Forecast Model of Sugar Loss Due to Mechanical Harvesting of the sugarcane crop

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Abstract: Mechanical harvesting brings about a great advantage to a cane grower. Time saving and cost reduction are important merits, but the mechanical harvesting becomes harmful whenever it is applied under unsuitable conditions. Namely, long delay in milling of the harvested billets during mechanical harvesting of the sugarcane crops will cause loss of the juice from the torn cells, commencement of the respiration and enzymatic processes in the living tissues of the billet in abrasion and failure points and ultimately reducing the purity and sugar content of the juice due to sucrose inversion. The aim of the present research, having been carried out in Khuzestan Amirkabir Agro-industry Unit sugarcane farms, was estimating the sugar loss and quality degradation of the billets resulting from mechanical harvesting. For predicting the sugar loss, a regression model including explanatory dummy (qualitative) and quantitative variables was used. Quantitative explanatory variables included eight interval times of 30 minutes, 6, 12, 18, 24, 36, 48 and 72 hours between harvesting and milling of the sugarcane. Qualitative explanatory variables were billets with four grades of damage, i.e. sound, light, medium and heavy damages and the dependent variable was the cane billets’ reducing sugar ratio. Results showed that more than 92% of the reducing sugar ratio changes is described by different damage degrees of the cane billets and the interval time between the harvesting and milling in cane mill. It was inferred from the results of the qualitative data that medium and heavy mechanical damages of the cane billets are the most important factors in sugar loss and declining the quantity of the refined sugar during the harvesting and post harvesting time; so that a comparison between the medium and heavy damaged billets’ regressions from the one hand and the base regression (sound billets) from the other, shows a statically significant differential slope coefficient for the two types of billets.

Key words: Sugarcane, Mechanical harvesting, loss, dummy variable, regression modeling.

INTRODUCTION

In sugarcane industry, one of the most important factors indicating the technological quality of sugarcane and affecting the white sugar exploitation quantity is the cane billets properties and the damages developed in them by the mechanical impacts at harvest time as well as the interval time between harvesting and milling in the cane mill. In economic evaluation of the mechanical harvest, estimating the mechanical damages resulting from the mechanical process constitutes the most decisive element determining the efficiency and profitability of a sugarcane harvester (Mohammad-Ghasemnejad et al., 1999).

Sugar loss is measured relative to a production system which would give a maximum yield of sugar if the best conditions were provided. In order words it corresponds to the potential yield of sugar (Ueno et al., 1993). Amin et al., (1977) reported that, if cane was not milled within a few hours after cutting, inversion of sucrose commenced and that respiration and enzymatic processes in the living tissue were major factors causing deterioration of cut cane. Egan (1965) and Fuelling (1980) showed that one of the key factors in reducing deterioration of chopped cane was to minimize the delay between harvest and crush. Experiments by Ueno et al., (1986, 1993) showed that the quality of burnt cane deteriorates faster than that of green cane and they reported that damaged cane deteriorates faster.

When evaluating the crops mechanical damages in Khuzestan agro-industry unit, normally due to simplicity of work-only the visible physical damages are considered (e.g. the billets having been cut across the farm by the harvester but not gathered or those thrown to the ground in harvesting process) and the quality of the harvested billets which in fact comprises the best part of the sugar loss is overlooked. Thus, the sugarcane harvester performance tests and mechanized harvesting economical evaluation as well as surveying and choosing the most appropriate sugarcane transportation system from the farm to the cane mill must be accomplished considering the factors influential in quality of the harvested billets. Consequently, determination forecast model of sugar loss due to mechanical harvesting and post harvest process of the sugarcane crop in khuzestan province agro-industry units seems necessary.
MATERIALS AND METHODS

The present research has been carried out in 2011 in Khuzestan Amirkabir Agro-industry Unit sugarcane farms using the cp48-103 variety, having been cultivated under the conventional farming conditions. In this study, the longitudinal distribution of the sound billets have been established and performed according to the following definitions and based on the recommendations made by Tully Co-operative Sugar Milling (Patch et al., 1982).

- **Good billets**: Sound billets 250-350 mm long.
- **Long billets**: Sound billets greater than 350 mm long.
- **Short billets**: Sound billets less than 250 mm long.

Recognition and segregation of the sound billets from the damaged ones in this research has been effected through considering the factors influencing the quality of the billet and the recommendations made by Bureau of Sugar Experiment Stations (Agnew, 2002) as well as the studies accomplished by Krose et al., (1994) and Fueling (1980,1983,1998) and Mohammad-Ghasemnejad et al., (2008) has categorized the mechanical damage intensity of the cane billets in the following three groups:

- **Light damage**: cane billets with partial abrasion or partial split physical damage.
- **Medium damage**: cane billets with major abrasion or medium split physical damage.
- **Heavy damage**: cane billets with deep split or shattered physical damage.

