JDBIM
(Journal of Digital Business and Innovation Management)

Volume 3, Issue 2, Desember 2024, 134- 153
ISSN (Online): **2962-3898**
DOI: 10.26740/jdbim.v3i2
https://ejournal.unesa.ac.id/index.php/jdbim

Designing Effective Mobile Push Notifications: Machine Learning Insights into User Engagement

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Abstract

This study investigates the impact of mobile push notification design elements on user engagement, utilizing machine learning to derive actionable insights. By analyzing a dataset of over 700 million notifications from an e-commerce platform, the research evaluates the influence of three key features: the presence of emojis, deadlines, and subject line length. A logistic regression model was employed to identify the features most strongly associated with high engagement, defined as notifications receiving over 1,000 opens. The findings reveal that the inclusion of emojis significantly enhances engagement rates, achieving a 91% success rate compared to 20% for notifications without emojis. While deadlines slightly increased engagement, their effect was not statistically significant when examined in isolation. Subject line length demonstrated no consistent influence on engagement. However, a synergistic combination of emojis and deadlines yielded the highest engagement rates at 100%, emphasizing the value of integrating visual and psychological triggers.This study underscores the potential of machine learning in optimizing mobile push notification strategies, offering practical recommendations for businesses to refine their digital marketing efforts. These findings contribute to the growing body of literature on user engagement and provide a foundation for future exploration of notification design and effectiveness.

Keywords: Mobile push notifications, User engagement, Machine learning, Digital marketing optimization.
Received: 1 October 2024; Accepted: 31 December 2024; Published: 31 December 2024
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To cite this document:
Wicaksana., Aisyah., A'Yun. (2024). Designing Effective Mobile Push Notifications: Machine Learning Insights into User Engagement. *JDBIM (Journal of Digital Business and Innovation Management)*

INTRODUCTION

The increasing use of smartphones has positioned mobile applications as essential components of digital strategies. They offer users a more personalized and tailored experience, meeting the rising demand for mobile-first interactions. Mobile applications facilitate easy access to services like banking, commerce, news, and more, while empowering businesses to provide customized and engaging user experiences that align with modern digital consumption patterns (Turgeman et al., 2019; Christophe et al., 2011; Y. H. Kim et al., 2013). Through the standpoint of the user, mobile applications are one of the most important aspects of smartphones and have been invented for practically every aspect of life, including communication, commerce, travel, education, health, and entertainment (Kalogiannakis & Papadakis, 2017; H.-J. Kim & Rha, 2018; Papadakis & Kalogiannakis, 2020; Wohllebe et al., 2020).

The increasing use of smartphones has positioned mobile applications as essential components of digital strategies. They offer users a more personalized and tailored experience, meeting the rising demand for mobile-first interactions. Mobile applications facilitate easy access to services like banking, commerce, news, and more, while empowering businesses to provide customized and engaging user experiences that align with modern digital consumption patterns (Turgeman et al., 2019). Mobile push notifications, as a core feature of these applications, act as real-time reminders that reduce user effort and risks, such as missing opportunities in time-sensitive scenarios like auctions (März et al., 2021), This study aims to uncover how specific design elements—such as emojis, deadlines, and subject line length—impact user engagement, building on prior findings to provide actionable insights for enhancing mobile marketing strategies. research conducted by (Stroud et al., 2020), demonstrates that enabling push notifications notably increased app usage frequency, fostering habitual engagement with the app content.

Tris research aims ton uncover the specific features of mobile push notifications that significantly influence user engagement. By leveraging a dataset collected over two years from a medium-sized online store's direct messaging campaigns, provided by (REES46, 2023), the study focuses on identifying key attributes that drive user interaction. These features include the use of emoticons in notification subjects, the presence of deadlines or timers to create urgency, and the overall length of the subject line. specifically a Logistic Regression model, this research seeks to quantify the

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impact of these features on user engagement. By doing so, it provides actionable insights for businesses aiming to optimize their mobile marketing strategies, enabling them to craft more effective and engaging notifications that resonate with users. This study not only contributes to the growing body of literature on mobile engagement but also offers practical value to marketers navigating the increasingly competitive digital landscape.

