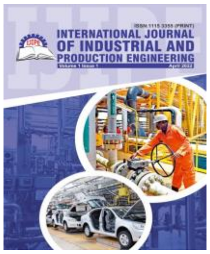

Vol. 3 No. 3 (2025)

INTERNATIONAL JOURNAL OF INDUSTRIAL AND PRODUCTION ENGINEERING (IJIPE)

JOURNAL HOMEPAGE: https://journals.unizik.edu.ng/index.php/ijipe/

Determination of Timeliness Cost and Muscle Energy Requirement of Nylon String-Blade Mowers in Lawn Maintenance Operations

Desmond O. Amaefule[1], Chukwudi H. Ezeanolue[2], Ifeanyichim C. E. Umeghalu[3], Juliana N. Ogbuagu[4]*, Uju P. Ojukwu[5], and Izunna I. Asoegwu[6]

1,2,3,4,6 Department of Agricultural and Bioresources Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[5]Department of Polymer Engineering, Nnamdi Azikiwe University, Awka, Nigeria

Authors Email: da.amaefule@unizik.edu.ng, ezeanoluechukwudi@gmail.com, umeghaluice@gmail.com, nj.ogbuagu@unizik.edu.ng upc.ojukwu@unizik.edu.ng izuu2012@gmail.com,
**Corresponding Author: nj.ogbuagu@unizik.edu.ng*

Abstract

This study evaluated the timeliness cost, and muscle energy needs of a nylon string-blade mower, commonly used for small lawn maintenance. It utilized a penalty-based model to quantify the decline in lawn aesthetics, by expressing it as a monetary penalty when mowing is delayed. Aesthetic loss in terms of reduction in lawn appeal caused by excessive grass height, clumping of cuttings, or thatch accumulation were considered in this study, and found to reduce acceptability of the lawn for its intended use. Heart rate, a physiological workload index, was used to estimate muscle energy expenditure based on ergometer calibration, while rate of perceived exertion was used to assess the physiological strain. Results from the study show that the optimal mowing interval was found to be 14 days, with hourly losses of ₦114.52/ha for early mowing and ₦890.48/ha for delayed mowing. When accounting for lawn aesthetics losses, the total average mowing cost increased by an hourly amount of ₦114.52 per hectare for early mowing and ₦678.55 per hectare for delayed mowing. 40.96 W muscle work rate, corresponding to operator heart rate of 127 bpm was observed for the mowing, and was perceived as a light intensity task. The equivalent sound pressure level recorded at the operator's ears distance to the exhaust outlet was found to be 62.5 dB during mowing. These were within the recommended safety limits, ensuring that operators are not exposed to excessive work rate or hazardous noise levels. These findings will offer lawn managers minimized cost and safer mowing decisions support.

Keywords: Human energy cost, Lawn mowing, Aesthetic penalty, String-blade mower

1. Introduction

Lawn maintenance is a vital part of landscape management, especially in institutions, parks, and residential areas. Proper grass care is essential for maintaining an attractive lawn and preventing pests, rodents, and dangerous reptiles, along with the problems they cause (Shivaswamy, 2024).

Regular mowing boosts grass density, improving visual appeal and shielding the soil from erosion (Pirchio *et al.*, 2019). It also promotes carbon capture, thereby helping to improve adverse climate conditions. The timing, method, and quality of mowing directly influence the lawn's appearance. One common mower in developing countries like Nigeria in the recent times, is the string-blade mower. This type uses a nylon line-blade that extends from the vertical cutter head, spinning horizontally and driven by a long, slender shaft connected to the motor. It works by the impact force of the nylon line moving at high speed. For instance, a 4.5 kg Makita XRU09 cordless model has an idle speed of 6500 rpm (Makita, undated). String-blade (nylon cord) trimmers are popular for small to medium lawns because they are affordable, portable, and versatile, even though traditional lawn mowers are still common (Caballero, 2024). Despite these benefits, using string-blade mowers presents several challenges, especially in tropical regions like Nigeria. These include high physical stress on the operator, poor ergonomic posture during use (Dutta *et al.*, 2016; Pamujula and Bhaskar, 2021; Kroemer *et al.*, 2018; Edwards, 2024), and operational inefficiencies (Trenholm *et al.*, 2009) caused by improper mowing schedules.

