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# Improvement of timber recovery from pine sawlogs using a band sawmill

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## ABSTRACT
Band sawmills used in Uganda require operators to manually make sawing decisions; a situation that is resulting into low recovery given operator's inability to manually optimize sawing decisions. This study aimed at providing a decision support system by developing optimal log cutting patterns. Top diameter, taper, eccentricity and sweep of 150 logs selected at Albertine Timbernet Sawmill and recovery under the existing milling practices were determined. Cutting patterns for each log top diameter were then developed using mathematical analysis and maximum recovery for each log determined. Cluster analysis was used to assign logs to classes, one way ANOVA was used to test the difference in recovery of the log classes while the difference in existing and maximum recovery was tested using an independent t-test. Log classes significantly differed in recovery. Optimal patterns yielded a mean recovery of 41% which was significantly higher than the existing recovery which was 27% indicating a potential for recovery improvement. Implementation of the proposed patterns, doing analysis based on revenue and market demands and determining the applicability of the patterns at other mills are recommended.

Key words: Batch log processing, cutting pattern, decision making, Uganda

## RÈSUMÈ
Les scieries à ruban utilisées en Ouganda obligent les opérateurs à prendre manuellement des décisions de sciage; entraînant une faible récupération étant donné l'incapacité de l'opérateur à optimiser manuellement les décisions de sciage. Cette étude visait à fournir un système d'aide décisionnelle basé sur des modèles de coupe de grumes optimaux. Le diamètre supérieur, la conicité, l'excentricité et le balayage de 150 grumes sélectionnées à la scierie Albertine Timbernet et la récupération selon les pratiques d'usinage existantes ont été déterminés. Des modèles de coupe pour chaque diamètre supérieur de grume ont ensuite été développés en utilisant une analyse mathématique et une récupération maximale pour chaque bûche déterminée. L'analyse de cluster a été utilisée pour attribuer des bûches aux classes, une méthode ANOVA a été utilisée pour tester la différence de récupération des classes de bûches tandis que la différence entre la récupération existante et maximale a été testée à l'aide d'un test t indépendant. Les classes de bûches différaient considérablement dans la récupération. Des modèles optimaux ont donné une récupération moyenne de 41%, ce qui était significativement plus élevé que la récupération existante qui est de 27% indiquant un potentiel d'amélioration de la récupération. Il est recommandé de mettre en œuvre les modèles proposés, d'effectuer une analyse en fonction des revenus et des demandes du marché et de déterminer l'applicabilité des modèles dans d'autres usines.

Mots clés: Traitement des bûches par lots, schéma de coupe, prise de décision, Ouganda

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## INTRODUCTION

While Uganda had more than half of its total land area forested in 1900, forest cover consistently declined to 24% by 1990 and 8% by 2018 (Manishimwe, 2018). The rapidly growing population, great reliance on bio-energy, rising demand for construction timber and inefficient conversion of trees to timber have been the leading causes of such deforestation (NFA, 2017). According to UBOS (2018), annual population growth rate doubled from 1.5% in 1910's to an average 3% starting from 2002. Additionally, about 96% of the population derive energy from firewood and charcoal (MWE, 2016). Although the country had about 15,000 ha of pine plantations in the 1960's (Turyahabwe and Banana, 2008), they were unsustainably harvested leaving about 1,000 ha by 2003 (Nabanyumya, 2017). The depletion of plantations coupled with increasing pressure on natural forests consequently resulted into reforms in the forest sector.

In 2001, the 1988 Forest Policy was revised and a new Policy formed, whose statements 3 and 4 called for plantation establishment and efficient timber processing, respectively (MWLE, 2001). Consequently, 200,000 ha of land were set aside for plantation development, and according to Nabanyumya (2017), more than 80,000 ha of plantations had been planted by 2017. According to MWLE (2013) however, little progress has been made in improving timber processing efficiency. Indeed MWLE (2002), recovery from softwoods in the past seldom exceeded 25% which was due to poor quality logs, poor technical capacity and inappropriate sawmill technologies notably pit sawing and circular sawmills. Fortunately, the current plantations have been comparably managed properly following provision of technical knowledge and finances by the Sawlog Production Grant Scheme (SPGS). There is also increasing investment in efficient band sawmills which is in line with the recommendation by Kambugu *et al*. (2005)

