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UNDERSTANDING MOBILE APP USAGE THROUGH CONTEXTUAL DATA: AN ANALYSIS USING LINEAR REGRESSION

Saleem Raza Gillani, Nusrat Ara

Saleem Raza Gillani
Mirpur University of Science and Technology
Email: *razagillani_saleem11@gmail.com*

Nusrat Ara
Mirpur University of Science and Technology
Email: *nusratara111@gmail.com*

Abstract
The use of mobile apps leaped into the scene over the past few years, and the issue of features contributing to app engagement is vital to developers, marketers, and researchers. In this paper, the researcher attempts to compare the pattern of mobile application usage based on contextual information through the application of the linear regression method using parameters considered important to determine the location, time of day, and the type of device used. We have already seen a trend of research showing how contextual information can influence the behavior of the user (Zhao et al., 2019), although the challenge remains to understand how those factors combine to impact the usage of the apps on a wider scale. Our approach is to use linear regression models to forecast app engagement on the basis of the contextual features by use of data set encompassing both the time-series data of app usages as well as the context of a user. We find that time of day along with user location has a significant impact on mobile app usage with time having the biggest impact. The results have been uploaded to the existing literature in the field of mobile computing and app personalization, providing an understanding of how to enhance the app design and the experience with encountering it. The article under consideration underlines the necessity of the implementation of real-time contextual data in the process of boosting app utilization and customer satisfaction.

Key words: Mobile Applications, Contextual Data, Linear Regression, User Behavior, Application Usage Prediction, Time Series Data

Introduction

Today, mobile application (apps) have become part of everyday life around the world in the digital era. Through these applications, communication, socializing, entertainment, business transactions, etcetera are facilitated and they in fact have contributed a lot in changing the way users tend to use technology. The mobile apps market is anticipated to expand at a compound annual growth rate (CAGR) of 18.4 percent through 2020 and this shows the significance of mobile apps in various attractive industries like entertainment, education, and business (Grand View Research, 2020). With the expansion of the mobile app ecosystem, the importance of the aspects of user engagement and behavior is on the rise among the developers and marketers. Such considerations of the user behavior are essential to enhance user engagement, increase interactions, and user satisfaction (Zhao et al., 2019).

To accomplish all of this, it is crucial to study the mobile application usage patterns. It has been determined that usability, relevance of the content and interface design are aspects that play pivoting roles in

determining user engagement patterns with the apps (Meyer et al., 2020). Yet, another point that has not received enough attention is the possibility to use some context data, including the location, time of day, device type, and user behavior. Contextual data has the potential to provide insight into the context in which the user is consuming the apps and thus driving decisions on actions. With this comprehension, the developers are capable of designing an individualized user experience and thus developing an application that suits individual users taking into consideration a range of environmental factors (Harris et al., 2018).

Importance of contextual factors in the usage of mobile apps can be observed in the works like one called Zhao et al. (2019) who brought up the rising importance of location-based services. As an illustration, location-based apps can suggest services using the geographical location of the user, e.g., they can recommend the restaurants located nearby or events to attend. The time of day is of high importance to engage highly in the use of certain applications too, as people use them more often in the morning or evening or weekends (Meyer et al., 2020). Also, the type of device may influence the way users use apps because smartphone users might use them differently than tablet users. These findings show that it is necessary to take into account the contextual information to develop adaptive, situational applications that respond to the needs and likes of users.

With the continuous development of mobile technology, the role of predictive modeling in discovering the behavior of the users has taken a greater significance. Linear regression is one of the most well-known statistical tools that can be applied to modeling the usage patterns of the mobile app and allow developers to analyze the impact of contextual data on user behavior patterns. Developers and researchers, thus, are able to find out the most important contextual factors influencing the behavior of the users by applying linear regression and adjust the app experience accordingly in real-time (Saxena et al., 2017). Using linear regression, it is possible that the relationship between the dependent variables (app usage) and independent variables (location, time of day, and device type) could be determined and insights as to how contextual factors contribute to user behaviour would be a valuable asset.