Ergonomics studies highlight the importance of posture and muscle workload, since excessive muscle strain, prolonged bending and maintaining flexed postures can lead to musculoskeletal disorders (Arx *et al.*, 2021; Edwards *et al.*, 2024). For example, in the mowing activity shown in Plate 1, the operator in Plate 1a is at an incorrect tilt, while those in Plates 1b and 1c maintain correct postures.

a b c

Plate 1: Postures in Lawn Mowing

Muscle work incurred for a given task can be estimated using physiological indices, eg heart beat rate. Equally, the strain on the muscle from the task can be indicated in terms of the rate of perceived exertion (RPE); assessed on the basis of breathing rate, heart rate, increased sweating and muscle fatigue (Cave, 2024). This simple self-rated measure of a subject's muscle strain from the task undertaken is accurate and correlates linearly with heart rate (HR) (Borg, 1967). The subject rates how hard he/she feels the task on a scale of 0-10 (with 1 being very light, and 10 being maximum effort), or an alternative scale of 6-20. On the 6-20 scale, the RPE is equivalent to 0.1 of HR.150-175 bpm are associated with heavy work and 75-100 bpm with light work (Borg, 1967; Torres *et al.*, 2025). Morishita *et al.* (2018) gave the strain levels in further details as shown in Table 1. RPE assessment can also be based on the subject's ability to simultaneously hold conversation (Cave, 2024) as also shown in Table 1. Excessive vibration and noise from these machines could also pose long-term health risks (Bello, 2020; Esparcia, 2023), as noise and vibration from the equipment and environment can affect the operator's health and increase muscle energy demands. The equivalent sound level over a period is the sound level that will give the same effect on the hearer as all the sound the hearer is exposed to within the period.

Table 1: Rate of Perceive Exertion and Their Correlated Task Intensity and Heart Beat Rate

6-20 RPE Scale-Basis			0-10 RPE Scale-Basis			Heart Rate (HR) (bpm)
Scale	**#Task Intensity**		**Scale**	***Task Intensity**	**#Talk-test Outcome**	
6	No Exertion	Sitting, At Rest	0	At Rest (No Exertion)		*60
7	Extremely Light	Very Light Activity	1-2	Very Light Activity		**70
8						**80
9	Very Light					**90
10		Fairly Light Activity	3-4	Light to Moderate Activity	Can Easily Hold Conversation	**100
11	Light					**110
12		Moderate Activity				**120
13	Somewhat Hard		5-6	Moderate to Somewhat Hard	Breathing A Little Harder, but Still Able To Talk	**130
14						**140
15		Somewhat Intense Activity				**150
16			7	Hard Vigorous		**160
17	Very Hard	Very Intense Activity	8-9	Very Hard		**170
18						**180
19	Extremely Hard	Extremely Intense Activity			Breathing Hard, and Barely Able To Talk	**190
20	Maximal Exertion		10	Maximum Exertion		*200

Sources: #Cave *Borg 1967 ** Morishita *et al.* 2018

Nonetheless, string-blade mowers offer advantages such as increased mowing capacity and the ability to maintain grass cover. The nylon material used for the string-blades has inherent strength, stiffness, toughness, elasticity and resistance to wear, giving it adequate capabilities for grass cutting (Kumar and Reddy, 2020). As a result of this, the mowers can trim grass at obstacles' boundaries, and in unknown areas without having to worry about damage from unseen obstacles. According to Esparcia (2023) and Mech-marvels (2021), awkward spaces and very odd angles; like around, near and along fences, trees, and other features, can be easily trimmed by string-blade cutters. Steep and undulating terrain can be handled as well, thus making these devices utility mowers. In addition, the offset configuration allows the operator to view the cutting path. The string trimmer has thus become a common place machine for lawn mowing lately because of its high capability and ease of use, light weight, maneuverability, variety of attachments, and low purchase cost.