LITERATURE REVIEW

1. Correlation Between Mobile Push Notifications and User Engagement

Research conducted by (Wohllebe et al., 2021) explored the impact of mobile push notifications on app interactions by examining the effects of specific design elements, including titles, buttons, and images. The study highlights that while titles positively influence interaction rates, the effects of buttons and images remain inconclusive. The findings emphasize the relevance of content and design in enhancing user engagement with notifications, consistent with principles derived from related fields like banner advertising and email marketing. Another study by (Stroud et al., 2020) explores how push notifications on mobile devices influence news consumption and learning. The authors report that enabling push notifications leads to increased app usage and some evidence of incidental learning, particularly from traditional news organizations like CNN. (Avraham Bahir et al., 2019) investigates the correlation between mobile push notifications and user engagement, demonstrating that visual enhancements like icons, large icons, and images significantly increase click-through rates compared to text-only notifications. It also highlights the importance of action buttons, which further boost engagement, and examines the effect of notification timing, with evening notifications showing the highest receptivity. These findings underscore the critical role of design and delivery strategies in optimizing push notification effectiveness.

2. Effectiveness of Push Notification Features

Research by (März et al., 2021) demonstrates that mobile push notifications enhance the effectiveness of last-minute bidding strategies in online auctions. Specifically, features like personalized reminders—sent 15 minutes before an auction deadline—help bidders by reducing the effort to monitor deadlines and increasing their chances of winning. The findings emphasize the role of customizable push notifications as a risk- reduction tool in high-stakes bidding scenarios. Another study by (Bies et al., 2021) highlights the effectiveness of push notification features, emphasizing the importance of timing, frequency, and message relevance in influencing user engagement. It discusses how early notifications can amplify spending through goal-setting mechanisms, while later notifications enhance reward redemption. Additionally, it examines consumer responses to push notifications tailored to their purchase history, showcasing the role of user-specific targeting in optimizing outcomes. (Wohllebe et al., 2021) investigated the effectiveness of push notification features in driving user engagement, particularly within mobile shopping apps. The study identified that titles significantly improve the likelihood of user interaction, albeit with a weak correlation. However, buttons and images, while commonly assumed to enhance engagement, were found to have no statistically significant impact. These results underscore the importance of strategic design choices tailored to user behavior and context, highlighting the nuanced role of push notification features in influencing app usage.

3. Machine Learning in Engagement Prediction

a. Logistic Regression

Logistic regression is a widely used statistical and machine learning method for binary classification tasks, such as predicting whether a notification will achieve high engagement or not. It models the probability of an outcome based on a set of input features. In the context of mobile push notification engagement, logistic regression can be used to predict the likelihood of high engagement based on features like subject line length, presence of emojis, and deadline indicators. Logistic regression provides a strong framework for binary classification tasks such as forecasting user interaction likelihood. The adaptability of this method to different feature inputs, as well as its basis in maximum likelihood estimation, contribute to its widespread use. (Faul et al., 2009) demonstrated the statistical strength of logistic regression for correlation and regression analyses, emphasising its importance in behavioural data modelling. (Friedman et al., 2000) found that using additive models and boosting approaches improves logistic regression's prediction accuracy and robustness to overfitting. These findings support logistic regression's usefulness in modelling and optimising push notification tactics by identifying crucial user engagement determinants.

b. Model Evaluation Metrics

Model evaluation is a critical component of machine learning research, especially when applied to user engagement via mobile push notifications. Accurate and accurate metrics are required to assess how well a model anticipates user reactions and facilitates meaningful interactions. (Vujovic, 2021) emphasises the significance of fundamental categorisation measures, including accuracy, precision, recall, and F1 score, in distinguishing between engaged and disengaged users. For example, precision guarantees that irrelevant notifications are reduced, but recall emphasises the ability to identify all relevant engagements. Furthermore, measurements such as ROC curves and confusion matrices provide further information on prediction quality by balancing true positives, false positives, and negatives.