The research question that will be answered in the current paper is as follows: How do the contextual factors (the location, time of the day, and the type of the used device) affect the mobile app usage? In the present paper, it was applied to linearly regress the relationships between these contextual influences and patterns of mobile app usage. The study of the interaction between these factors and their influence on the user preferences should yield operational results that can be utilized by developers and marketers to allow users to develop more personalized and contextually-aware apps. Customizing the user experience based on these variables will help developers to engage their users more and ensure their satisfaction, leading to a long-term usage.

An important realization about the factors that govern the behavior of users is essential to improve the user retention rates and prompt a long-lasting connection to the mobile apps. Context-aware apps provide personalized experience, in line with user needs according to their preferences, as well as the context of usage of the app. As illustration, the location-based services can recommend the appropriate help relative to the environment that the user is geographically in, and time-sensitive content can be used to increase engagement with the user as they move along with the content at a time relevant to them. Moreover, context-aware applications have the capacity to personalize the apps depending on devices and make the apps more effective when using a smartphone or tablet. Incorporating these contextual factors in developing the app would not only enhance user engagement, but indeed build brand loyalty as the user is likely to remain in apps that provide more personal experiences (Zhao et al., 2019; Harris et al., 2018).

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The context in which this study is relevant is that in research on the development of mobile apps, there has been a need to reconcile theory and practice which has been provided in this study as part of the literature surrounding the topic of context-aware computing. The results will also assist the developers to optimize their applications depending on real time data in a contextual way resulting in improved end user experience. Due to the growing relevance of context-aware computing to the mobile technology and artificial intelligence domains, this study contributes to the literature by introducing some insights on how contextual factors affect the usage of the app, and therefore forms the basis of the future improvements on personalized app customization (Harris et al., 2018).

Literature Review

Contextual data and its role in determining mobile app use have drawn great attention in the recent years. With the spread of smartphones and mobile applications, it is important to know investigations of factors that exert any impact on user behavior are significant amongst the developers and researchers too. It is an established fact that the earlier researches associated with mobile computing were all centered on simple usage statistics, say session duration and app interaction frequencies (Patel et al., 2019). Nonetheless, these research papers had limitations in their research capability of explaining the role of contextual factors including time of day, location, and device type in determining user engagement with mobile applications. The coming of contextual data has created new avenues of predicting and modeling on the application of user behavior in mobile applications. Contextual data is the data reflecting the context within which a user can experience an app, the location of a user, the time of the day, and what kind of device the user operates. When this information is used to create predictive models, developers will understand how users interact with apps in a variety of situations, and then they will be able to provide more user-specific and relevant experiences (Chen et al., 2022).

In the last ten years, various methods of machine learning have been popular in modelling user behaviour according to the user-available contextual data, specifically linear regression. Linear regression has also been a viable tool in the prediction of mobile app usage by the analysis of how dependent variables (like the app engagement) correlate with a set of independent contextual factors (like time, location, and device types). In the case of Kumar and Singh (2021) they employed a linear regression analysis and predicted the utilization of mobile applications through incorporating indices of context such as time of day, location, the type of device. Their results were based on the fact that all these reasons impacted significantly on user behavior and engaged them.

Besides regression models, time-series has come to be a useful tool when dealing with user behavior over time. Time-series determines the temporal progression of the use of an app, enabled the analysis of changes under the conditions of daily variations in the use of an app, weekly, seasonal ones. Zhao et al. (2019) proved the significance of time as the contextual aspect of the research, proving that the app was most frequently used in the evenings and on weekends, when users were more free. This explains why the developers should plan the delivery of the content and notifications at the best times of the day so that people use it the most.

The aspect of location as a contextual aspect has also been greatly described. An analysis by Meyer et al. (2020) revealed that urban users were more active in using mobile apps and this was because they had greater internet connectivity and access to location-based services. The user receives different types of services and recommendations based on the geographic location like the recommendation of nearby restaurants or events. To illustrate, the location-based services will enable personalized recommendations,

assuming that the user is close to a particular site and contributing to the relevance of information and the more active use of the application.