From literatures a 0.934 kW human-powered reel blade mower was fabricated by Nkakini and Yabefa (2014). It operates at 1500 rpm, and is based on scissors action. Falana *et al.* (2020) modified a shoulder-strapped 1.67 kW metal-blade brush cutter for Kenaf harvesting. The field capacity was 0.14 ha/hr, and field efficiency was 69.15 – 81.21%, with 46.91 L/ha fuel consumption. A cut height of 30 mm was achieved compared to 70 mm for tractor-driven mowers. Cordless low weight-electric motor-driven versions of string mowers, designed to be borne by both hands and powered by rechargeable battery are currently available (Makita, undated). The design has versions with telescopic transmission shaft and 180° mower head inclination adjustments, as do the newer versions of the shoulder-strapped types. The general mowing practice for aesthetic lawns is to leave the grass chops *in situ* to decay and replenish the soil nutrients (Shivaswamy and Jagga, 2024, and Roshanianfard *et al.*, 2025). For even mulch distribution and easier decomposition, and for prevention of clumping Roshanianfard *et al.* (2025) recommended a chopped grass length of not more than 30 mm. Excessive grass growth impacts the aesthetics of the lawn and the acceptability of the concerned environment (Plate 2). Plate 2a shows a well-mowed lawn, while 2b lawn contains long-chops. The lawn in 2c has a thatch layer of dead organic matter, while 2d and 2e lawns have overgrown grass that is overdue for mowing.

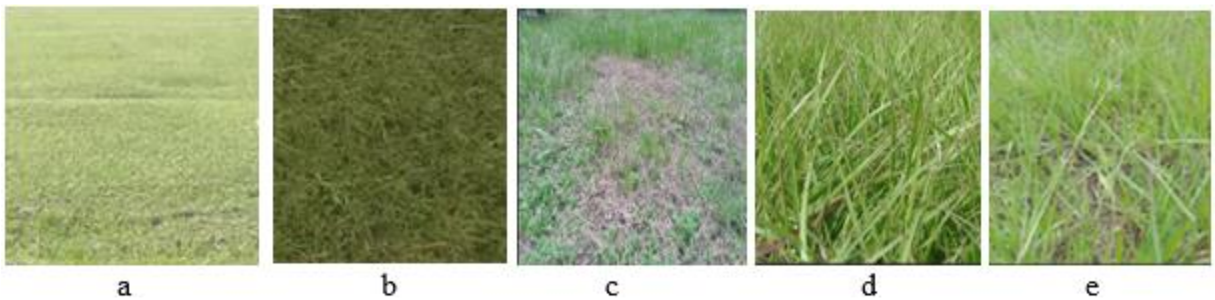

Plate 2: Comparative Appeal of Good-looking and Overgrown Grass Lawn

Another critical, yet often overlooked, aspect of lawn mowing is timeliness. Timeliness cost is predominantly practiced in crop production and is quantified by economic losses in terms of yield. The timing of lawn mowing directly affects turf quality and maintenance costs. Timeliness cost is a cost category in field operations that is not traditionally accounted for but arises from the failure of the chosen machine or method to accomplish the required task within the required time. Delayed mowing can reduce lawn quality, leading to reseeding or extra care needs, while mowing too often can waste effort and increase fuel and labor expenses. Interestingly, there are limited studies on the application of timeliness cost to lawn mowing operation, where aesthetic rather than yield is the primary value. Turgeon (2005) highlighted that mowing frequency, technique, and timing directly influence both the appearance and biological sustainability of the turf. Gunnarsson (2008) and Najafi and Torabi (2015) agree that when the field operation is not performed on time, the value of the crop may decrease in quantity and or quality. These lead to economic consequences called timeliness costs (ASABE, 2006). They further emphasized that timeliness costs are essential for optimizing equipment selection and use. Studies by Lerman *et al.* (2018) showed that mowing frequency not only affects aesthetics but also biodiversity, especially in suburban environments. Caballero (2024) reported that while bi-weekly mowing may reduce costs, it often leads to rough cuts and increased wear on machinery, suggesting a need to balance economics with lawn appearance. For optimum harvest, for example, the choice of planting period should not adversely affect the subsequent crop development and harvest stages or their related operations (Gunnarsson, 2008). For lawn mowing, the operation timing should not limit the achievement of minimized machine costs and optimal returns with respect to the lawn quality and effectiveness. Poor lawn quality and loss of turf grass can arise from the native weeds germinating and re-invasion of the lawn. Turf grasses can be outcompeted by native weed in some lawn portions due to untimely and improper mowing as can be seen in Plate 2c. Insufficiency of conducive conditions for the appropriate lawn-grass regrowth, build-up of pests or disease pathogens, ease of traffic on the terrain, and intra seasonal variations in weather make the timeliness of mowing operations important. Timeliness costs are higher under reduced available operation periods; as in multiple cropping/lawn mowing per season, or in regions that experience winter or prolonged rainy or dry periods (Van den Berg *et al.*, 2007). De Torre (2005) reported that studies on timeliness have been centered on harvest-related agriculture, like crop production. He argued that the timeliness cost is difficult to predict for partially cultivated or uncultivated fields. While there is a dearth of data on direct cost estimation of delayed lawn mowing, the models used for cropping operations can be helpful. Irel Limited (2024) included daily rated financial penalty clause in grass mowing contract for any day the non-commencement occurs during the schedule or the non-completion outside the schedule. Upcounsel (2025) reported that financial penalties, legal disputes and enforcement actions can arise from breaking of contracts and that compensatory damages are aimed at indemnifying the non-breaching party.

