cheaper imported sugar to cater the needs of 96 million Filipinos is considered the biggest threat to the country’s sugar producers. The cost of production of sugarcane in international markets is set at $0.14, while the cost of production of sugarcane in the Philippines is at least $0.17. Currently, the government has been imposing tariffs on imported sugar to protect the local producers. This inefficiency in harvesting contributes to further increase in costs of production. A solution to this would be to automate some parts of the harvesting process. According to [3], the Philippine agricultural sector’s plan to sustain growth is to increase the farmers’ access to technology.

In an interview with experts and officials from the Sugar Regulatory Administration (SRA), the authors learned that a mechanical harvester is almost always expected to have a lifter. The stalks sag a lot, especially due to the wet local climate and the characteristics of local sugarcane stalks (long and thin). Also, it has been reported that there are plenty of unused mechanical harvesters due to issues on adaptability to different terrains (i.e. sloped, rocky, or muddy). Lastly, having a topper would also be a huge help to the harvesters but the variability on the height of different sugarcane species makes this challenging. Having a mix of quantitative and qualitative factors makes it a challenging task to design an equipment that will have commercial success. The following is a case study demonstrating the capability of the Analytic Hierarchy Process (AHP) methodology to capture expert decision making with regards to machine design. For a designer, it is straightforward to produce cost effective and efficient machines, but it is quite a challenge to guarantee that the intended user will find value in it and actually use it. Capturing customer priorities using AHP before diving into the actual design process ensures that the designer fully understands the needs of the customer.

Examples of MCDM work conducted similarly for agriculture studies include using conflict analysis model to analyze crop choice of Philippine farmers [4]; using multi-attribute utility theory to study collaborative farming in Japan [5]; and using SWOT analysis and AHP to understand the decision-making of the local sugar industry in Algeria [6].

Using AHP, expert decision making of stakeholders may be captured. Both quantitative and qualitative factors may be quantified and converted into a single criterion, which will aid in the design of an appropriate harvester. The goal of this preliminary study is to describe a harvester design that would provide value to the local sugarcane industry. The paper is outlined as follows: a brief background on sugarcane and mechanical harvesters are discussed in the next section, to be followed by the methods, results, conclusions and acknowledgements in the proceeding sections.

2. Background: Sugarcane harvesting and mechanization
2.1 Sugarcane
Saccharum officinarum, the scientific name of sugarcane, is a member of the Poaceae or grass family. It is widely cultivated as it provides an approximate of 70% of the world’s sugar. Sugarcane, also known as the noble cane, accumulates a significant amount of sucrose in its stalk, which is then harvested and processed to produce sugar crystals [7].
2.2 Sugarcane in the Philippines

The following sugar cane varieties are currently available in the Philippines: PHIL 99-1793, PHIL 97-2041, PHIL 97-1123, PHIL 97-0693, PHIL 94-0913, PHIL 93-3849, and PHIL 93-3155 [8]. Varieties are described by their stalk characteristics, stalk diameter, millable stalk, average yield, potential yield, and districts with high yield of a certain breed or variety. Indicated varieties are commercial hybrid cultivars; thus, were specially bred to maximize production.

Some common properties and characteristics of the sugar cane varieties in the Philippines are cylindrical, ovate, barrel and conoidal in shape; small flat, semi-bulging to flat and corky cracks/patches; bud grooves and no bud groove; dark yellow-purple stalks, green-purple stalks and brown-purple stalks; green–yellow and yellow-green internodes. The average diameter size, millable stalks and potential yield are 2.81 cm, 2.31 stalks per stool at harvest and 2.34 L/kg/TC; 132.68 TC/Ha, respectively.