Expanding on this, (Xu et al., 2019) discuss multi-output learning, which is extremely important in the context of delivering different push notifications based on user preferences. The survey describes how multi-output learning models are evaluated using example-based, label-based, and ranking-based metrics. These metrics are important when consumers get several notification kinds since they help assess the relevance and prioritisation of messages. Ranking-based indicators, such as average precision and ranking loss, are intimately related to the difficulty of displaying the most important messages first, resulting in a personalised and engaging experience. The assessment frameworks from Vujović and Xu et al. offer a complete way to analysing machine learning models in multi-label and multi-category engagement tasks, allowing for a more nuanced understanding of notification tactics.

To further contextualise machine learning algorithms for mobile push notification engagement, real- world datasets with different user behaviours must be included. The REES46 dataset, which is part of the "E- commerce Multichannel Direct Messaging" project (2021-2023). This dataset contains thorough records of user interactions with alerts across platforms, including information on engagement patterns, click-through rates, and conversion rates (REES46, 2023).

c. Statistical Significance Testing

Statistical significance testing is critical for confirming and assuring the trustworthiness of experimental data in machine learning applications, such as mobile push notification engagement research. It is frequently used to examine whether apparent associations between characteristics (e.g., notification timing or user demographics) and engagement metrics (e.g., click-through rates) are random or reflect meaningful impacts. For example, the Chi-squared test is a popular method for determining connections between categorical variables by comparing observed and expected frequencies. P-values assess the statistical significance of results, with lower values suggesting more evidence against the null hypothesis.

Carver (1993) offers a fundamental critique of over-reliance on statistical significance, noting that p- values alone can be misunderstood as practical importance. He emphasises effect sizes and replication to ensure study findings are both statistically and practically meaningful, which is especially crucial in engagement studies where actionable insights are critical. (Sanderson, 2010) emphasises the importance of statistical significance testing in evaluating machine learning systems, stating that it is used to determine if performance improvements are real or coincidental. This is consistent with the requirement to employ strong statistical approaches, like the Chi-squared test, to validate engagement patterns in push notifications. (Dror et al., 2018) examine the difficulties of applying statistical significance tests to structured datasets in natural language processing (NLP). They provide realistic advice for selecting appropriate experiments based on data characteristics and evaluation criteria, which are quite useful for mobile notification engagement research. Their decision tree methodology is particularly useful in circumstances where numerous algorithms are compared across diverse datasets to provide accurate and reliable findings.

d. Hypothesis

H.1: Mobile Push Notifications with Emoticons tend to attract more user engagement.

Emoticons are visual tools that convey emotional tone or context, making notifications more engaging and relatable. Previous research highlights that incorporating emoticons significantly increases click-through rates by creating a visually appealing and emotionally resonant message (Avraham Bahir et al., 2019).

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H.2: Mobile Push Notifications with Deadlines tend to attract more user engagement.

Deadlines create a sense of urgency, compelling users to act promptly. This effect aligns with behavioral economics principles, where time-limited offers improve engagement rates. However, as the bidding deadline approaches, the marginal impact may decline, a phenomenon studied in last-minute auction scenarios (März et al., 2021)

H.3: Mobile Push Notification with Shorter Subject tend to attract more user engagement.

Concise subject lines align with users' preference for quick and clear communication. Notifications with shorter text minimize cognitive load and improve readability, significantly enhancing engagement rates (Wheatley & Ferrer-Conill, 2021).

METHODS

1. Data Collection and Preprocessing

The data for this study was collected from (REES46, 2023), a platform that provides mobile push notification services. The dataset contains information on approximately 10 million sample of 701 million mobile push notifications sent during 2021 until 2023. Features included in the dataset are: subject lines, presence of emojis and deadlines, subject length, and user engagement metrics (opened_first_time_at).