It should however be noted that whereas band sawmills were recommended by Kambugu *et al*. (2005) on account of high recovery, recovery that is being reported is still low and does not significantly differ from that of previous sawmill technologies (MWLE, 2016). The poor performance is mainly due to limited decision making capacity, where sawing decisions are manually made mostly by semi-skilled operators. Technically, most sawmill operators receive little, if any, training in sawmilling. Even with the few skilled operators, Steele (1984) asserted that optimal sawing decisions cannot be manually made owing to many variables that must be considered. Moreover, there are no recommended cutting patterns to guide operators on extraction of optimum timber volumes from the various logs processed. As a result, logs are being randomly sawn to meet markets demands with little, if any, attention paid on recovery optimization. This is resulting into low recovery seldom exceeding 30% (MWLE, 2016), which impacts negatively on sawmill profitability and sustainability of wood resource utilization. The objective of this study was therefore to develop optimal cutting patterns that would guide operators on optimal extraction of timber volumes from the various logs sawn.

## MATERIALS AND METHOD

Characterization of logs timber recovery under existing milling practices. Top diameters, sweep, taper and eccentricity of 150 randomly selected logs were determined. Log taper was computed as the difference in bottom and top diameter divided by log length; log sweep was calculated as the ratio of log bow to log length; and log eccentricity was computed as the ratio of minor and major axis of the top diameter. The volume of each log was determined from Equation (i) as follows;

$$V_l = \frac{\pi d^2 l}{4C} \qquad (i)$$

Where; $V_l$ = log volume ($m^3$), d = average log diameter (cm), l = log length (cm), and C = conversion factor ($1x10^6$) factor from $cm^3$ to $m^3$. Log breakdown was done by the operator with no intervention. Timber volume from each log was obtained using nominal dimensions. Recovery from each log was computed as a ratio of timber volume to log volume. Recovery of a log class was obtained as the average for the logs in such a class while the overall recovery of the saw mill was obtained as the average recovery of the 150 individual logs.

Cutting patterns for maximum attainable recovery. Mathematical analysis was used to develop cutting patterns for each log top diameter (11cm to 33cm) sawn at the saw mill. Three timber dimensions (15cm x 5cm x 420cm, 10cm x 5cm x 420cm and 7.5cm x 5cm x 420cm) sawn at the study sawmill were considered. Since timber was being sawn to uniform length (420 cm), the task was similar to finding the different combinations of the timber cross sections (width and thickness) which could be fitted in the cross section area of each top diameter. The problem was solved following the mathematical structure detailed in Maness and Adams (1991); step one involved building the largest full length cant of a given width while step two involved maximizing the volume of side timber pieces extracted. Modifications in the objective function and constraints were however made. Contrary to Maness and Adams (1991) that aimed at maximizing profits and timber value, this study had a single objective of timber volume maximization. The objective function was therefore formulated as in Equation (ii) as follows;

$$Max \sum_{x} \frac{V(x, I_x, J_x, K_x)}{C} \qquad (ii)$$

Where; V = Volume (m3) of side timber pieces sawn, Ix = thickness (cm) of piece x, Jx= width (cm) of piece x, $K_x$ = length (cm) of timber x and C = conversion factor ((1x106) factor from $cm^3$ to $m^3$. Since timber was sawn to different lengths in Maness and Adams (1991), the objective function was constrained to log top diameter, length and taper. In this study however, timber was being cut to a uniform length (420 cm). Extraction of inner-side pieces was constrained to Equation (iii) while the extraction of outer-side pieces was constrained to Equation (iv);

$$\{(0.5 \times CW + s + I_x)^2 + (0.5 \times J_x)^2\}^{0.5} < r \qquad (iii)$$

$$\{(0.5 \times CW + 2 \times s + I_{x-1} + I_x)^2 + (0.5 \times J_x)^2\}^{0.5} < r \qquad (iv)$$