Where:

- **Sound Billets**: These billets enjoy an even cross section, an intact skin clear from any abrasion, crack and failure in appearance.
- **Partial Abrasion**: Billets with an area of less than 400mm\(^2\) of the rind removed, exposing the interior of the stalk and/or several instances of the same damage with total area of less than 400mm\(^2\).
- **Major Abrasion**: Cane billets with an area of more than 400mm\(^2\) of the rind removed, exposing the interior of stalk and/or several instances of the same damage with total area of more than 400mm\(^2\). In such a kind of damage, part of the stalk may have been separated together with skin due to abrasion.
- **Partial Split**: Cane billets with a split smaller than 40mm and/or several splits smaller than 40mm; such splits cause a crack to appear on the skin without separation of the two cross sections.
- **Medium Split**: These splits cause separation and splitting of the billet. The cane billets with a split smaller than or equal to 80mm in length and/or several splits with a total length of 80mm belong to this group. This length does not include the growth cracks and the cracks less than 40mm in length are not considered as split.
- **Deep Split**: Cane billets with a split larger than 80mm, provided that no more than two instances of such split exist on the billet.
- **Shattered**: The billet is broken or squashed in such a way that numerous rind cracks appear on the billet and a portion of the cane is reduced to a pulpy condition and removed from the billet.

Sampling was done during the mechanized harvesting with Austoft 7000 sugarcane harvester from the baskets used for carrying billets. Then the samples’ content was segregated into other subcategories like sound billets, damaged billets, trash and extraneous matter. The cane billets were then categorized from the mechanical damage point of view into 4 categories of sound, light damaged, medium damaged and heavy damaged cane billets, according to definitions mentioned above. In each repetition of the experiment for any one of the said mechanical damage intensive degrees, a sample of 10kg was put in free air and a sample of 10kg was poured into a bag (the bagged samples were alike in conditions as those billets which were within the baskets). After passing 30 minutes, 6,12,18,24,36,48 and 72 hours from the sampling time, the free air samples and bagged samples of each damage severity were combined with each other to simulate the actual conditions. Then the resulting samples were crushed in a test mill to extract approx. 60% of the sample juice. The juice gathered was weighted and its sucrose ratio was measured using polarimeter (Saccharimeter) device. Also the brix, the reducing sugar ratio and pH of the sample juice were measured using refractometer (In sugar industry, all the solution combinations including the sugar and non-sugar materials are called the Brix). The juice purity and its reducing sugar ratio were determined using the standard formula (ICUMSA, 1994).

Data analysis was performed using the regression model including explanatory dummy (qualitative) and quantitative variables through using Eviews software (Gujarati, 2002 and Shirinbaksh, 2009). The explanatory dummy variables included the cane billets with Light, medium and Heavy damaged conditions as well as the sound billets and the dependent variable is the cane billets’ reducing sugars ratio. The explanatory quantitative variables included the interval time between the mechanical harvest of the crop and milling in the cane mill, for which eight interval times including 30 minutes (0.5hr), 6,12,18,24,36,48 and 72 hours after harvesting have
been considered in this study. The model was approximated using the OLS method. The regression used in this study is as follows:

\[ Y_{\text{RSR}} = \alpha_1 + \alpha_2 \text{Dum}_L + \alpha_3 \text{Dum}_M + \alpha_4 \text{Dum}_H + \beta_1 \chi_t + \beta_2 (\text{Dum}_L \cdot \chi_t) + \beta_3 (\text{Dum}_M \cdot \chi_t) + \beta_4 (\text{Dum}_H \cdot \chi_t) + u_t \]  

(1)

Where:

- \( Y_{\text{RSR}} \) = the Reducing Sugars Ratio %
- \( \chi_t \) = time (hr)

If the billet is light damaged: \( \text{Dum}_L = 1 \)
Otherwise = 0

If the billet is medium damaged: \( \text{Dum}_M = 1 \)
Otherwise = 0

If the billet is heavy damaged: \( \text{Dum}_H = 1 \)
Otherwise = 0

\( \alpha_1 \) indicates the intercept for the base (benchmark) category or the sound billets and the differential intercept coefficient of \( \alpha_2, \alpha_3 \) and \( \alpha_4 \) indicates the regression intercept difference relating to other three mechanical damages from the benchmark intercept. \( \beta_1 \) indicates the slopes coefficient of the Benchmark category and \( \beta_2, \beta_3, \beta_4 \) are the differential slopes coefficients denoting the difference of the coefficients of determination relating to the sound billets from function slope coefficient of other damaged billets including light, medium and heavy damaged billets.

