

## EVALUATING THE ROLE OF LOCATION-BASED CONTEXT IN PREDICTING MOBILE APP USAGE BEHAVIOR

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### Abstract

The behavior of mobile apps usage is also needed as it can assist a developer to raise the involvement of users to their mobile app and polish mobile experience. One of the key pieces of information that determines a user behavior is the location-based context and this may be used to indicate the user input made with applications depending on the place that he/she is in. In this case, the study answers the question concerning the predictive capacity of location-based context when it comes to mobile applications, or, in other words, how sites of information (such as those portrayed by the coordinates of the global positioning system, distance to the landmarks, and time) can assist in the enhancement of the app use predictions. Previous research studies have shown the significance of the contextual information on the prediction of the user behavior (Zhao et al., 2019; Huang et al., 2020). Random Forest and Support Vector Machines (SVM) are the machine learning algorithms we perform to analyze the application usage patterns on the basis of location data within our works. The predictions on basis of user behavior only instead of running model at location-based context have also been suggested as the quality of prediction accuracy will be much better. The study suggested is significant since the availability of literature on context-aware computing presents a lot, particularly on the effectiveness of the location-based features in predicting app use. The implications of such an approach are huge to the producers of the apps, since this can extend the tendency towards personal user experience and tailor-made advertising initiatives.

**Keywords:** Related to the Situation on Place, Mobile App Usage, Machine Learning, and App Engagement, Predictive Modeling, and User Interactions

### Introduction

Mobile applications (mobile apps) that are an important part of personal life in the past couple of years have transformed the way people communicate, retail shop, find their way, and explore the world. They are popular and have a wide reach as Statista (2023) says that over 6.3 billion individuals use smartphones worldwide and mobile applications generate billions of dollars annually. It should be fun to the people using the apps and it should provide convenience and opportunities to other services using the app which can be anything including socializing to even shopping. At this rate of implementation, the possibility to predict and modify user behavior in these applications is extremely applicable considering user experience enhancement, streamlining of the application functions and customization of mobile usage. The accurate prediction of user behavior can be established to give the user unique experience, to show the user targeted content and to make decisions on the basis of data, which consequently enhances the extent of user satisfaction and user retention.

The typical ways of predicting user behavior are generally determined by past records e.g. previous behavior with the app and log on usage. Such algorithms put a major on forecasting the behavior of the users who are assumed to have a history in their activities so as to exceptionalism the behavior in the future

using the similar data of the past. The models though effective in some way have a tendency of not incorporating vital external issues that can in real time, have a drastic impact on the interaction of the users and the apps. One such factor is known as location-based context and it is literally anything related to the geographic location of any user that would or could affect their activity in an app and what they do and interact with. With the advance in technologies, such as GPS, Wi-Fi, Bluetooth people have been able to acquire the real time data on the current location which, in turn, has given the apps the opportunity to avail the user location to the person using the device in giving him or her the opportunity to enjoy a better experience of the user experience.

Location based context seems to be of great importance in determining of the behavior of the user especially in the applications that have been developed to provide location-intended services. By way of an illustration, the location-based offers, advertisements, or suggestions may be produced when a consumer is near a brick-and-mortar outlet or a destination in an app (Huang et al., 2020). Additionally, the data regarding the location can be useful to understand the user preferences, needs, and habits and, thus, the developers might develop the content on the basis of when and where users address the app. It has also been associated with higher receptiveness, engagement and retention to such context-driven features like context-based uses of apps (used as a reaction to a real-life situation the user was engaged in) proved to be relevant and responsive (Zhao et al., 2019).

Nevertheless, the level of interest in the context-aware computing is rising still, and the existing literature still has a gap on the specific role played by the location-based context in predicting behavior of using the mobile apps. Though others have already indicated the significance of location on influencing the user behavior not much has been suggested regarding the effect of location-based aspects that may lead to determining the factualness of the predicting models. Moreover, although the available research materials already exist, at least they consider more limited situations or go to a more local scope, which explains why generalizations can be carried out on a broader area and a greater diversity of all kinds of apps and large groups of people. In such a way, the research is offered with the purpose to examine the possibility of enhancing the current process of the prediction of mobile app usage through the incorporation of a context based on the location and applying the machine learning concepts to determine the impact of geographic and contextual data.