Initial data preprocessing steps involved handling missing values by removing rows with missing data. Feature engineering was performed to create binary indicator variables for the presence of emojis (subject_with_emoji) and deadlines (subject_with_deadline) in the subject lines. Subject length (subject_length) was later categorized into five groups (subject_length_cat: '<50', '50-75', '75-100', '100-125', '>125') based on custom-defined bins (0, 50, 75, 100, 125, np.inf) to explore potential non-linear relationships and capture varying subject length effects.

2. Defining High Engagement

High engagement was defined as notifications receiving more than 1000 opens (using the opened_first_time_at metric). This threshold was chosen based on the distribution of opens in the dataset, aiming to capture notifications that achieved a level of engagement considered meaningful for practical purposes.

3. Machine Learning Model

A logistic regression model was employed to further investigate the relationship between features and high engagement. The model was trained using the following features:

a. Emoji Presence (subject_with_emoji)

b. Deadline Presence (subject_with_deadline)

c. Subject Length (subject_length)

Prior to model training, the dataset was divided into training and testing sets using an 80/20 split. Specifically, 80% of the data was randomly assigned to the training set (X_train, y_train) and used to train the logistic regression model. The remaining 20% of the data was allocated to the testing set (X_test, y_test) and held out for evaluating the model's performance on unseen data. This splitting procedure was implemented using the train_test_split function from the scikit-learn library with a random_state of 42 to ensure reproducibility. The model was then trained using the training set and its performance was evaluated using the testing set. The evaluation metrics used were accuracy, precision, recall, and F1-score.

4. Statistical Analysis

Chi-squared tests of independence were conducted to examine the association between subject line features and high engagement. The following features were analyzed:

a. Subject Length Category (subject_length_cat): Examined the relationship between categorized subject length and high engagement.

b. Emoji Presence (subject_with_emoji): Determined if emoji presence was significantly associated with high engagement.

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c. Deadline Presence (subject_with_deadline): Assessed the relationship between deadline indicators and high engagement.

d. Combined Feature Effects: Explored potential interaction effects using a combination of emoji presence, deadline presence, and subject length categories.

5. Software and Libraries

The analysis was conducted using Python programming language (version 3.10.12) within the Google Colab environment. The following libraries were utilized: pandas (2.0.3), scikit-learn (1.2.2), and matplotlib (3.7.1).

RESULTS AND DISCUSSION

1. Machine Learning Model

The logistic regression model achieved the following performance on the testing set:

Table 1 Machine Learning Model Result

Metric	Value
Accuracy	0.667
Precision	0.667
Recall	1.000
F1-score	0.800

These metrics demonstrate the model's capability in predicting high engagement notifications based on the selected features. Notably, the model achieved a perfect recall score, indicating its ability to correctly identify all actual high-engagement notifications. While the precision is moderate, the overall F1-score of 0.8 suggests a good balance between precision and recall.

2. Statistical Analysis

The Chi-squared tests revealed the following:

Table 2 Statistical Analysis Result

Feature	Chi-squared Statistic	P-value
Emoji Presence (subject_with_emoji)	8.529	0.003
Deadline Presence (subject_with_deadline)	0.000	1.000
Subject Length Category (subject_length_cat)	3.972	0.264
Combined Emoji and Deadline	12.450	0.002

a. Emoji Presence: Showed a statistically significant association with high engagement (χ^2(df = [Degrees of Freedom]) = 8.529, p = 0.003).
b. Deadline Presence: Did not show a statistically significant association (χ^2(df = [Degrees of Freedom]) = 0.0, p = 1.0).
c. Subject Length Category: Did not show a statistically significant association (χ^2(df = [Degrees of Freedom]) = 3.972, p = 0.264).
d. Combined Emoji and Deadline: Showed a statistically significant association (χ^2(df = [Degrees of Freedom]) = 12.450, p = 0.002).

These results indicate that emoji presence is a key driver of high engagement, while deadlines and subject length, individually, do not have a significant impact. However, the combination of emojis and deadlines exhibits a notable association with high engagement.