Several studies have explored either the economic aspects of machinery use or the physiological effects of tool use. For instance, Amaefule *et al.* (2025a,b) evaluated ownership and operational costs of string-blade mowers but did not include human energy demand. Similarly, Roshanianfard *et al.* (2025) evaluated sound levels and prime mover power usage in autonomous mowing systems but did not explore timeliness and human energy issues. Beardsley (1973) suggested that to evaluate the subjective and hard-to-quantify aesthetic value, degradation beyond a certain level should be punished economically, thus giving it monetary outcomes. The aesthetic penalty can be given numerical values derived from surveys, professional assessments, or by setting acceptable turf quality thresholds. Lawn appearance and health condition may be better yardsticks than the measurable financial losses from crop loss when adapting timeliness loss models used in cropping operations. Therefore, this study is aimed at assessing both the timeliness cost and the muscle energy requirement associated with the use of nylon string-blade mowers. The noise level of the mower in operation was also evaluated. A penalty-based model is introduced to quantify lawn aesthetic losses from mowing delays, while physiological workload is assessed through heart rate and RPE analyses. Together, these provide a sound decision-support framework for scheduling lawn maintenance in a way that balances economic efficiency, aesthetic outcomes, and operator well-being. By combining field performance data, physiological measurements, and economic modeling, the study offers a comprehensive evaluation to support evidence-based lawn care decisions.

2. Materials and Methods

2.1 Study Location and Equipment

The mowing experiments were conducted on lawns at Nnamdi Azikiwe University, Awka, Nigeria (6.2459°N, 7.1199°E). An Aspero CG 430 string-blade cutter (43cc, 0.931 kW) was used for the mowing operation, and its details are provided in Table 1.

Table 1: Relevant Parameters of the String Cutter

String Cutter Parameter	Parameter Values
Drive Option	43-cc 2 Cycle
Make and Model	Aspero CG 430
Power Output (kW)	0.931 (1.25 hp)
Field Capacity (Work Rate) (ha/hr)	0.0731
Purchase Price (N)	120,000
Weigh (kg)	7
Cutting Device	Nylon Strings

Source: Amaefule *et al.* 2025a

2.2 Timeliness Cost Assessment

2.2.1 Penalty-based timeliness cost model

Timeliness costs for the grass mowing were determined from measurements during grass mowing operations on regularly mowed lawns at the study area. It was estimated using a penalty-based approach, which assigns a monetary value to the reduction in lawn quality caused by delayed mowing. The optimum mowing interval was identified as 14 days, based on both field observation and lawn manager feedback. The penalty reflected visible deterioration in turf appearance, including excessive grass height, clumping of cuttings, uneven distribution of mulch, and overgrown thatch, which compromise lawn aesthetics. Following the approach of Beardsley (1973), this decline in visual quality was translated into economic terms by applying a penalty equivalent to twice the maximum machinery cost for every 7-day delay beyond the optimum interval. This approach allowed the otherwise subjective decline in lawn appeal to be quantified and integrated into the total average mowing cost model. The mowing costs were then evaluated for intervals (t) of 7, 14, 21, and 28 days. Each mowing frequency was tested on three replicate plots. The timeliness cost was calculated by evaluating the increase in operational and penalty costs for deviations from this frequency. It is assumed that the penalty increased linearly up to twice of the maximum mowing machinery cost every seven days.

