

Application of the Stochastic Approach to Estimation of the Number of Rainy Days for Highway Construction in the State of Georgia

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Adverse weather can play a significant role in highway construction. Not only does it cause delays in scheduling but it can also have a significant effect on the cost, quality and duration of the project. Precipitation in the form of rain, sleet, snow or hail can completely halt highway construction, disrupting the construction process and causing major damages. Accurate scheduling is essential for the success of any construction process but uncertainties will always exist in even the most well prepared schedules. This paper presents an application of stochastic approach with the Gamma density function to estimate the number of rainy days in three major cities (Atlanta, Macon, and Savannah) in the state of Georgia. The past 20-year historical weather data of the cities was collected from National Oceanic and Atmospheric Administration and was utilized to obtain relevant statistical information for further analysis. The cumulative Gamma distribution curves provide a foundation to predict the potential number of rainy days in Georgia, month by month, with various degrees of reliability. Both owner and contractor could take advantage of the stochastic results in establishing clearer contract terms in consideration of the potential rainy days to build more reliable schedules.

Key Words : Stochastic Estimation, Highway Construction, Construction Delay, Construction Scheduling, Construction Contract Conflict

Introduction

Adverse weather can play a significant role in highway construction because of its potential damaging effects of cost, quality and duration of a project. Precipitation in the form of rain, sleet, snow or hail can completely halt highway construction, disrupting the construction process and causing major delays. Construction delays have unfavorable effects on any construction process, and they are usually caused by unforeseen conditions that can result in the loss of millions of dollars annually. Highway construction is especially vulnerable to construction delays because of its exposure to surrounding conditions. This exposure, and the inability to predict future conditions, makes it increasingly hard to develop dependable schedules and unambiguous contracts that allocate risk confidently. Generally, the Department of Transportation of each state allocates this risk by providing contractual provisions for weather delays but there is not often a concrete approach used to determine what constitutes a weather delay. The Georgia Department of Transportation (GDOT) is a prime example as it does not have a clear methodology when determining what qualifies as a weather delay (McClinton et al., 2001). In most cases it is left up to a competent person or manager to determine if construction should be halted or not. This method could inevitably lead to litigation and delay claims because of ambiguity. When the construction phase begins, the owner and contractor may not agree on what constitutes grounds for a delay but if those grounds are stated clearly in the contract, much friction may be avoided.

Objective and Scope of the Study

The objective of this research is to apply the weather-related delay estimation system that Apipattanavis et al. (2010) proposed, to three major cities in the state of Georgia. This study is to see the applicability of the estimation system with realistic weather data. A probability density function using Gamma was used to estimate the number of precipitation days on a monthly basis, with various reliability levels. Amongst various adverse weather factors, such as wind, low temperature, frozen ground, and precipitation, precipitation was chosen to be focused upon in this research as the other weather factors have a relatively low impact on construction in Georgia. Also, it should be noticed that the two terms, rain and precipitation, were interchangeably used in this paper based on the assumption that the other types of precipitation (e.g., snow, hail, sleet) are rarely observed in Georgia and, even if there is, the impact may be relatively insignificant as compared to precipitation.

Since the amount of rainfall is another variable to be considered in terms of estimating the number of rainy days, due to the fact that the determination of whether a certain field work activity can be executable or not is dependent upon the nature of the work item, this study employed three threshold levels with respect to the amount of rain on a day as follows:

DP01: Number of days in month with greater than or equal to 0.1 inch of precipitation
DP05: Number of days in month with greater than or equal to 0.5 inch of precipitation
DP10: Number of days in month with greater than or equal to 1.0 inch of precipitation

Reviews of the Previous Studies

For years, researchers have studied the effect of adverse weather on construction inspired by the fact that adverse weather produces unfavorable conditions in any type of construction process, delays the pre-determined construction schedules, and could trigger conflicts between the owner and contractor. These inspirations lead (Moselhi et al. 1997) to develop a system that estimates the productivity loss and work stoppage due to adverse weather. Several weather data inputs were included in the system such as humidity, wind speed, snow, temperature, and rain to calculate work duration with and without weather impact. Other studies have been published that illustrate how weather significantly affects different types of construction, especially in the form of precipitation. One study, of how rainfall impacts highway construction, conducted interviews with experts to develop a knowledge base for a weather support system where the experts indicated that one of the main factors that contribute to productivity loss due to rainfall depends on the intensity of the rainfall (El-Rayes and Moselhi, 2001). The study also shows that individual construction activities may be affected differently by the same amount of rainfall. This shows that there is a need to provide weather thresholds within contracts because what may cause a weather delay for one construction process may not cause a delay in another. Contractors and owners will be able to take advantage of this by clearly defining within the contract what the grounds to be considered a weather delay are.

Weather related delays are inevitable when it comes to construction projects and they are usually incorporated in the project schedule with a "dummy" activity. Even though owners and contractors protect themselves by adding clauses within their contracts regarding weather delays, they are often ineffective in reducing delay claims. This is because there is not a strong foundation on which to base what qualifies as a weather delay. In one study the conclusion stated that "much of litigation resulting from weather delay disputes is based on the lack of adequate definition of terms in contracts" (Apipattanavis et al. 2010). There have also been several studies conducted that show how important it is to have a clear methodology when determining what qualifies as a weather delay or not. One such study stated that "a contract should define anticipated weather delay days…and provide threshold values for weather parameters…" (Nguyen et al. 2010). The study also states that threshold values should be included in the contract because they "play a critical role when differentiating unusually severe weather from usual severe weather". This will make contracts clearer thus reducing delay claims. Another study, after observing the inconsistencies between the practices of different DOTs, also concluded that "normal anticipated weather" should be clearly defined (Hinze and Couey, 1989).