On the same note, user interaction with mobile apps identified by simply the type of device used could also have a huge influence. According to Zhao et al. (2019), smartphone users have a higher frequency of shorter interactions with apps and such users access apps in a less detailed fashion whereas, tablet users display a more prolonged use of apps with a tendency toward using them in greater detail. These differences are paramount to the consideration of the app developers and the choices they make in designing apps to accommodate various devices and optimizing the apps to suit the various devices. A good example would be that of mobile apps over smartphones potentially focusing on fast, abridged content and the different use of tablets apps with more in-depth and interactive activities.

There are few studies that have cast a light on interactions between contextual factors and their impact on use of mobile apps. Zhao et al. (2019) found patterns of app consumption to be dependent on time of day and the location, namely higher use of apps in the evening that were used more often in urban settings. The results emphasise the identifiable interdependency of various contextual conditions and acknowledge the potential of not only aggregating many different contextual variables but also establishing more contextual variables in predicting user behaviour. An example would be urban areas would have a high level of app usages during the evening hours with a high internet speed connection, rural areas would have a low usages with low internet speed connection and the lack of location-based services.

Even with numerous studies done with respect to contextual factors, a gap still exists regarding the studies taking into consideration different contextual variables in any one framework. The research on the factors of time of the day or location has been limited to one or two of these factors. However, we have not had an in-depth model that includes various contextual elements to determine the interactions of these various variables in determining user behavior. Besides, longitudinal data, essential to finding long-time patterns in the use of apps, have not been included in most studies. This could be remedied by longitudinal data that would give a more precise representation of the changes of the contextual factors over time and influenced user behavior, thus enabling developers to produce more effective, context-sensitive apps.

The paper tackles all these gaps by integrating a number of contextual variables in a single model including time, places and type of devices. Examining these materials along with the time-series will ensure that the research offers a deeper insight into how such contextual factors can impact the situation regarding mobile app usage in the long run. The fact that the study will involve the longitudinal data will also make it possible to have a more dynamic analysis to study the way of how users behave and will help to discover patterns in changes over time as well as seasonal variations in app usage.

Rationale and Statement of Problem

The mobile app technology has developed very fast, and thus, the app has become an inseparable unit of everyday life. Increased numbers of users and people have started using apps though, causing pressure on the developers to enhance user experience (UX) and user engagement. Contextual parameters that influence the user behavior include time of day, location, and type of device. This understanding is key towards the realization of this objective. Although numerous researches have investigated the effects of individual contextual factors, the evidence of the interaction of those factors, and their combined effects on app engagement is scarce.

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Existing mobile application building practices tend not to take into account non-trivial interactions among these contextual constructs thus failing to provide a more personalized, context-aware application development opportunity. This knowledge gap does give the chance to conduct future studies on how these variables affect each other and how they can be fitted into the predictive model capable of predicting user behavior. This gap should motivate developers to develop apps that cater more to user needs, create more engagement and develop a better user retention.

This study is being driven by the necessity to fill this gap and supply the developers with the integral information about the impact of the contextual factors on the app usage. The purpose of this research is to have a more refined model that takes into account several variables in context in order to enhance user satisfaction and retention, and in the final, the overall efficacy of mobile apps.

Linear regression analysis is used in the study to analyze the contextual factors affecting the use of mobile apps namely location, time of the day, and the type of device. The situation is that one envisages user engagement based on such contextual parameters. The selection of linear regression is due to the existence of the possibility of painting an estimate of a complex relationship that links a dependent value (app usage) with independent values (contextual factors). The technique will enable app developers and marketers to obtain actionable intelligence on the effects of these contextual elements on the use of their apps.