Where; CW = cant width (cm), s = sawkerf (mm), $I_x$ = timber thickness (cm), $J_x$ = timber width (cm) and r = radius (cm) of the small diameter end. To understand the physical meaning of these constraints, consider the y and x-axes of a log on a cross bunk. The width and height of the central cant would be in the x and y-direction, respectively. Side pieces are extracted in such a way that their thicknesses and widths are oriented in the x and y-direction, respectively. Because the cant is centrally extracted from the log, side pieces can be added in pairs, one to the left and the other to the right side of the cant. This allows concentration on one half of the log cross section on assumption that a piece fitting on one side would also fit on the other side of the cant. The length of a log in the x-direction that would be required to extract a side piece of thickness I cm would then be the summation of half the width of the central cant, sawkerf and the thickness of the side piece to be sawn. An inner-side piece can only be extracted when the summation of these three values are less than the radius of the log. When fitting the outer-side pieces, Equation (iii) slightly changes to Equation (iv). The length in the x- direction required for extraction of the outside pieces becomes the summation of half the width of central cant, twice sawkerf, thickness of the earlier sawn inner-side side pieces and the thickness of the outer-side piece. Maness and Adams (1991) also did not consider feasibility of fitting four inner-side pieces to the central cant. In this study, extra widths of 15.2 cm and 20.2 cm were used to determine whether four inner-side pieces of widths 7.5 cm and 10 cm, respectively, could be fitted at each side of the central cant. These widths were calculated from Equation (v) as follows;

$$w = j_x\ 2 + s \qquad \text{(v)}$$

Where; w = total width (15.2 cm for jx = 7.5 cm or 20.2 cm for $j_x$ = 10 cm), s = sawkerf (mm). Recovery of each pattern was obtained as the ratio of timber volume produced to the log volume. A pattern that yielded the maximum recovery was considered optimal for such a log top diameter.

**Data analysis.** Cluster analysis was used to assign logs to classes basing on their top diameters. Average taper, sweep and eccentricity in each formed class were computed using Microsoft excel. The difference in recovery between log classes was tested using a one-way ANOVA at 5% significance level while an independent t-test was used to test the difference in existing recovery and the maximum recovery that could be attained if each log was sawn using its optimal cutting pattern.

**Validation of the optimum cutting patterns.** Validation experiments were conducted to determine whether logs could be sawn using the formed patterns. Logs in each top diameter were first sawn using the corresponding optimal pattern. In case of failure for a log to be practically sawn by the optimal pattern, the remaining patterns were tested, starting with the second best pattern until a practical pattern was obtained, which was then considered the optimal pattern. Side pieces of 75 mm x 50 mm width were simply replaced with side pieces of 50 mm x 50 mm for logs with top diameters 19cm, 20cm, 21cm and 22cm

## RESULTS

**Characterization of logs.** Cluster analysis at 20% dissimilarity in log top diameter yielded three log classes that have been designated A to C (Table 1). Analysis of variance indicated significant difference ($P < 0.05$) in taper between log classes. Post hoc test showed

**Table 1. Size and visual characteristics of logs sampled**

| Log class | Top diameter range (cm) | n | Average | | | |
|---|---|---|---|---|---|---|
| | | | Top diameter (m) | Taper (mm/m) | Eccentricity | Sweep (mm/m) |
| A | 11 to 19 | 99 | 0.153 | 0.707 | 0.927 | 2.207 |
| B | 20 to 29 | 40 | 0.219 | 0.619 | 0.924 | 2.199 |
| C | 30 to 33 | 11 | 0.308 | 0.411 | 0.945 | 2.251 |

**Table 2. Analysis of variance in characteristics of log classes**

| Variables | | Sum of squares | Df | Mean square | F | Sig |
|---|---|---|---|---|---|---|
| Top diameter | Between classes | 0.314 | 2 | 0.157 | 331.085 | 0.000* |
| | Within classes | 0.070 | 147 | 0.000 | | |
| Taper | Between classes | 0.967 | 2 | 0.483 | 10.926 | 0.000* |
| | Within classes | 6.502 | 147 | 0.044 | | |
| Eccentricity | Between classes | 0.004 | 2 | 0.002 | 0.405 | 0.667 |
| | Within classes | 0.754 | 147 | 0.005 | | |
| Sweep | Between classes | 0.023 | 2 | 0.011 | 0.405 | 0.667 |
| | Within classes | 4.276 | 147 | 0.029 | | |

that log classes A and C, and B and C significantly differed in taper. Sweep and eccentricity did not significantly differ between log classes (Table 2).