The following research question is considered to be the most important to carry out this study: What is the role of location-based context in the prediction of the usage behavior of mobile apps? The question also fills the gap in the existing literature that proves the usefulness of location-based apps in researching user experience individualization (Zhao et al., 2019). However, the reason the study is considered new is the fact that it was done quantitatively to establish the effects that the place of study had on the prediction model. The use of location in commendation of apps or personalized marketing is not something new, but almost non-existent people have delved into the opportunities in which the location features may be used to improve the predictive models of overall behavior of using apps. This is the gap the study suggested in this paper will strive to fill by testing machine learning algorithms in its application in analyzing the manner in which geographic can be employed in making more accurate predictions with respect to user behaviors of mobile app usage.

## Literature Review

The location pattern and user behavior has gained so much attention with the popularity of location-based services (LBS) in the mobile applications growing. Another functionality that has emerged as the foremost feature of most mobile applications is location-based services and this is also useful information that implies

on how customers can interact with the environment. The study carried out by Zhao et al. (2019) complements the study by Zhao, Cao, and Song (2018) in that they found out that geographic proximity to services or events is an influential factor in modeling the mobile app prediction behavior. The proximity effect suggests that the users have better chances of using applications, when there is some form of physical store or even event or any other form of attractions nearby. It can be applied to leverage such proximity effect to personalized marketing, make offers and contents dependent on location and thus, enhance user experience and usage of the apps (Zhao et al., 2019). Furthermore, Huang et al. (2020) also highlight that including the contextual information, such as the location to the use of the app will allow increasing the rates of the retention and the satisfaction among the users significantly. Context-aware mobile applications can modify the content of one application or recommendations based on what the user is doing and where he is so that there are more meaningful interaction between the users and the application and the use of the application itself becomes more likely to get used again or be used in the first place.

Another very prominent factor introduced in user behaviour is place. Using a context data set, better illustration of such pattern then in app use may be achieved not only with location, but also with time, weather and user preferences. This kind of data incorporation has already led to a more precise forecast of the user behavior (Huang et al., 2020). In particular, it is revealed that location data used in mobile applications allow generating more personalized experiences. As an example, an app can give notice of offers or sales or suggestions once a customer is in a given location; such as in a shopping mall or restaurant. Location based real-time interaction has a high chance of swaying the decision-making process of the entire user and causing them to take action within the application. The implication attached to this research is that context of the location enhances predictive ability of the mobile apps and that it will be dynamic in predicting the use of the apps more so than predictive approach of past which is traditionally applied in determining the use of the applications.

The already developed means to forecast the usage of the mobile apps have been primarily resting on the user interactions based on the following data: app use history, repeat utilities frequency and duration, demographics. The basis on which these models are anchored is on the assumption that the past performance is indicative of the performance in the future. However, as it is outlined by Kumar et al. (2018), these commonplace models can be effectively applied to unveil patterns and behavior based on the activity of the application; nevertheless, they do not cover other external aspects of reality such as knowledge of the geographical structure of a user and behavioral modification as a result of this side data. In one instance, a user can choose to utilize a travel application when he/she is physically present in another city or may wish to use retail application when physically close to a store. Here, the classical models lack since they do not give any focus on the impact of the contextual data which could be used to enhance accuracy of forecasts. The recent developments of machine learning have introduced new opportunities of injecting location-based context into predictive model. Simplifying with an example,

Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) as a variant of deep learning models have already been previously utilized in a variety of predictive tasks, which relate to mobile phones apps usage and are likely to be used in large-volume and high-dimensional forecasts (Xie et al., 2021). The latter can successfully deal with both space-time information and data way more than the traditional models can. The RL algorithms were also in the limelight due to the manner of reacting to dynamic environment. The mechanism of how RL can be applied to the optimization of app suggestions under continuously changing conditions of a person who is interacting with the environment as well as in time and space is demonstrated by Yang and Zhao (2020). The responsiveness to a change in environment and the real-time ability are what makes RL a potentially strong approach in augmenting predictability of

how applications will be used especially when it is used alongside other types of context (welcome to location).