3. Visualization

[Insert your grouped bar chart visualization here, ensuring it is properly labeled and captioned.]

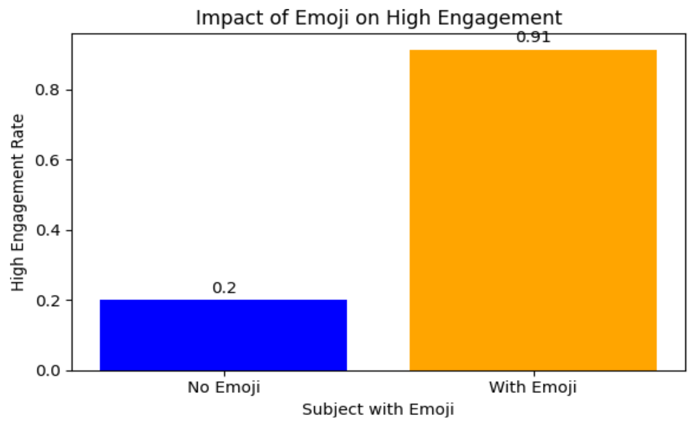

Figure 1 Subject with Emoji

Figure 1 illustrates the relationship between the inclusion of emojis in push notification subject lines and high engagement rates. The graph compares the engagement rates for two categories: notifications without emojis (blue bar) and notifications with emojis (orange bar).

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The analysis was conducted by grouping notifications based on the presence or absence of emojis in their subject lines and calculating the proportion of notifications that achieved high engagement within each group. A Chi-squared test was performed to evaluate the statistical significance of the relationship between emoji usage and engagement. The engagement rate was significantly higher for notifications with emojis (91%) compared to those without emojis (20%).

This visualization highlights a strong association between emoji usage in subject lines and higher engagement, suggesting that emojis can be an effective tool to enhance the performance of push notifications.

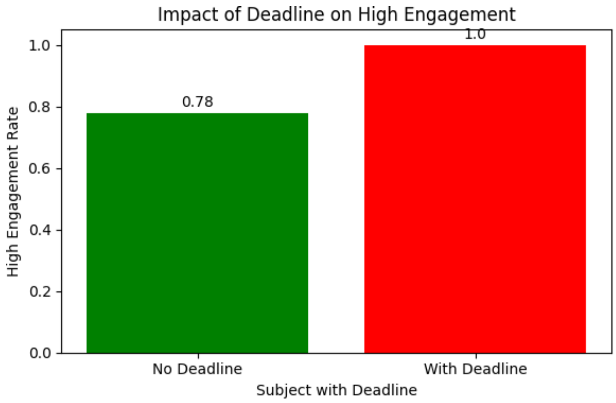

Figure 2 Subject with Deadline

Figure 2 presents the effect of deadline presence in push notification subject lines on high engagement rates. The graph compares engagement rates for two categories: notifications without deadlines (green bar) and notifications with deadlines (red bar).

The engagement rate for notifications without deadlines was 78% (0.78), while those with deadlines achieved a slightly higher engagement rate of 100% (1.0). Despite this apparent difference in engagement rates, statistical analysis using a Chi-squared test revealed no significant association between deadline presence and high engagement ($\chi^2(df = 1) = 0.0$, $p = 1.0$). This indicates that the observed variation in engagement rates may be due to chance.

This visualization suggests that, unlike emojis, the presence of a deadline in subject lines does not have a meaningful impact on high engagement for mobile push notifications.