**Timber recovery under existing milling practices.** Analysis of variance indicated significant difference (P<0.05) in recovery between log classes (Table 3). Log classes A, B and C had mean recovery of 25%, 28% and 43%, respectively, while the weighted average recovery of the sawmill was 27%.

**Cutting patterns for improved timber recovery.** An independent t-test showed a significant difference (P< 0.05) in the existing recovery and recovery that could be obtained if logs were sawn using the developed optimal patterns (Table 4). Mean recovery that could be obtained from log class A, B and C are 37%, 46% and 61% while the weighted mean recovery of the sawmill would be 41%. The developed validated optimal cutting patterns for each log top diameter are showed in Table 5.

## DISCUSSION

Nearly 90% of the logs sawn had top diameters below 23 cm. These logs are smaller than those sampled in earlier studies like Kambugu *et al*. (2005) and this might be attributed to the fact that the sawmill was processing second thinnings, which according to Zhu *et al*. (2007) are often small diameter logs of about 15 cm. Compared to sweep and eccentricity, log taper is highly correlated with log diameter (Monserud *et al.,* 2004) and this might have resulted into the significant difference in taper between the log diameter classes. Logs at the study sawmill greatly varied in diameter and taper. Following recommendations of Lindner (2015), better recovery can be attained if these logs are sawn in batches, each with logs of slightly similar diameter and taper.

The mean existing recovery of the study sawmill (27%) still conforms to the less than 30% recovery that was reported by Turinawe and Mulimba (2007) to have characterized the industry in the past. Additionally, it is lower than the mean expected recovery from band sawmills reported by Kambugu *et al*. (2005). The difference in the obtained recovery and recovery from Kambugu *et al*. (2005) might be attributed to the differences in log sizes and sawing methods used by the operators. It should be noted that whereas milling in this study was done by the operator without any intervention, milling in Kambugu *et al*. (2005) was experimentally designed and probably executed using better practices. The yielding of higher recovery by log class C might be attributed to the large diameter and low taper associated with the corresponding logs which is also in line with the results of Missanjo and Magodi (2015). Log characteristics that greatly impacted recovery were diameter and taper. As explained earlier, it is important that the operator highly considers these characteristics during log breakdown.

**Table 3. Analysis of variance in recovery between log classes**

| Recovery | Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between log classes | 3367.101 | 2 | 1683.550 | 13.279 | 0.000* |
| Within log classes | 18637.039 | 147 | 126.783 | | |

**Table 4. Samples t-test in the existing and maximum attainable recovery**

| Recovery | t-test for equality of means | | | | |
|---|---|---|---|---|---|
| | T | Df | Sig. (2-tailed) | Mean difference | Std. Error |
| Equal variance assumed | 11.416 | 298.000 | 0.000 | 14.253 | 1.248 |
| Equal variance not assumed | 11.416 | 278.680 | 0.000 | 14.253 | 1.248 |