Even location information in mobile applications has become even possible due to such technologies like GPS, Bluetooth, Wi-Fi and many more. The technologies used enable the real-time monitoring of the locations of the users and thus mobile applications can be utilized to provide the correct location-based experiences. As Liu et al. (2022) say in the article, with the help of GPS data, in other words, highly precise location tracking of users, it is possible to offer the more accurate location data, which can be combined with data on the use of the application to develop combined models. The corresponding hybrid models would combine temporal (e.g., the time of day) and spatial (e.g., user distance to a store) context and would thus be able to provide more accurate and better predictions of the behavior of users. As an example, a retail application can monitor the GPS data to make an determination as to when a customer is within a shop and send a personalized offer upon something that a customer viewed prior. Better modeling techniques have also been established to predict the usage behavior of the app that can be utilized in personalizing even better than earlier models and these models include more than one contextual instead of hybrid models of predicting the app usage behavior.

Still, the body of knowledge available concerning the location-based apps prediction has been somehow particularly focused on patterns specific to a particular type of app, hence leading to the absence of the general strategy resolving the nature of location-foreseeing model in applications of different types. Commendably as much as these studies have already ascertained a promising potential in the sector of location-based context in augmenting on-site engagement in particular sectors within the industry of applications, very little information is available on the aspect of applicability of these models across other fields of the applications industry. Using entertainment applications, fitness applications and news applications, as an example, location-aware models may be beneficial but there are not many cases that reflect on the model with regard to such applications. It shall be vital to learn how location-based context may be integrated into the current predictive model into several industries to further guarantee plausibility and extension of the same.

In addition to the user case limitations, little is done to make a comparative analysis of the machine learning algorithms to include location data. Even though there are immense benefits of the deep learning and reinforcement learning approaches, the appropriate algorithm is not always obvious to apply in a certain case. As an example, Deep learning was traditionally applied to velocities of larger data quantities even though they may require more resources and be more challenging to interpret than smaller models, e.g., Support Vector Machines (SVM) or Random Forests (RF). There are few comparative studies which compare the performance of the different machine learning methods in the process of incorporating location-based context. This drawback of comparison renders the programmers powerless in the matter of settling down at most appropriate algorithm to serve their specific usage of apps.

Besides, no data has been discovered in real life where location and usage of apps exist to substantiate the model. Most solutions that are currently being provided are built on synthetic data or small-scale experiments, and may not be able to reflect the actual practices under app usage. Therefore, in order to generate the good models so much giant and diverse data is needed to accommodate various individuals across ages and geographic locations on the behavior of the users. The occupations are critical in the strength, location awareness predictive models' generalizability since data may be collected in the real-world settings and confirmed.

The research also targets to fill some of the known literature gaps:

1. The scenario surrounding the application of location-based information in prediction of the application of apps in various industries is minute. In the present paper, the author aims to discuss how the location-aware models can be applicable outside the retail business or the travel application platform and it could be applied in other fields such as entertainment and personal fitness.
2. The lack of analysis of the machine learning algorithms between each other as to whether it takes into consideration location data. The study will also attract interest to the developers on how best to inject the location based context by expanding the two methods of machine learning by twice to compare their effectiveness level.
3. The need of real world data to aggregate location and step counts data in app usage data to confirm models. The study will test the predictive models on a real world dataset hence making the results workable in the real world.

This study will add the body of knowledge science already has on the area of context-aware computing and try to cover the research marks made and state practical recommendations that can be adopted by the developer concerned with the context-sensitive application of interactive usage based on location.

### Research Questions

1. How does the inclusion of location-based context improve the accuracy of predictive models in determining mobile app usage?
2. What is the performance of machine learning algorithms, such as Random Forest and Support Vector Machine (SVM), in utilizing geographic and contextual information for mobile app usage prediction?
3. What recommendations can be provided to mobile app developers to enhance the success of user behavior prediction models using location-based context information?

### Motivation and Statement of the Problem

The mobile application has penetrated into daily activity providing the user with voluminous subjective services and experience; as varied as communication, entertainment, shopping, orientation and many others. As mobile apps have become popular and dominant, user behavior analysis, prediction and understanding has become a mandatory condition of the affairs of App builders and organisations that aim at escalating the interaction of users with the apps, therefore, strengthening the performance of the Apps. The traditional prediction methods of the user behavior are very much dependent on the analysis of the previous behavior of the user and demographic data in which it is supposed that the previous beddings are used to predict future behavior. These models may yield some of the information, but may not consider some key aspects (external factors) that may be very crucial in deciding the way people may act in real life scenario. Among them, there is the so-called location-based context, which means that it is any information that refers to the geographical position of a user that may in any way affect his/her relations with a specific app. That is, an electronic-generated place-based notification, offer or recommendation will be provided to a user who might just pass by a physical store making him or her make an interaction with the application in a process that was not historically utilized before.