The scholars use the linear regression to estimate the effects of the contextual variables on mobile app usages. It is possible to reflect the association of a single dependent variable (the use of the apps in the given case) with multiple independent variables (the region, the time of day, and the type of equipment) by means of linear regression models (Kumar & Singh, 2021). The dependent variable is the usage of the app, which is determined by the length of the session, the amount of interaction and the frequency of that use. The contextual factors that are independent variables include location, time of the day, and device type. Linear regression is adopted because it is simple, easy to interpret and can help establish the effect of the contextual variables on app usage.

The dataset used to find the data is publicly available anonymized data on mobile app usage. It consists of half a year of time series with more than 10,000 users, and it includes data on interactions of the users with the mobile applications or factors that can impact this interaction, including location, day of the week or time of the day and the type of the device. Most important are the location of the user (GPS coordinates), day and time (session timing), device (smartphone, tablet) and app usage (session duration, interactions, frequency).

This paper employs the scikit-learn library in Python, which is used to conduct a linear regression. There are steps of data preprocessing: dealing with missing values, normalization of the numeric variables and encoding of the categorical variables. Correlation analysis and Recursive Feature Elimination (RFE) are used to find out the most influencing predictors and as such, feature selection runs. Training and testing of the model are based on different datasets to test the performance of the model and figure out the accuracy of prediction and conspicuity of the model by using Means Absolute Error (MAE), R-Squared (R 2), and Root Mean Square Error (R M S E) as the method to determine reach accuracy and fit of the model. These measures are used to give a full analysis of the predictive power of the model.

Results and Assessment

This study, using the implementation of a linear regression model, revealed a high correlation between the contextual factors a time of day, location and device type and the mobile app use. The model has scored an

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R2 of 78 percent meaning 78 percent of variance in app usage could be attributed to contextual features incorporated in the model. This is an encouraging finding and it implies that the set of contextual factors used offer strong explanatory capacity in the interpretation of user behavior on the expanses of mobile app utilization.

The Model Performance

The score of R 2 (0.78) shows that the linear regression model is able to identify underlying patterns of app usage depending on contextual data. A score of R in predictive modeling higher than 0.7 is regarded as high, and this indicates that the model is both good and has the potential to generate serious information about the effects of context on the use of apps (Kumar & Singh, 2021). But the variance that it cannot account for which is 22% may be as a result of other variables not captured in this model like the demography of the users, specific features of the apps, or the unknown contextual variables that might ignite the usage of apps. However, this limitation is in fact reflected in the high R 2 value, that shows the validity of the model in predicting behaviors of the users, according to the contextual variables chosen.

To learn more about the effectiveness of each of the contextual factors to the model, we examined the coefficients of the linear regression model that point to the strength and direction of the association of each of the predictors and the apps use. The subsequent sections give an in depth assessment of the major predictors.

The time of the day

Time of day was a most notable factor in prediction of mobile app engagement, as it had the largest value of coefficient in the model. This conclusion is consistent with the earlier discussion by Zhao et al. (2019) who found time-related dynamics of usage of mobile applications, especially increased app consumption at one particular time of the day. The coefficient linked to time of day also indicates that there is a high likelihood of using an app at a particular time of the day and it shows specific surges at specific times like in late afternoons and evenings. Such a result is not surprising in terms of the natural rhythm of use of users in the natural regime day, when mobile applications are most frequently used in their off-work time, to entertain or socialize (Meyer et al., 2020).

As an example, social media-associated apps, messaging, or entertainment apps are usually used mostly at night, as this is the time when users are not working or have any other business. Conversely, productivity-oriented applications may have the possible peak of use in mornings or early afternoons whenever users have to do with work-related activities. The predictor of the time of day is particularly useful to the developing people and marketers because it gives them clues as to the time that the user will have the chances of the highest level of interaction with his apps. Through this knowledge, it is possible to optimize the content delivery and push notifications by time and user retention and satisfaction in the mobile app development.

In addition, the time of day also assists to customize the user experience to reflect that of the user and enhance meaningful and timely interaction. Take the example of a fitness app; you may see users who come in and are prompted to record their physical activity or given workout routines as per the time of the day (Stretches in the mornings or workouts in the evenings), making the experience more personal and indulging.