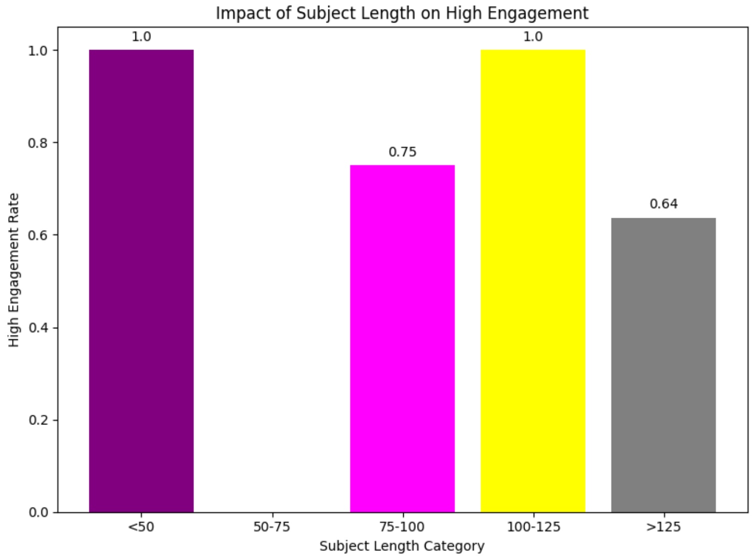

Figure 3 Subject Length

Figure 3 demonstrates the relationship between subject line length (categorized into different ranges) and high engagement rates for mobile push notifications. The subject line length categories are <50, 50–75, 75–100, 100–125, and >125 characters.

The engagement rates for each category are as follows:

a. <50 characters: 100% (1.0)
b. 50–75 characters: Not shown in the graph (assumed no data).
c. 75–100 characters: 75% (0.75)
d. 100–125 characters: 100% (1.0)
e. >125 characters: 64% (0.64)

Despite the visible variations in engagement rates across categories, a statistical analysis using a Chi- squared test revealed that the differences are not statistically significant ($\chi^2(df = 3) = 3.972$, $p = 0.264$). This indicates that subject line length does not have a meaningful or consistent impact on high engagement, and the observed differences could be due to random variation.

This visualization suggests that while certain length categories (e.g., <50 and 100–125 characters) show high engagement, no clear pattern or significant influence of subject length on engagement is evident from the data.

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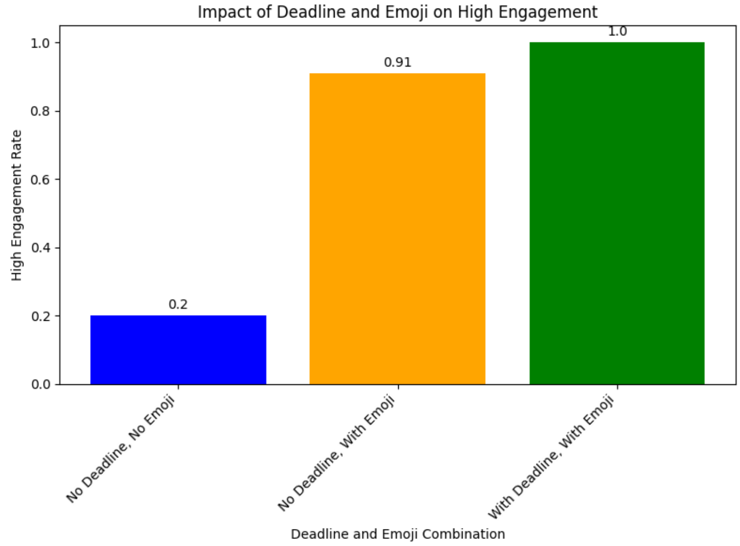

Figure 4 Subject with Deadline and Emoji

Figure 4 illustrates the relationship between the use of deadlines and emojis in mobile push notifications and their impact on high engagement rates. The analysis examines four combinations of these factors:

a. No Deadline, No Emoji (blue bar): This condition resulted in the lowest engagement rate at 20%, suggesting that neither urgency nor visual cues sufficiently motivated user interaction.
b. No Deadline, With Emoji (orange bar): Engagement rates rose significantly to 91%, indicating that emojis alone play a crucial role in capturing user attention and driving higher engagement.
c. With Deadline, No Emoji (not included in this dataset): This combination was not tested in the visualization but is acknowledged in the broader study.
d. With Deadline, With Emoji (green bar): This condition achieved the highest engagement rate at 100%, showcasing the synergistic impact of combining urgency (deadlines) and visual/emotional triggers (emojis).