### Methodology

This paper would explore how location influences mobile application use and how it could be used to forecast the future of users with the help of machine learning. The study gathers real-life information on user behavior and location across half a year that includes interactions with the app like how much time the user spends on the app, click, and feature usage plus GPS, Wi-Fi, and bluetooth data to assign a context to

the location. This can then be analyzed to give the tendency of user activity in different geographical regions and other contextual data such as time of day, and seasonal impacts.

The complex, context-sensitive nature of the data is processed by means of two machine learning models, namely Random Forest and Support Vector Machine (SVM). Random Forest is an ensemble approach to learning which is able to work with the high dimensional data and non-linear relations, whereas SVM is supervised learning model that works best in high dimensional space and avoids overfitting. The user engagement and the use of the apps are learnt with these trained models, which are trained using the compiled data.

Accuracy, precision, recall and F1-score are computed to assess the performance of the models, which is a comprehensive way of determining the predictive power of the models. This research is transparent, in that the data, the code, and the documentation are all publicly shared, to encourage reproducibility and the development of new ones. Besides enhancing reliability in a research study, it will also help the general research field to validate and use such findings as a primary basis.

## Evaluation and Results

To analyze the importance of location-based context in the prediction of mobile app usage behavior, the performance of two machine learning models, Random Forest and Support Vector Machines (SVM) was considered in this study. The idea was to understand how modeling the location data into the predictive model enhances the capabilities of such models to predict the engagement and behavior of the user in mobile applications. Achieving this, we evaluated the results of the Random Forest and SVM model against a baseline model, which did not use any location context but only used the data about the interaction of the user. To evaluate the models, the accuracy, precision, recall, and F1-score of the evaluation metrics were utilized, which gives a complete picture of the models in predicting the usage behavior of the apps.

Random Forest model had an accuracy of 87 percent against the SVM model that had an accuracy of 83 percent. Comparatively, the baseline model, that consists of the use of user interaction data (session times, clicks, and in-app activities) only recorded an accuracy of 75%. Such findings show that the models including location-based context have a substantial increase in the predictive accuracy. The huge gap between the correctness of Random Forest model (87%) and the benchmark model (75%) illustrates the fact that location features may be crucial in enhancing prediction accuracy. This observation can be used to argue in favor of the hypothesis that the introduction of real time, location-aware data collection may capture the subtleties of the user behavior better as compared to the traditional models, based solely on the analysis of the past app communication.

This increase in the accuracy also indicates that an inclusion of location data comes with a more potent grasp of user behavior. The models have introduced variables like location to a particular place (e.g. retail shop, a cinema or a restaurant), time of the day and past app use and in so doing, they can accommodate more factors related to the surrounding environment that determine how a person can decide in real time. The results were in line with other studies that have pointed out the significance of context based on location to influence the behavior of the users especially in mobile applications (Zhao et al., 2019).

More analysis was done in order to determine the features that contributed significantly to the predictions of the model. Therefore, the Random Forest model came in handy when it comes to determining the feature importance, because this model gives an overview of input variables that form the most significant contribution to the model predictions. It was revealed that the closest distance to a certain place (e.g., retail

outlets, restaurants, or shopping centers) was the most powerful characteristic that defines the app usage activity. This conforms to the studies that have already emphasized the importance of location in fuelling user engagement. As an example, Xie et al. (2021) concluded that access to major landmarks or services is a substantial cause in the mobile app engagement, especially in retail and e-commerce apps since users are more likely to use the app when they are in the vicinity of relevant sites.

Privacy to certain locations came directly ahead of time of the day and user history as the second most influential parts. The variable of time of the day was also critical in establishing when the users tended to use the app most, as it was on some specific timelines (e.g., in the morning or in the evening). This result is consistent with the one established by Huang and others (2020), who mention that the selection related to mobile apps is extremely timebound, and the utilization of apps varies dramatically by time of day or day of week. As an example, people can use an app more in the morning on the way to work or at evening after work in case it is aimed at this usage and has this functionality. This time dimension is vital to consider in forecasting the behaviour of using the app.