Location

The model was also significantly influenced by location-based features in the usage of the app. In particular, greater frequency of app usage was observed in users who were based in the cities than in those who were

based in the countryside. The result is also congruent with the findings of Meyer et al. (2020), who compared urban and rural users and determined how the former are more prone to interacting with mobile apps because of the higher access to high-speed internet connection, the more frequent use of mobile devices, and the availability of location-based services. Location, in turn, has always been acknowledged as a significant contextual aspect of mobile computing, particularly, regarding apps that employ location-based services, including navigation, local recommendations, or social networking services (Zhao et al., 2019).

Local services through apps are seen by the urban users more likely to be used (delivery, transportation, event notifications, etc.). In addition, the concentration of mobile networks and internet connection in cities also contribute to even better and more frequent application usage and therefore, more engagement. The rural in contrast may not have full network coverage thus their interaction with the mobile apps may be inhibited. These results outline the necessity to take geographical aspects into account to design and optimize mobile apps as the apps focused on urban setting might have to include more resilient network-related elements, whereas the experience of those using mobile apps in the rural areas will have to take connectivity issues into account to foster successful interaction.

The position is also very important when it comes to the success of location-based ad and recommendation. As an example, the applications which provide custom recommendations about the location of the user, e.g., restaurant recommendation or city-related events, may experience greater engagement in urban locales. This indicates that app developers could use their features to suit the local contexts to make the most engagement.

Device Type

Although the type of device proved to be a poorer predictor of the app usage than time of day and location did, it also helped to gain valuable insight in user behavior. Specifically, it turned out that users of a tablet stayed longer with the app in contrast to users with a smartphone. That finding is consistent with the prior research stating that tablet users show a higher propensity to have protracted, immersive interactions, whereas smartphone users report non-protracted, more regular sessions because of its small size and ability to emphasize short activities (Zhao et al., 2019). Apps that need extended usage, like gaming, streaming or consumption of content are more well-suited by the bigger screens of the tablets and more ergonomic design which could be the reason behind longer session time with tablets.

Alternatively, smartphone users can increase the mobile application use frequency but at the shorter sessions due to the ease and accessibility of smartphones in small interactions. Such usage differences between the tablet and the smartphone are a crucial fact that app developers need to take into account because this shows that mobile applications running on a smartphone should strive to be fast, easily accessible, and highly functional, whereas mobile applications on a tablet can afford to be more detail-oriented, immersive.

Even though it is a less powerful predictor, the influence of the device type on the behavior of users demonstrates the significance of developing apps which are adapted to various forms of devices. Responsive apps will also display superior engagement regarding the type of device since both smartphones and tablets contain apps that vary according to the specific size of the screen and user interaction style.

Model Performance Evaluation

Key metrics to measure the performance of the model were determined such as R 2, Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). The large value of R 2 (0.78) shows that the model could be

used to explain much of variance in app usage and contextual variables explained 78 percent of the observed behavior. Also, the magnitude of prediction errors was measured using MAE and RMSE. The two metrics showed that the model was fairly precise and the erroneousness was also very minimal to the extent that the model could be confidently relied upon to predict the utilization of the apps depending on the contextual characteristics.

Discussion

The study findings are consistent with other studies on the significance of contextual issues influencing the mobile app usage patterns. Our results are consistent with the study by Zhao et al. (2019) proving the importance of time of day as a factor that determines the level of app engagement. Also, the analysis supports the research results attained by Meyer et al. (2020), as they showed that urban users use applications much more often than rural users. This study can advance knowledge on contextual variables and app engagement by reaffirming these earlier findings, hence, establishing their interaction to influence the app engagement. In addition, it further builds on the previous literature by giving a more in-depth discussion on the collective nature of these factors which gives valuable information to developers and marketers who want to improve user engagement and satisfaction.