2.2.2 Penalty model derivation for timeliness cost

To develop the penalty-based cost model, mowing cost data were analyzed across different mowing intervals to obtain the difference in their mowing machinery costs. Any deviation beyond this interval was treated as a deterioration in aesthetic quality, since it will in practical term lead to that. Monetary compensation penalty contained in Irel Limited (2024) contract was adapted and reflected in the model. It was considered that a contractor can be denied his pay for the services for portions of the lawn mowed beyond the schedule. In this way the timeliness cost incurred is accounted as twice the cost of executing the job. The model objective was to minimize (CT_t) the total penalty-inclusive mowing cost (Eq. 2). Following Beardsley (1973) and Irel Limited (2024), and adapting from timeliness models in crop production (ASABE, 2006; Najafi & Torabi, 2015), a penalty equivalent to twice the maximum machinery cost (CM_t) observed within the optimum interval (7–14 days) was added for every additional 7-day delay. This scaling was chosen to reflect the compounding effect of overgrowth, thatch buildup, and poor cut quality on lawn appearance. Thus, penalty values were not arbitrary but were benchmarked against the actual machinery costs to ensure economic realism.

$$\min CT_t = CM_t + CP_t \qquad \forall\ t\ 1{,}244\ days \qquad (1)$$

Subject to

$$CP_t = 0 \qquad \forall\ t\ 1{,}14\ days \tag{2}$$

The optimum aesthetics mowing interval was set at 14 days, based on the experience of the consulted manager. When mowing is delayed beyond 14 days, aesthetic quality decreases, and a penalty cost is therefore added to the total average mowing cost.

$$CP_t = (t-14)\left(\frac{2}{7}CM_{max}\right) \qquad \forall\ t\ 15{,}244\ days \tag{3}$$

Penalty cost valued at twice the maximum machinery cost CM_t obtained within the experimented intervals t = 7,14 days is added for every 7 days delay

$$CM_{max} = \max CM_t \qquad \forall\ t\ 14{,}28\ days \tag{4}$$

2.3 Ergometer Calibration for Muscle Energy Estimation

The physiological workload of the operator was quantified using heart rate as a physiological index for energy expenditure. To establish a reliable relationship, the operator first underwent a controlled ergometer experiment, where heart rates were recorded under four known resistance loads (2 N, 4 N, 6 N, and 8 N) and work rates in watts were simultaneously measured by the ergometer. A linear regression model was then developed to correlate heart rate (HR) to work rate (Wk) in Equation 5. The resulting calibration equation provided a conversion factor that allowed field heart rate data collected during mowing to be translated into actual work rates and caloric expenditure. This ensured that physiological workload measured in the field was standardized against known laboratory conditions, minimizing bias due to individual variability in heart rate responses. Linear model of work rate and calorie burn, were obtained from ergometer output using Excel tools.

$$Wk_x = \frac{\sum(Wk_i - Wk_1)}{\sum(HR_i - HR_1)} \times HR_x + C \tag{5}$$

Where;
Wk_x= actual work done in the field which we want to evaluate
$Wk_{1,i}$= actual work done on the ergometer
HR_x= heart beat rate obtained from the field work
$HR_{x,1,i}$= heart beat rate obtained from the respective work done on the ergometer
C= a constant

Heart rate value (HR_x) of the mowing operation was measured using an MMIZOO W1681 wrist device. Using Equation 6 and the HR_x, the operator's work rate in Watts (Wk_x), expended in the mowing operation was evaluated from operators data calibrated from the ergometer exercise. Similarly the operator's muscle work rate (Mk_x) was obtained in like manner from Equation 7.

$$Wk_x = 1.2218 \times HR_x - 114.21 \tag{6}$$

$$Mk_x = 0.0014 \times HR_x + 5.4044 \tag{7}$$

The muscle strain from the exertion imposed by the mowing task was expressed as the operator-indicaed RPE on a 6-20 scale, as portrayed in Table 1 following Cave (2024) method. The talking test were also administered during the ergometer experiment and mowing operation.

2.4 Sound Level Measurement

The noise level of the mower in operation was measured at a distance of 0.70 meters, which was equal to the mower exhaust muffler port distance from the operator ear, the noise level of the running mower engine in operation was recorded. The sound was also measured at a closer distance to the port; namely 0.10 m. A sound meter software; Decibel Meter was downloaded on an Apple IOS device and used for the measurement. The software display the recorded sound graphically. The measured sound was compared with the 80 dB safe limit of sound exposure.

3. Results and Discussion

3.1 Timeliness Cost

The lawn mowing machinery cost (CM_t), the total average mowing cost (CT_t) and timeliness cost (CP_t) were plotted against the mowing frequency (t) in Figure 1. Machinery cost decreased with reduced mowing frequency, with the total cost being lowest at 14 days. Beyond this, aesthetic penalties led to a sharp increase in total cost.