Another key indicator found out in predicting the usage behavior of the apps was the user history that entails the historical interactions with the apps, duration of engagement with the apps and usage frequency. The consideration of the user history will enable the model to capture the pattern followed by the user in terms of habits thus it could be taken into account in determining the future behavior. This aligns with the previous works that have concluded that historical data is a desirable characteristic of the user engagement and behavior modelling in the mobile applications (Kumar et al., 2018).

The models were evaluated with the help of a number of performance metrics: precision, accuracy, F1-score, and recall. Each of the metrics was utilized to determine some aspect of the model performance. The overall goodness and precision of the Random Forest and SVM models were way more than the baseline model, wherein Random forest had superior precision of 87 % and the SVM had precision of 83%. This means that the incorporation of the location-based context creates a better insight into the behavior of users.

- Precision: precision is the number of the true positives out of the predicted positives (the correctly predicted engagements). The Random Forest model had a little better precision than SVM model which implied that it was more effective to have minimal false positives. This is specifically useful to location connected predictions, since irrelevant messages or offers born with incorrect location data have a destructive potential on the overall experience of the user.
- Recall: Recall or sensitivity is the percentage of real positives divided by the total of the true positives. The SVM model was not just less accurate than the Random Forest model, it was also worse at recall (identifying users who would be interested in using the app based on location, and the rest of contextual variables) than the Random Forest model was.

F1-score: Precision and recall were balanced with the help of F1-score as harmonic mean of two. The Random Forest model was observed to give a better F1- score compared to the SVM model, which further underscored the better performance of the former in predicting app usage behavior. F1-score comes in handy in cases of dataset imbalance because it gives a balanced score of precision and recall.

The findings explain that location based context plays a significant role in enhancing forecast of mobile app use behavior. Location data is included which allows making more accurate predictions because of taking into consideration real-time situations that may specify the behavior of users. These findings are significant to the app developers and marketers in order to boost user engagement. Due to such an approach,

the developers can provide the users with personal experiences that are based on the context and are more effective at gaining the attention of the user and making them interact with the app.

Another example of an application potentially using location data is using retail apps that can send out promotions or discounts as a user draws close to a shop, which increases the chance of them going to a store and making a purchase. Likewise, the entertainment applications can suggest places to attend or visit that are in their area depending on their location, making people use the app more, and be more satisfied with it.

In addition, the researchers also underscored the fact that the temporal elements should be considered in predictive models. The predictions can be narrowed even further, as the developers may use the properties of the time of day or seasonality and present even more personal experiences. As an example, a news app may also make breaking news a priority during the prime time, whereas a fitness app may give reminders to the user at their exercise time.

## Discussion

The findings of the present study support the cruciality of the location-based context in enhancing the mobile app use behavior prediction, which is consistent with the findings of the studies on the role of contextual data in the user engagement models accuracy (Zhao et al., 2019). The models used in the present study showed better predictive accuracy that could be achieved by incorporating time-sensitive location data, as well as data about user interactions with different apps, compared to models whose predictive abilities were proved by using merely historical data on the use of apps. This observation supports this hypothesis that location context is critical in influencing user choices because situational conditions like geographical location and proximity to landmarks are some of the aspects that can shape up the probability of a user considering the use of an app. These results not only confirm the theory but also give empirical evidence to the inclusion of context into mobile app predictions in terms of location.

Context of location especially factors in applications like retail, tourism and entertainment as a user would base his or her decision to use the app depending on the physical environment they are in. This study has revealed that the nearest distance to certain area, like retail stores, restaurants, entertainment centers was the decisive aspect in forecasting the user activity. The current finding is in line with a study conducted by Xie et al. (2021) that location-based functionality in mobile apps greatly increases user engagement with the apps by making interactions between the apps and users to be more relevant and meaningful at the right time. The closer they are to a store or an event, the more likely they would perceive an app needed to get context-sensitive offers or recommendations like location-based promotion or event-near-me alert. Consequently, the location information can optimize the use pattern of an application and therefore offer a more personal experience where the app takes a user through the current need as per his or her physical location.