**Table 5. Validated optimal cutting patterns per log top diameter**

| Top) diameter (cm) | Number of cutting patterns | Optimal cutting pattern cutting patterns | | | | | | Average recovery |
|---|---|---|---|---|---|---|---|---|
| | | Cant pieces | N | Side pieces | | | | (%) |
| | | | | Inner-side pieces | n | Outer-side pieces | n | |
| 11 | 1 | 3x2 | 1 | | | | | 28 |
| 12 | 2 | 3x2 | 1 | _ | _ | _ | _ | 26 |
| 13 | 2 | 3x2 | 1 | _ | _ | _ | _ | 38 |
| 14 | 2 | 3x2 | 2 | _ | _ | _ | _ | 41 |
| 15 | 2 | 4x2 | 2 | _ | _ | _ | _ | 47 |
| 16 | 3 | 4x2 | 2 | _ | _ | _ | _ | 40 |
| 17 | 3 | 4x2 | 2 | _ | _ | _ | _ | 37 |
| 18 | 3 | 3x2 | 3 | _ | _ | _ | _ | 37 |
| 19 | 3 | 3x2 | 3 | 2x2 | 2 | _ | _ | 42 |
| 20 | 3 | 3x2 | 3 | 2x2 | 2 | _ | _ | 44 |
| 21 | 3 | 3x2 | 3 | 2x2 | 2 | _ | _ | 42 |
| 22 | 4 | 3x2 | 3 | 2x2 | 2 | _ | _ | 40 |
| 23 | 4 | 4x2 | 4 | 3x2 | 2 | _ | _ | 60 |
| 24 | 6 | 4x2 | 4 | 4x2 | 2 | _ | _ | 60 |
| 25 | 6 | 4x2 | 4 | 4x2 | 2 | _ | _ | 59 |
| 26 | 7 | 4x2 | 4 | 4x2 | 2 | _ | _ | 56 |
| 27 | 7 | 6x2 | 4 | 3x2 | 2 | _ | _ | 60 |
| 28 | 8 | 6x2 | 4 | 4x2 | 2 | _ | _ | 60 |
| 29 | 9 | 3x2 | 5 | 4x2 | 4 | 3x2 | 2 | 65 |
| 30 | 12 | 6x2 | 5 | 4x2 | 2 | _ | _ | 62 |
| 31 | 12 | 6x2 | 5 | 4x2 | 2 | _ | _ | 59 |
| 32 | 15 | 6x2 | 5 | 4x2 | 2 | _ | _ | 55 |
| 33 | 19 | 4x2 | 6 | 4x2 | 4 | 3x2 | 2 | 66 |

Mathematical analysis indicated that a given top diameter log can be sawn using various cutting patterns; for instance, a 33 cm top diameter log can be sawn using 19 different patterns each yielding different recovery. Ideally, it is practically impossible for the operator to manually saw such a log using the optimal pattern and this might be the reason for the low existing recovery at the sawmill. The significantly higher recovery that could be obtained if logs are sawn using the proposed pattern (41%) indicate a potential for recovery improvement by 14%. Considering the price of 1m3 of timber at the sawmill (325,000 shs; i.e., approximately US$90,000), a 14% recovery improvement would translate to 45,500 shs increment in revenue per 1m3 of logs sawn which is likely to boost annual revenue by about 53 million assuming the average daily log volume (3.98 $m^3$) milled by the sawmill.

**Grouping and visual aids for implementation of cutting patterns.** To facilitate the implementation of the proposed patterns, logs were grouped basing on top diameter, width of the central cant and presence/absence of side timber pieces in the optimal pattern (Table 6). Logs can either be sorted while at the deck and sawn in groups or sawn randomly but by sawing each log with its optimal pattern. The optimal cutting patterns of the different log top diameters were also presented as 2D diagrams generated using Solid Edge software.

## CONCLUSIONS

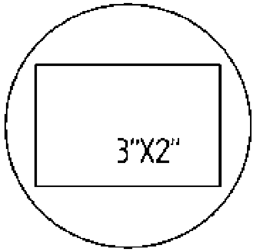
This study has indicated that recovery of band sawmills is being compromised by the inability of operators to optimally allocate cutting patterns to the various logs sawn. Furthermore, it showed that implementation of optimal cutting patterns that were developed could increase timber recovery by up to 14% which could boost the saw mill's revenue by 45,500 shs per cubic meter of logs sawn. The findings suggest that the study saw mill should adopt and implement the proposed cutting patterns. Determination of the applicability of the proposed cutting patterns at other mill types and doing analyses based on market demand and profit maximization should be considered.