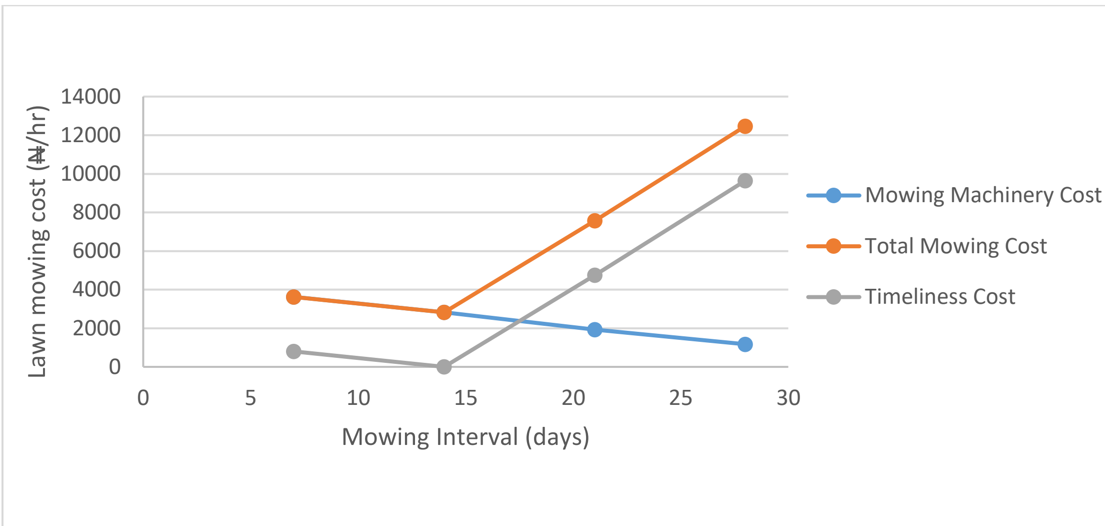

Figure 1: Variation of Mowing Operation Costs with Mowing Interval

From the results obtained, it was observed that the standard deviation was within 5% of the average values for cost. This supports the reliability of the data trends. While machinery ownership cost is fixed, the operating cost varies and is known to increase with machine use (Hunt and Wilson, 2015). Also, Amaefule *et al.* (2025b) reported that the operating cost of a string-blade mower makes up 90.66% of the mowing machinery cost, while the fixed cost constitutes 9.34% of this cost. Additionally, a penalty-inclusive total average mowing cost model serves as a decision-support tool for lawn managers, offering a cost-minimization framework when choosing mowing intervals as the penalty cost inclusive decreases at the hourly rate of ₦114.52/ha till 14 days of mowing frequency. Thereafter, it started increasing at ₦678.55/ha. The total cost function was modeled as given in equations 8 and 9.

$$CT_t = CM_t + CP_t(|t - 14|) \quad \text{for } t > 14 \text{ days} \tag{8}$$

Timeliness cost showed a similar trend:

$$CTI_t = CP_t(|t - 14|) \qquad \text{for } t > 14 \text{ days} \tag{9}$$

where $|t - 14|$ is the absolute value of $t - 14$.

These results reinforce the economic significance of mowing frequency. A 7-day interval, although maintaining excellent aesthetic standards, imposed unnecessary labor and fuel costs. Conversely, the 21-day and 28-day intervals incurred substantial aesthetic penalties due to overgrowth, thatch accumulation, and poor cut quality, which are detrimental to the visual and functional attributes of the lawn. Turgeon (2005) reported that wrong mowing practices can lead to grass losses and attendant grass reseeding cost. Gunnarsson (2008) reported both quantitative and qualitative losses in forage harvest operations. Najafi and Torabi (2015) reported that timeliness cost increases as the operation period moves away from the optimal time. Timeliness cost serves as a valuable index for decision-making, quantifying the intangible losses that occur when optimal schedules are not followed. This also highlights the risk of underestimating aesthetic degradation in cost planning. The linear penalty model used in this study may be adapted or refined in future work to accommodate non-linear effects, such as seasonal growth variability or grass type. Nevertheless, the framework presented offers a reliable basis for scheduling frequency that balances performance with sustainability in lawn care practices.