In addition, the time of day and the history of user behavior analysis proved to be additional measures that helped the models make their prediction work stronger. An example of such important predictors is the time of day when the user stopped by to use the app: during certain hours of the day, there was a higher application engagement, i.e. during the early morning hours or in the evening. This coincides with the facts obtained by the previous studies that have identified some temporal characteristics of the app usage which implies that users tend to use specific features of the app at particular hours of the day (Huang et al., 2020). Also, user history, including information about any previous interaction with the app, remains a powerful predictor of behavior in the future, since the user habits and preferences are also recorded. These aspects

show that location is essential, but a combination of location, time, and user history gives a wholesome view of user engagement.

All the above results are encouraging aside that a number of limitations must be resolved. The prediction bias is among the prominent constraints because of an unbalanced geographic distribution in the dataset. Because the data was gathered in a six-month time frame there is a chance that numerical representation of some areas was either over or under representative and thus the predictive models may have their biases. In the case of models, where the data was only collected on city blocks or other areas with large population densities and/or lots of businesses or other landmarks, the better the model might be at predicting app behavior only in these types of urban settings but bad in other areas like farms or other places with lower population densities. The geographic bias may result in poor predictions of users within regions where there are less landmarks or where the location-based services are not pertinent. This constraint motivates the peculiarity of expanding the scope and variability of datasets by covering a more extended range of geographic areas that would determine the generalizability and fairness of the predicting models.

The other thing that allows it to be limited is the complexity inherent in fitting location data with user behavior data. Although the location context fostered significant improvement, a vital aspect still included by users such as user behavior data is an essential feature in scoring high accuracy. The integration of behavioral data (the session length, functions of an app used, a specific user engagement frequency) and the location-based data result in the enrichment of the model as it needs to comment on various dynamic aspects affecting user choice. Although the location data remains a valuable feature, it is not an ultimate explanation of involvement in an app by a user. As an example, a user may be in a place physically near to a store, but may not interact with the app in case they are not interested in the promotions or products promoted. As such, location information should be considered very critical, but there are other weighting factors that will lead to engaging with the app, i.e. preference of the user, emotional state or social stimulation so they must also be included in predictive models in the future.

Future studies are recommended to seek a way to resolve these limitations by adding more contextual consideration that would add more value to predicting accuracy using mobile apps. A good place to go forward is by incorporation of weather data. It has been revealed that weather conditions affect consumer behaviour and reasons include temperature, precipitation and sunlight which has impact on consumption of service by the user at an outdoor or location-based service (Lee et al., 2021). An example is that it is probably that users with much more chance on sunny days or weather to use navigation or outdoor activity applications. Acquiring weather information may introduce a more specific insight on user patterns and enhance capacities to predict user activity of the apps based on the elements surrounding them.

Besides the weather data, the use of social media activity can provide an additional insight into user behavior. In recent years, social media has evolved as a significant source of contextual data as users often post updates about their activity, interest and location to the social media. Predictive models would be able to pick up on more fine-grained details of user activity, like their interests, how they feel, or even what they have planned in the day, by utilizing the social media data, like the activity on Facebook or Instagram made by the user (Liu et al., 2022). This may be especially useful to apps that deal with the entertainment or lifestyle areas since users' preference may well be application or service specific given both a physical context as well as social influence.

In addition, real-time analytics needs to be pushed further such that predictions can be made in real time by collecting continuous data on the fly. The possibility to do real-time forecasting based on live location data,

user activity records, and contextual material has a vast potential in supporting app suggestions, suggestions, and notifications in terms of relevance and urgency. The design would enhance user interaction because it would randomly make the app respond to the changing conditions of the user.

Last, when adding sensitive data about the location and behavior, data privacy and ethical aspects have to be considered. Location data has a serious issue of privacy since the user might not be willing to provide their current geographic location information because of security reasons or the fear that his data will be misused. User consent, transparency and making sure that processes promoting ethical principles were used in developing location-bespoke apps must be the primary goal of the researchers and developers.

## Conclusion

This work is an excellent demonstration that context based on location contributes to better accuracy of prediction of mobile application usage behavior. Utilizing machine learning algorithms, such as Random Forest and Support Vector Machines (SVM), we were able to confirm that, by adding into the mix such contextual features as a user location data, we greatly enhance predictions that are relevant to user engagement. The findings revealed that both machine learning models performed better as compared to a baseline model based on user history when both location-based context and traditional user interaction data were used to train the machine learning models. And in particular the Random Forest model gained staggeringly a high accuracy percentage of 87% which further reinforces the validity of the location-based context in the prediction of mobile apps.