A Time of Day as an Important Predictor

Among the most interesting results of this study there is such an indicant that time of day has a great influence on using mobile applications. Among the contextual variables, the coefficient of time of day was the highest and it is an indication that the time during which users use apps is important in identifying the pattern of apps use. The observation hardly contradicts the findings of Zhao et al. (2019) that certain apps are utilized more frequently at specific hours of the day, i.e., evenings and weekends. It seems that such time-oriented trend can be explained by the everyday schedule of the users as they are most likely to spend non-working hours on non-work-related activities, be it dedicating their time to perusing social media or spending time on entertainment or gaming.

The real-life implication of this finding is immense. This behavior can be exploited by app developers who must make sure to enhance their app engagement techniques based on this time-sensitive behavior. An example is to ensure that output is delivered, notification or promotion at specific hours of the day, then developers can take advantage of the popping behavior of users with their app interaction, and thus have higher chances of engagement. As an example, a fitness application may provide an alert to perform exercise regimes in the morning or at the end of the day, whereas a shopping app may send notifications of sales during the evening hours or on weekends when the customer is likely to have some time to shop and conduct some purchases. Because of this mnemonic matching of the app interactions with the app user behavioral pattern, developers will be able to design more personal and realistic user experiences that are consistent with their daily time schedules and, as a consequence, will increase user interaction and satisfaction.

Limitations and Future Research

Although the research has created great knowledge on how contextual issues affect the app engagement, it is notable that it has a number of limitations. To begin with, the proposed research is based on linear regression model wherein there is an assumption that the correlations between the predictors and the outcome variable are linear. Although linear regression is very useful, it does not have the potential to represent fully non-linear relationships or intricate interactions between the contextual factors. As an example, the impact of location on an app could differ in case of various urban, or rural settings, as well as the effect of time of day could show difference when using different kinds of app (e.g. social media or

productivity). Further studies can consider using more sophisticated formulas of machine learning, e.g., decision trees, support vector machine, or neural network that have the advantage of fitting non-linear relationships and the incorporation of non-linear interactions among predictors (Kumar & Singh, 2021).

Also, the dataset that was used in this research contains a generalized picture of app usage habits; however, the scope of the dataset and contextual detailing within the dataset are its limitations. It would be interesting to extend the research with some additional contextual variables, i.e., the demographics of the users (e.g., age, gender) or psychological factors (e.g., motivation, mood) so that a more articulated model of app engagement could be built. Moreover, longitudinal data might give an idea of how the factors that are contextual might affect the usage of the app in the long run, which would enable seeing a deeper picture of the patterns of engagement.

Conclusion

This paper explores how contextual features that include time of day, location, and type of device influence the mobile app usage and the researcher examines the problem through linear regression analysis. The outcomes reveal that the predictor of app engagement related to time of day and location, with time being the most powerful one. People use apps more on non-working days and weekends, more so on such apps that entertain, socialize and inform. This observation corresponds to the ones that are obtained in the past studies (Zhao et al., 2019). This knowledge can help app developers and marketers make their users interested and engage with the app or promotion at the right time by delivering the content and offering based on time and location-based targeting.

Place is also a very important aspect in the use of the apps as the urban inhabitants use it more than the rural because they have better internet connections as well as location services. This implies that mobile applications must be designed to cater to different geographical locations, having location-specific features to urban users and taking into consideration bandwidth constraints when in the rural settings.

Although the Type of a device was less predictive, the users of tablets also had more time spent on phone devices than the users of smartphones, which signals that the optimization of the apps should be done differently by type of the device. Apps to be developed in a smart phone must support quick, everyday interactions and tablet apps must be able to support the more in-depth, immersive content.

The results are pertinent to the app developers, and marketers, as this provides possible insights to developers into the time and location to offer anyone the content, notifications, owing to different individual patterns. Nevertheless, the linear regression model used in the study has some limitations especially in its assumptions which include a linear relationship. Subsequent study work may investigate sophisticated machine-learning algorithms to recognize non-linear relations and take into consideration other factors of context, including, multiculturalism and psychological characteristics, potentially raising the precision of the forecast and optimizing long-term engagement.

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