3.2 Muscle Work Requirements

The HR measured during mowing was 127 bpm, corresponding to a work rate of 40.96 W. This is significantly below the 75 W threshold commonly accepted as the average human endurance limit. The operator's muscle work rate was 0.093 calories/sec (≈0.389 W), well within the 6.296–7.755 W range defined as "light workload" by the Minnesota Department of Health (2024). Based on the task intensity-RPE details in Table 1, the 127 HR measured during the mowing operation indicated that the lawn mowing falls in-between fairly light and moderate activities. Equally the operator was able to hold conversation easily giving a confirmatory inference that the lawn mowing operation was a fairly light activity. Thus, the physical workload posed by the mower is ergonomically acceptable for healthy users over typical mowing durations.

3.3 Noise Levels

Noise levels at the operator's ear (0.70 m) had 62.5 dB equivalent value. It ranged from 61.3 to 67.4 dB, see Figure 2. This falls below the 80 dB threshold recommended for safe prolonged

Figure 2: The Mower's Sound Level at 0.7 m (Left) and 0.1 m (Right) from Exhaust Port

exposure (The Engineering ToolBox, 2004). At a closer distance of 0.10 m from the exhaust, values ranged from 81.6 dB to 93.3 dB, with an equivalent of 89.2 dB. These results align with the general sound attenuation principles of mechanical equipment. Roshanianfard *et al.* (2025) obtained a sound level of 67.3 dB to 76.2 dB for his developed electric motor-driven autonomous mowing system. This suggests that while close-proximity exposure could be risky without ear protection, regular use at normal operating distance is within safety limits. The operator however always put on ear protection equipment during work.

4. Conclusion

This study evaluated the timeliness cost, and muscle energy requirement of lawn mowing using a nylon string-blade mower. A 14-day mowing interval was found to offer the best balance between cost-effectiveness and lawn appearance. Delaying mowing beyond this period led to significant penalty costs due to decreased lawn quality, while more frequent mowing increased operational expenses unnecessarily.

The penalty-based cost model developed in this research provides a useful framework for scheduling lawn maintenance by quantifying the economic and aesthetic trade-offs associated with mowing frequency. It emphasizes the importance of maintenance scheduling and reinforces the idea that operational efficiency must balance both cost and visual performance. In addition, the mower's human energy demand was found to be a "somewhat light task" based on RPE assessment, and thus ergonomically safe, and the noise levels within acceptable limits, supporting its continued use in institutional and residential settings. These insights can guide landscaping contractors, institutions, and private lawn owners in selecting optimal mowing schedules, improving resource use, and protecting operator health. Future research could explore further ergonomics issues and the influence of terrain type, operator experience, and mower configurations on cost, energy output, and long-term lawn sustainability.

References

Amaefule, D. O., Ezeanolue, C. H., Nwajinka, C. O., Umeghalu, I. C. E. and Ojukwu, U. P. (2025a). Determination of the Field Capacity and Field Efficiency of String-Cutter Grass Mower", UNIZIK Journal of Engineering and Applied Sciences. 5(2): 2326-2333.

Amaefule, D. O., Ezeanolue, C. H., Ogbuagu, J. N., Nwajinka, C. O., Ojukwu, U. P. and Adama, J. C. (2025b). Ownership and operation cost of string-blade cutter in lawn mowing operation. Umudike Journal of Engineering and Technology. 11(1): 138-142

ASABE. (2006). ASAE Standards: Agricultural Machinery Management Data. American Society of Agricultural and Biological Engineers.

Arx, M. von, Vollenweider, S., & Herzog, F. (2021). Impact of mowing frequency and posture on ergonomic health in urban lawns. Urban Forestry & Urban Greening, 59, 126996. https://doi.org/10.xxxx/ufug.2021.126996

Beardsley, J. (1973). Earthworks and Beyond: Contemporary Art in the Landscape. Abbeville Press.

Bello, R. S. (2020). Ergonomic modification and performance evaluation of a shoulder-strapped brusher cutter. Indian Journal of Engineering 17(48): 323-331.

Caballero, F. (2024). Comparative performance of string trimmers and rotary mowers on urban lawns. International Journal of Landscape Management, 29(1), 75–89.

Cash Flo Ltd. (2024). Cordless string trimmer with adjustable shaft and swivel head unpublished product brochure.

Cave, K. M. (2024). Rate of perceived exertion (RPE) scale explained. Nasmfitness (Fitness Newsletter) National Association of Sports Medicine (NASM)

De Torre, C. (2005). Modelling timeliness costs in field operations: An integrated systems approach. Biosystems Engineering, 91(2), 211–222.