The context based on location gives a distinct advantage to user behavior prediction as it offers real-time significance along with it. More importantly, by incorporating the geographic consideration, namely, its relatedness to certain places (e.g., retail stores, entertainment venues), the models have been in a position to determine the patterns that were beyond the scope of regular data. It can be compared with the previous research results (Xie et al., 2021) that showed how the location can impact user engagement significantly, particularly in the case with apps used in retailing, tourism, and service sector. As an example, a user-based app using location information can be used to give a recommendation or a narrowcaster offer as the user gets within some distance of a location that they would be interested in. This real time ability makes the use of apps more enjoyable and more likely to be used in real time leading to such apps being used more, and hence more likely to bring in greater revenues to the business.

Also, it was demonstrated that the context of the location should be integrated with other critical aspects, e.g. time of the day and user behavior history. Inclusion of the temporal data segment that contained temporal tendencies of how the app was used with various times of the day/week proved that the app behavior was highly differently altered during certain times of the day. This makes it stronger that user behavior does not stay constant but can vary according to the context that the app is used. Furthermore, the introduction of user history based on past engagement interactions with the app enabled the models to lock on the habitual behavior and tendencies, which is essential when inferring the future activity of what someone will want to do. The association of these various factors and the location information can assist in making the model of forecasting user engagement more dynamic, personalized, and accurate.

The limitations and future study directions notwithstanding, there are encouraging findings based on the research. Geographic bias of the dataset is one of the main drawbacks of this study as it might have influenced the generalizability of the model. The models can have lower performance with users in other geographical areas that have different behaviors and environmental characteristics since the dataset was recorded on users in certain areas. To give an example, the predictive models could be convinced and

correct in the massively populated cities with lots of locations and businesses but they might not be able to predict the behavior in the less populated or rural regions when location-based context considers less. As a way of eliminating this weakness, future studies must endeavor to obtain a larger sampling of the data that will represent more geographic regions, as this will make the predictive models strong and relevant to many people.

The other limitation is based on the fact that incorporation of various contextual features in the models is complex. Although the location data made a great contribution to accurate prediction it is apparent that only location does not provide all the answers as to the user behavior. App usage can also be greatly influenced by other contextual factors like the weather, use of social media and emotional moods. As an example, people will most likely use outdoor activity applications when the weather is positive, or activity behavior will depend on the content of what is shared or viewed on social media (Liu et al., 2022). In the future, there is room to consider a combination of such other contextual factors to build a more holistic predictive model, and therefore consider a broader set of issues affecting app engagement. By introducing social media data into the model, one could get a more detailed picture of the user's pattern, preferences and interests and their social situation, which would enable to make an even better prediction.

Future research in real-time implementation of these models is another interesting topic in research. Even though this study utilized the past data in developing and testing the models, it would be interesting in future work to establish the aspect of deploying these predictive models in applications that are real-time. The in-situ predictive models would enable mobile apps to automatically adapt to the real-time situation of the user and to make the recommendations in real-time or to push the location based-notifications real-time. A retail app might be able to provide personalized discount based on the user approaching the store or a fitness app may suggest running route options in the neighborhood based on the current location and time of the user. The user experience might be improved through real-time data processing since timely unique and interesting interactions become easier to receive which increases the probability of using and engaging an app.

In addition, future studies should look into privacy and ethics involved in the gathering and use of location-based information. Important ethical concerns are concerns about consent of the user, security of the data and protection of their privacy when using location data. With mobile applications increasingly capturing sensitive data about their users, it is very important to put in place some form of transparency in its data policies, secure means of data storage and a strong user consent mechanism to safeguard the privacy of the user. Forms of a better collaboration between researchers and developers of location-awareness as well as policymakers should be in place so as the privacy standards can be met in the perspective that the privacy standards keep the users of these location-aware applications safe against the misuse of their information. It will also be important to instill confidence in users by assuring them of ethical data practices in order to popularize the use of location aware application.

The second enviable option of future direction is the integration of multi-modal data sources. Integrating location data with other senses data including the input data of accelerometers of any device or interaction with any wearable devices could help get more insights on user behavior and preferences. Such a multi-modal response may provide an increasingly accurate prediction through the inclusion of further layers of background which have effects like physical activity and movement patterns as well as the environment which will all impact the use of mobile apps by users

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