Table 1. Levels of mechanization of various crops in the Philippines. [9]

| Operation                  | Rice & Corn | Vegetables, Legumes & Root Crops | Coconut | Sugarcane | Fruits | Fiber Crops |
|----------------------------|-------------|----------------------------------|---------|-----------|--------|-------------|
| Land Preparation           | Intermediate to High | Low | Intermediate to High | Low | Low |
| Planting/Transplanting     | Low         | Low | Low | Intermediate to High | Low | Low |
| Crop Care Cultivating      | Low         | Low | Low | Low to High | Low | Low |
| Harvesting                 | Low         | Low | Low | Low | Low | Low |
| Milling/Village level      | High        | Low | Low | Low | Low | Low |
| processing                |             |      |      |      |      |             |

2.3 Mechanization and Sugarcane Harvesting Processes Locally

Hand cutting is the most common harvesting method utilized throughout the world; however, more developed nations such as the USA, Thailand, and Brazil have adopted mechanical harvesting to increase the harvesting yield. After harvesting, the cane is loaded into a trailer or truck, where it is transported to a mill. Along with other local agricultural processes, the Philippines have low levels of harvesting mechanization for sugar cane crops. In Table 1, the levels of mechanization for various crops in the Philippines are presented.

The predominance of manual labor and lack of development in agricultural technology are the reasons for the low mechanization of the majority of agricultural operations. Table 1 above indicated the high level of mechanization of pre-harvesting sugarcane processes, which may be due to the presence of imported tractors utilized by large-scale farms; however, as stated by T.D. Lopez (personal communication, April 2016) in an online interview conducted by the authors, most Filipino farmers cannot afford these machines as the cheapest available in the market still exceeds PHP 1.8 million. Furthermore, the lack of mechanization for sugarcane harvesting processes reduces the production yield as it cannot sustain the level of production yield that pre-harvesting processes possess. Reviews of many of the models that were developed at SASRI (South African Sugarcane Research Institute) on primarily the development of harvesting machines were taken down over a span of 20 years.

Fully automated sugarcane harvesters have limitations with regards to the terrain they are deployed on. In addition to their limitations, these harvesters are very expensive and can only be afforded by a few companies. Innovations have been made which led to the development of the semi-automated sugarcane harvester. Semi-automated sugarcane harvesters have addressed most of the requirements in the harvesting process such as proper consideration of the various slopes possibly encountered, the different types of cane that is harvested, as well as the topping requirements.
3 Methods

3.1 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) methodology is used to design the survey questionnaire and process the responses. AHP is a multi-criteria decision making method that was originally developed by Thomas Saaty [10]. It is a method to derive ratio scales from paired comparisons. The method is particularly useful when subjective opinions such as satisfaction and preference need to be quantified. The AHP methodology should capture how the decision makers in the sugarcane industry think, teach the authors how to prioritize over the numerous design considerations (e.g. ergonomics, machine performance and functions), and determine the most important factors contributing to the most effective design. All of these are necessary for the development of a potential commercial product. The methodology starts with a decision structure, which summarizes the factors that could affect the decision making of the stakeholders. The decision superstructure is shown on Figure 1 and is based on prior consultation with other stakeholders.

![Figure 1. Decision superstructure based on preliminary consultation with stakeholders.](image1)

The survey questionnaire is designed as a series of pairwise comparisons between the different factors found in the superstructure. The comparisons require the stakeholder to identify which factor is more important and by how much (in a scale of 1 to 9, with 1 referring to equal importance and 9 referring to extreme importance). The responses are then converted into a matrix, as shown on Figure 2. If the factor on the vertical axis is deemed more important than the factor on the horizontal axis, \( x_{il} \) becomes the actual judgement value (from 1 to 9). On the other hand, if the factor on the horizontal axis is deemed more important than the factor on the vertical axis, \( x_{il} \) becomes the reciprocal of the actual judgement value. Upon completion of the matrix, the columns are normalized by dividing each term of the column to the sum of the column. After normalizing, the importance of each factor is called the priority vector and is determined by averaging each row (see Figure 3). The priority vectors of all respondents are aggregated by getting the arithmetic mean. This then becomes the importance rating of each factor. The readers are directed to Saaty [10] and Seyhan & Mehpare [11] for a more in-depth discussion on the AHP methodology.