Dutta, P., Singh, S., & Ghosh, M. (2016). Ergonomic analysis of agricultural field tools. Agricultural Engineering Today, 40(2), 26–32.

Edwards, M. (2024). Safety practices and musculoskeletal risk in small equipment operations. *Ergonomics International Journal*, *11*(3), 102–110.

Esparcia, S. (2023). Noise and vibration hazards in portable mowers: A field survey. Environmental Risk & Safety, 21(1), 33–40.

Falana, A., Omotayo, M., & Fashola, T. (2020). Modification and performance evaluation of a shoulder-mounted brush cutter for Kenaf harvesting. Journal of Agricultural Machinery, 15(2), 135–143.

Gunnarsson, C. (2008). Quantifying timeliness cost in forage harvesting operations. Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 58(3), 193–200.

Hunt, D., & Wilson, R. (2015). Farm Power and Machinery Management (11th ed.). Waveland Press.

Irel (India) Limited (2024). Annual Maintenance Contract for Removal of Bushes/wild Grasses, Vegetation and Plants in MK Plant Premises. Tender No: IREL/MK/ET/55/2024. IREL India Ltd.

Kroemer, K. H. E., Kroemer, H. J., & Kroemer-Elbert, K. E. (2018). Ergonomics: How to Design for Ease and Efficiency (2nd ed.). Pearson.

Kumar, B., & Reddy, V. (2020). Mechanical behavior and wear resistance of nylon composite for trimmer applications. Materials Today: Proceedings, 33(6), 2325–2330.

Lerman, S. B., Contosta, A. R., Milam, J., & Bang, C. (2018). To mow or not to mow: Mowing frequency affects biodiversity in suburban lawns. Biological Conservation, 221, 160–166.

Makita, (n.d.). Cordless Electric Grass Trimmer XRU09 Model Specification Sheet. Instruction manual.

Mech Marvels. (2021). Top performance features of string-blade mowers in modern landscapes. https://mechmarvels.com/string-trimmer-tech

Minnesota Department of Health. (2024). Workload classifications based on energy expenditure. https://www.health.state.mn.us

Najafi, N., & Torabi Dastgerduei, M. (2015). Assessment of timeliness costs for agricultural field operations. Agricultural Engineering International: CIGR Journal, 17(2), 45–53.

Nkakini, S. O., & Yabefa, S. (2014). Design and performance evaluation of a human-powered mower. Nigerian Journal of Technology, 33(2), 230–237.

Pamujula, A., & Bhaskar, R. (2021). Analysis of musculoskeletal strain in handheld mower operators. International Journal of Occupational Safety and Ergonomics, 27(4), 985–994.

Pirchio, R., Rossi, G., & Rascio, N. (2019). Grass growth, turf quality, and carbon sequestration under different mowing regimes. Urban Ecosystems, 22, 561–574.

Roshanianfard, A., Blum, T., Sigalingging, J. F., Cheng, Y., Saul, H. (2025) Development and performance evaluation of a grass-cutting attachment for an autonomous off-road platform. Smart Agricultural Technology, Volume 10, 2025, 100858, doi.org/10.1016/j.atech.2025.100858

Shivaswamy, P. (2024). Lawn mowing in tropical regions: Impact, maintenance, and pest control. Tropical Horticulture, 12(1), 22–29.

Shivaswamy, C. and Jagga, S. (2024). Turfgrass management. In Dey, S., Patel, P., Vidyashree S. and Khilari, M. (ed) Insights of Floriculture and Landscaping, Vol 3 Stella International Publication Kurukshetra: 117-144.

The Engineering ToolBox (2004). *Sound Pressure Level*. [online] Available at: https://www.engineeringtoolbox.com/sound-pressure-d_711.html [Accessed 25 June 2025].

Turgeon, A. J. (2005). Turfgrass Management (8th ed.). Pearson Prentice Hall.

Upcounsel (2025). Penalty for Breach of Contract: Legal Consequences and Remedies. https://www.upcounsel.com/consequences-of-breaking-a-contract. Site accessed 29 August 29, 2025.

Van den Berg, W., Van Ittersum, M., & Rabbinge, R. (2007). The role of timeliness in production and economic models. European Journal of Agronomy, 26, 173–181.