**Table 6. Recommended log classes for the study sawmill**

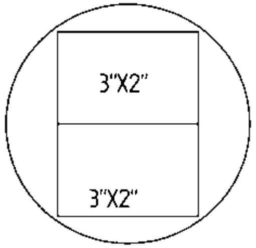
| Log class | Top diameter (cm) | Description |
|---|---|---|
| 1<br>12 | 11, 12, 13, 14, 15, 16, 17, 18 | Logs shall be sawn to only central timber pieces with no side pieces. 11, and 13 cm top diameter logs shall be sawn to one piece of 3x2 inches. 14 cm and 18 cm logs shall be sawn to two and three pieces of 3x2 inches, respectively. 15, 16 and 17 cm logs shall be sawn to two pieces of 4x2 inches. |
| 2 | 19, 20, 21, 22, 29 | Logs shall be sawn to central cant of 3 inch width. 19, 20, 21 and 22 cm logs shall be sawn to three central pieces of 3x2 inches and two side pieces of 2x2inches. 29 cm logs shall be sawn to five central pieces of 3x2 inches, four inner-side pieces of 4x2inches and two outer-side pieces of 3x2 inches |
| 3 | 23, 24, 25, 26, 33 | Logs shall be sawn to central cant of 4 inch width. 23, 24, 25 and 26cm logs shall be sawn to four central pieces of 4x2 inches. Side pieces from 23cm logs shall be of 3x2inches while 24, 25 and 26 cm logs shall be sawn to sidepieces of 4x2inches. 33cm logs shall be sawn to six central pieces, four inner-side pieces of 4x2inches and two outer-side pieces of 3x2 inches. |
| 4 | 27, 28, 30, 31, 32 | Logs shall be sawn to central cant of 6 inch width. 27 and 28cm logs shall be sawn to four central pieces. Side pieces from 27 cm log shall be 3x2 inches while those from 28 cm logs shall be 4x2 inches. 30, 31 and 32cm logs shall be sawn to five central pieces of 6x2 inches and two side pieces of 4x2 inches. |

**Table 7. 2D diagrams of proposed optimal patterns per log top diameter**

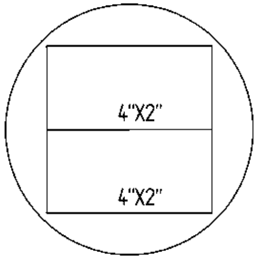
11cm, 12cm and 13cm



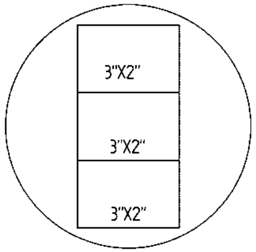

14cm



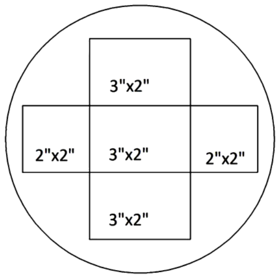

15cm, 16cm and 17cm



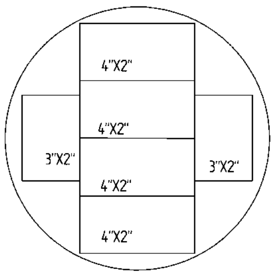

18cm



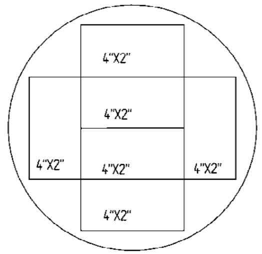

19cm, 20cm, 21cm and 22cms



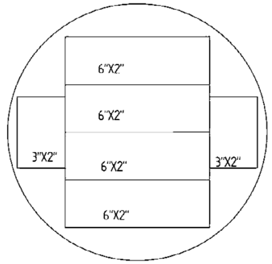

23 cm



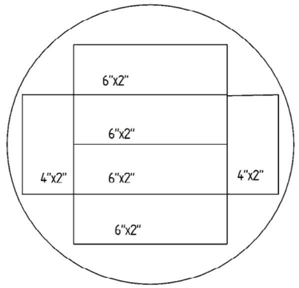

24cm, 25cm and 26cm



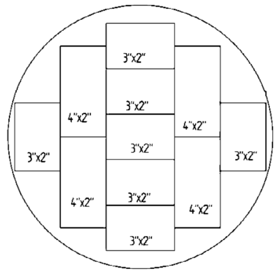

27cm



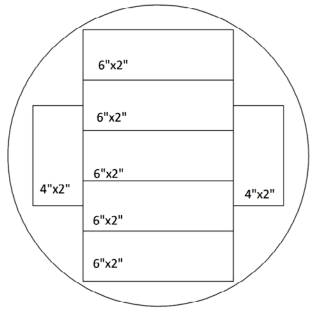

28 cm



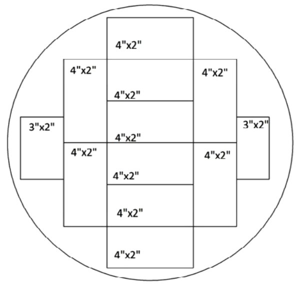

29cm




30cm, 31cm and 32cm




33cm



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## STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

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