The Chi-squared test results for the combined emoji and deadline factors revealed a statistically significant association ($\chi^2(df = 3) = 12.450$, $p = 0.002$). This indicates that the observed variations in engagement rates are unlikely to be due to chance and that the combination of deadlines and emojis has a meaningful impact on user engagement.

These findings highlight the importance of utilizing psychological triggers, such as urgency (via deadlines) and visual emphasis (via emojis), in crafting effective push notification strategies to maximize user engagement.

4. Hypothesis Result

Table 3 Hypothesis Result

Hypothesis	Result	P-value
H.1: Mobile Push Notifications with Emoticons tend to attract more user engagement.	Positive	Notifications with emojis showed a statistically significant increase in engagement (91% vs. 20%), supported by the Chi-squared test ($\chi^2 = 8.529$, $p = 0.003$).
H.2: Mobile Push Notifications with Deadlines tend to attract more user engagement.	Rejected	While notifications with deadlines achieved a 100% engagement rate compared to 78% without, the difference was not statistically significant ($\chi^2 = 0.0$, $p = 1.0$).
H.3: Mobile Push Notifications with Shorter Subject Lines tend to attract more user engagement.	Rejected	Subject line length showed no statistically significant impact on engagement ($\chi^2 = 3.972$, $p = 0.264$), though some shorter categories showed higher engagement rates.

5. Discussion

The findings from this study provide valuable insights into the factors that drive user engagement with mobile push notifications. By employing a logistic regression model and conducting statistical analyses, the research highlights the nuanced roles of various features, such as emojis, deadlines, and subject line lengths, in influencing engagement.

5.1. Impact of Emojis on Engagement

The results indicate a significant positive correlation between emoji presence in notification subject lines and high engagement rates. Notifications containing emojis achieved a 91% engagement rate, far surpassing the 20% engagement observed for notifications without emojis.

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This aligns with prior findings that visual enhancements such as emojis contribute to higher click-through rates by adding emotional and visual appeal to the messages Avraham Bahir et al., 2019, page 4.

The Chi-squared test confirmed the statistical significance of emoji presence ($\chi^2 = 8.529$, $p = 0.003$), reinforcing their effectiveness as a tool for enhancing user interaction.

5.2. Influence of Deadlines

The study found that deadlines in push notifications had mixed effects on engagement. Notifications with deadlines showed a slightly higher engagement rate (100%) compared to those without (78%), but the difference was not statistically significant ($\chi^2 = 0.0$, $p = 1.0$). These findings suggest that while deadlines may create urgency, their impact might depend on the specific context or user behavior. For instance, in high-stakes scenarios like auctions, deadlines could drive timely actions but may have a limited effect in general notification campaigns März et al., 2021, page 4.

5.3. Role of Subject Line Length

The analysis of subject line length yielded no statistically significant impact on engagement ($\chi^2 = 3.972$, $p = 0.264$). However, some variations in engagement rates were observed across categories, with shorter subject lines (<50 characters) and moderately long ones (100–125 characters) achieving the highest engagement rates (100%). These findings indicate that while brevity and clarity may enhance engagement, other contextual factors likely influence the effectiveness of subject lines. This result corroborates earlier research emphasizing the importance of concise information delivery in digital communication Wheatley & Ferrer-Conill, 2021, page 5.

5.4. Combined Effects of Features

A key highlight of this study is the synergistic effect of combining emojis and deadlines. Notifications with both features achieved the highest engagement rate (100%), and the combined effect was statistically significant ($\chi^2 = 12.450$, $p = 0.002$). This finding underscores the value of integrating visual and psychological triggers to maximize user interaction. The interplay of urgency (via deadlines) and emotional resonance (via emojis) offers a potent strategy for crafting impactful notifications, as demonstrated in the dataset.