![Figure 2. Matrix summarizing the survey responses.](image2)
3.2 Definition of factors
The following were the factors considered in the study and their descriptions.

3.2.1 Ease of Use. This refers to the user-friendliness of the machine. The machine should be simple to operate and should not require extensive training for the operator. The machine should also not cause body pain/strain on the operator.

3.2.2 Productivity. The machine should significantly reduce the harvesting time and manpower requirement.

3.2.3 Adaptability. The machine should be easily adaptable to most terrains.

3.2.4 With Lifter. The machine should come with a lifter to help straighten the canes before cutting.

3.2.5 With Topper. The machine should be equipped with a topper to cut.

The factors were shortlisted based on preceding interviews with stakeholders and literature review. A conscious effort was also done to ensure that they are simple enough for all kinds of respondents to understand.

3.3 Conduct of expert survey
The experts were a mix of planters, farm owners, engineers and technical service providers from the sugarcane industry. The survey was added as a side agenda of the recently concluded committee meeting on mechanical harvesting of the Sugar Regulatory Administration. The experts were presented with a 10-question survey. The questions were all pairwise comparisons of all considered factors. For each question, the expert had to select which of the two factors is more important than the other, and by how much degree (from equally important to extremely more important).

Table 2. Profiles of experts

|     | Age | Role       | Had used mechanical harvesting before? | Location         |
|-----|-----|------------|----------------------------------------|------------------|
| Expert 1 | 51  | Engineering | No                                     | <no info>        |
| Expert 2 | 56  | Operations  | Yes                                    | Pampanga         |
| Expert 3 | 46  | Operations  | No                                     | Negros Occidental|
| Expert 4 | <no info> | Engineering | No                                     | Negros Occidental|
| Expert 5 | 39  | Operations  | No                                     | Isabela          |

4 Results and discussion
The survey results validated the expert opinion of the interviewees from SRA. Figure 4 summarizes the results. The prioritization rating from the experts is translated into percent importance of each feature of the harvester.
It is definitely a requirement to have a lifter as 3 out of 5 experts selected it as their top priority. It is almost twice as important as all the other factors. Reiterating the point brought up by the experts from SRA, the wet local climate causes the stalks to sag a lot. This sagging affects ease and efficiency of harvesting a lot. A mechanical harvester is almost always expected to have a lifter to ensure the stalks are vertical when they are severed, otherwise, additional manpower will be required to assist in the lifting of the stalks. Adaptability is also the second most important factor. Likewise, 3 out of 5 respondents agreed that it should be the second priority. The variability of Philippine terrain makes it challenging to design a single machine that would be compatible to all conditions. Productivity, surprisingly, is not the main concern of the stakeholders. It is possible that this is a consequence of having more technical than business-minded respondents (2 from Engineering, 3 from Operations, 0 from Business Management). To recall, a possible reason as well is the fact that the major bottleneck in harvesting is actually the availability of trucks for hauling. Too much increase in productivity would be useless if the other problems (logistics) will not be addressed. Having a topper function was the second least important, while ease of use was ranked the last priority of the respondents. Not to be mistaken that farmer welfare is not important, this may imply that a sugarcane harvester has a naturally simple operation. There is practically no way to make it difficult to operate, and thus, designers can focus on other more important aspects.

**Figure 4.** Summary of survey results. EU - Ease of Use; PR - Productivity; AD - Adaptability; WL - With Lifter; WT - With Topper.

**5 Conclusion**

The present study demonstrated that the AHP methodology can effectively capture expert opinion on decision making for machine design. The information derived from the interview with SRA officials agreed with the results of the AHP survey. The most important factor in a semi-automated mechanical sugarcane harvester is having a lifter (28.7%), followed by adaptability (21.2%), productivity (19.4%), having a topper (17.6%) and ease of use (13.1%). The model may be further extended to consider more factors. The next step would be to evaluate if such a design can be developed at an affordable cost.

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