**RESULTS AND DISCUSSION**

The regression model was approximated for 32 observations through using Eviews software. According to the Table 1, if the sound billets are milled immediately after harvesting, the average value of Reducing sugar ratio in benchmark billets is 0.679%, which taking a time variable coefficient of 0.009 into account, it is expected that as per each 1 hour delay in milling the sound billets in the cane mill, the reducing sugars ratio of these billets is increased by about 1 unit, that is 1%. Based on the estimated function, the average value of reducing sugars ratio in sound billets is gained as follows:

\[ Y_{\text{RSR\ (sound)}} = 0.679 + 0.009 \chi_t \]  

(2)

<table>
<thead>
<tr>
<th>variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.679</td>
<td>0.124</td>
<td>5.439</td>
<td>0.000</td>
</tr>
<tr>
<td>Dum_light</td>
<td>0.038</td>
<td>0.176</td>
<td>0.218</td>
<td>0.829</td>
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<tr>
<td>Dum_medium</td>
<td>0.122</td>
<td>0.176</td>
<td>0.693</td>
<td>0.494</td>
</tr>
<tr>
<td>Dum_heavy</td>
<td>0.055</td>
<td>0.176</td>
<td>0.316</td>
<td>0.754</td>
</tr>
<tr>
<td>( \chi_t )</td>
<td>0.009</td>
<td>0.003</td>
<td>2.804</td>
<td>0.009</td>
</tr>
<tr>
<td>Dum_light ( \chi_t )</td>
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<tr>
<td>Dum_medium ( \chi_t )</td>
<td>0.013</td>
<td>0.005</td>
<td>2.678</td>
<td>0.013</td>
</tr>
<tr>
<td>Dum_heavy ( \chi_t )</td>
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<td>0.005</td>
<td>6.563</td>
<td>0.000</td>
</tr>
<tr>
<td>F-statistic</td>
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<tr>
<td>Prob.(F-statistic)</td>
<td>0.000</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>R-squared</td>
<td>0.92</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

1: \( \alpha_1 \) indicates the intercept for the base (benchmark) category or the sound billets.

The insignificance of the differential slope coefficient which is a product of light damage dummy variable multiplied by the time explanatory quantitative variable indicated that as per each 1 hour delay in milling the billets, there is no significant difference between the light damaged cane billets and sound billets as regards to reducing sugars ratio. Using the equation 1, the average value of reducing sugar ratio in damaged cane billets was determined from the following regression:
The differential slope coefficient which is a product of medium damaged dummy variables multiplied by the time explanatory quantitative variables of 0.013 indicated that as per each 1 hour delay in milling these billets, there is a significant difference of about 1.3% increase between the medium damaged cane billets and the sound billets as regards to reducing sugars ratio. The average value of reducing sugar ratio for this type of billets was determined from the following equation:

\[ Y_{RSS}^{(\text{light})} = (0.679 + 0.038) + (0.009 + 0.007)X_t \]  \hspace{1cm} (3)

Also considering table 1, the differential slope coefficient which is the product of heavy damaged dummy variable multiplied by the time explanatory quantitative variables is equal to 0.033; meaning that as per each 1 hour delay in milling these type of billets, there is a significant difference of about 3.3% increase between the heavy damaged cane billets and the sound billets as regards to the average value of reducing sugar ratio. The individual regression of these types of cane billets is as follows:

\[ Y_{RSS}^{(\text{heavy})} = (0.679 + 0.055) + (0.009 + 0.033)X_t \]  \hspace{1cm} (4)

The coefficients of determination of 0.92 in the Table 1, means that more than 92% of the reducing sugars ratio changes are described by different damage degrees of the cane billets and the interval time between the harvesting and milling in cane mill.

As it can be seen from the figure 1, the difference of the billet qualitative changes process during a 72 hour period after the mechanized harvesting has had little decrease among the sound billets and light damaged billets (the reducing sugars ratio is used as the representative of its quality loss) and in comparison between the two regressions using the dummy variables method, the differential intercept coefficient factor and differential slope coefficient of the two types of billets are not significant. But the process has had considerable decrease among medium damaged and heavy damaged cane billets and a comparison between each of the regressions with the base regression, that is the sound billets, shows a significant differential slope coefficient for the two types of billets. Ueno and Izumi (1993) have published a similar report in which meanwhile reporting consistent results, have suggested the reduction of purity ratio (%) and decrease in the refined sugar percentage through passing of time as a progressive issue. The direct and progressive relationship of the qualitative decline of the billet with the mechanical damage of the billets is of a kind that the loss of the said traits is sluggish at initial hours and intensely increases by increase in the amount of the reducing sugars through passing of time.

**Conclusion:**

It can be inferred from the results of the qualitative data that medium and heavy mechanical damages of the cane billets are the most important factors declining the quality and quantity of the exploited sugar during the harvesting and post harvesting time. Such decline is slow at initial hours after harvest and progressively increases through passing of time, so that intensely influences the quality of the cane billets; in an experiment aiming at determining the effect of passing of time on the quality of the mechanically damaged cane billets that was performed in different climatic conditions in continuation of this study, reading of the sucrose degree was practically impossible using polarimeter due to sever deterioration of the medium and heavy damaged cane billets. Thus, while economical estimating of the mechanical harvesting it would be necessary to consider the mechanical wastes not only from the quantitative, but also from the qualitative point of view; for in physical and quantitative estimation, the qualitative loss which includes most of the sugar loss is ignored. Also, to economize...
the mechanized harvesting, it is necessary to take measures as regards to providing more precise and appropriate conditions for harvesting and post harvesting stages which play a role in establishing sugar loss and mechanical damages, especially medium and heavy damages.

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REFERENCES