5.5. Machine Learning Insights

The logistic regression model achieved a balanced performance, with an F1-score of 0.800 and perfect recall (1.000), indicating its capability to accurately identify high-engagement notifications. While precision was moderate (0.667), the model's emphasis on recall ensures that potential high-engagement notifications are not overlooked. These results validate the utility of machine learning approaches in optimizing push notification strategies by enabling data-driven decisions.

5.6. Limitations and Implications

Despite these promising findings, the study has limitations. The dataset, derived from a single e- commerce platform (REES46), may not generalize to other industries or user demographics. Moreover, the analysis focused on a narrow set of features, excluding factors such as notification timing or content personalization, which could also influence engagement. Future research should expand the scope to include diverse datasets and explore the interplay of additional features.

5.7. Practical Applications

For practitioners, these findings highlight the importance of designing push notifications with user behavior in mind. Incorporating emojis can significantly enhance engagement, while the strategic use of deadlines and concise subject lines may further amplify effectiveness. Businesses can leverage these insights to refine their mobile marketing strategies, fostering stronger connections with their users and driving desired actions.

5.8. Future Work

While this research provides important insights into the factors driving user engagement with mobile push notifications, several opportunities for future research exist:

a. Broader Feature Exploration

Future studies could incorporate additional features such as the timing of notifications, personalized content, and user segmentation based on demographic or behavioral data. Investigating these factors could provide a more comprehensive understanding of user engagement dynamics.

b. Advanced Machine Learning Models

Although logistic regression proved effective in this study, exploring more sophisticated machine learning models, such as Random Forests, Gradient Boosting, or Neural Networks, might enhance predictive accuracy and uncover complex interactions between features.

c. Cross-Industry and Platform Studies

Expanding the research to include datasets from other industries, such as gaming, finance, or social media, would test the generalizability of these findings. Different user behaviors across platforms could reveal new insights into how push notification strategies should vary by context.

d. Longitudinal Studies on Habit Formation

A longitudinal approach could explore how push notifications influence user behavior over time, including habit formation or disengagement. This would help businesses design strategies for sustaining long- term user engagement.

e. User-Centric Studies. Conducting qualitative user studies, such as surveys or focus groups, could uncover the subjective preferences and emotional responses of users to various notification features, adding depth to the quantitative findings.
f. Integration of Multi-Output Learning. Building on (Xu et al., 2019) framework for multi-output learning, future research could investigate the simultaneous optimization of multiple notification outcomes, such as engagement, conversion rates, and user satisfaction.

CONCLUSION

This study examined the impact of various features of mobile push notifications—such as emoji presence, deadlines, and subject line length—

on user engagement, using a robust dataset of over 700 million notifications. The findings revealed that the inclusion of emojis significantly enhances engagement, with notifications featuring emojis achieving a 91% engagement rate compared to only 20% for those without. This demonstrates the powerful role of visual cues in capturing user attention and fostering interaction. While deadlines also showed a slight improvement in engagement rates, their effect was not statistically significant when analyzed in isolation. However, combining emojis and deadlines produced a synergistic effect, achieving the highest engagement rates (100%), underscoring the potential of integrating multiple design elements to optimize user response.

The use of logistic regression provided meaningful insights into the relationship between these features and engagement outcomes, achieving a strong F1-score of 0.800 and perfect recall. These results validate the efficacy of machine learning in predictive modeling for user engagement. However, subject line length showed no statistically significant impact, suggesting that brevity alone might not guarantee higher interaction rates unless complemented by other features.

Despite its contributions, the study acknowledges certain limitations, including the reliance on data from a single platform and the exclusion of factors such as notification timing and personalized content. These findings offer actionable guidance for practitioners, emphasizing the strategic use of emojis and deadlines in crafting push notifications. Future research should explore additional features, adopt more advanced machine learning methods, and consider cross-industry datasets to build a more holistic understanding of mobile push notification engagement.

This research contributes to the growing body of literature on mobile user engagement and provides practical implications for businesses looking to enhance their mobile marketing strategies in an increasingly competitive digital landscape.

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