In an effort to better understanding the possible construction delays due to adverse weather, Apipattanavis et al. (2010) developed an integrated framework for estimating construction delays due to adverse weather. The study conducted a comprehensive research on how adverse weather affects specific work activities (e.g., excavation, embankment, paving, etc) using a stochastic model. In his study, an analysis was completed of the effects of various types of weather (e.g., wind, temperature, rain, etc) on types of highway construction processes. Using this information combined with a threshold matrix, they were able to determine how much a particular weather event may occur, during a construction activity or prior to, before disrupting the construction processes. The weather model consists of weather data from the National Climatic Data Center. A prediction of the number of days that would cause the weather-related delay in construction could be used to aid in building better contracts and schedules.

Data Preparation

The most comprehensive weather database existing today can be found in the National Oceanic and Atmospheric Administration (NOAA). As part of its services to the public, this federal agency issues annual climatological summary that provides historical weather data that has been collated from numerous weather stations currently operated around the country (NCDC website, 2013). The data contains a number of meteorological elements such as temperature, precipitation, snow fall, degree days, wind speed, etc. The raw data used in this study was downloaded from the NOAA website. The weather data used in this study was limited to the data available for the state of Georgia. Three major cities in the State (Atlanta, Macon, and Savannah) were considered for data collection and analysis. Although there are several adverse weather elements that cause construction delay; this study considered precipitation as the only adverse weather contributor. It is due to the fact that the occurrence of the other elements (temperature, wind, and snow) is relatively rarely observed, as compared with precipitation within the state of Georgia.

The number of rainy days in each month was collected for the past 20 years (from January 1992 to December 2011) for the three selected cities. Some work activities in highway construction are greatly affected by the level of rain amount and whether those activities are to be executed or not on a rainy day is typically determined based on the nature of the work item. For example, applying bituminous prime on a base layer is strictly prohibited when rain is imminent (i.e., this particular activity can't be performed on a day with even very small amount of rain in accordance with general standard construction specifications in Georgia), while setting forms for concrete structures may be allowed as long as rain does not threaten the activity. Therefore, it is useful to consider the monthly rainy days depending on the amount of precipitation. As stated earlier, three threshold levels were selected to differentiate the amount of rain in a given month: DP01, DP05, and DP10.

Figure 1 shows a sample spreadsheet that contains the number of days in month with greater than or equal to 0.1 inch of precipitation (DP01) for 20 years for Savannah, GA. In the spreadsheet, the rainy days are presented for every month from January to December for each year from 1992 to 2011 and the average and standard deviation values of the rainy day for each month were calculated at the right side of the table. These basic statistics were used in estimating the probability of the rainy days in a particular month on a particular location which will be presented in the next section. It should be noted that similar spreadsheets were developed for DP05 and DP10 for all three cities.

DP01

Months	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average	Stdev
1	8	10	8	5	7	8	7	3	2	3	4	10	6	5	5	5	7	2	4	6	5.8	2.47
2	3	6	4	7	3	5	5	4	6	12	6	9	0	7	2	3	4	4	4	5	5.0	2.60
3	5	8	6	3	7	4	8	5	5	1	1	6	6	5	4	1	6	5	1	4	4.6	2.06
4	5	2	1	2	4	4	5	4	2	2	2	9	3	6	3	4	3	13	7	2	4.2	2.87
5	6	3	4	5	2	5	5	11	9	14	9	10	10	11	5	11	6	8	9	5	7.4	3.20
6	11	4	16	11	5	11	11	9	8	10	6	9	9	8	4	7	10	10	7	6	8.6	3.11
7	4	6	12	11	8	11	8	7	7	5	9	4	7	8	12	7	9	14	5	8	8.1	3.20
8	12	7	5	13	11	4	5	8	11	8	11	5	8	2	7	7	3	3	6	6	7.1	3.09
9	10	9	7	9	7	7	2	5	0	1	7	4	4	6	3	7	7	5	1	5	5.3	2.82
10	2	4	9	5	2	7	0	1	4	1	8	6	3	2	5	0	6	3	1	3	3.6	2.49
11	7	5	6	5	2	10	4	5	4	3	7	3	3	7	4	6	1	13	5	3	5.2	2.76
12	3	5	7	3	5	8	10	6	6	5	1	4	3	5	7	5	4	5	6	7	5.3	2.03
Sum	76	69	85	79	63	84	70	68	64	65	71	79	62	72	61	63	66	85	56	60	69.9	9.13

Figure 1: Number of Days in Month with Greater than or Equal to 0.1 inch of Precipitation for Savannah, GA

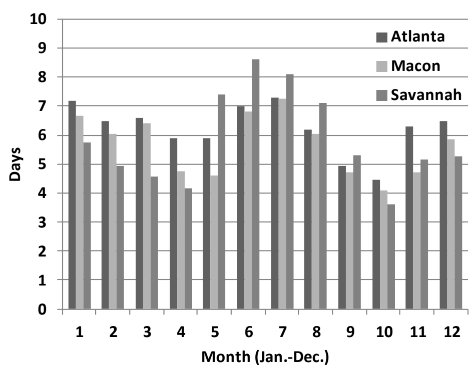
Presentation and Analysis of Precipitation Data

With the rainy day data on the three major cities in GA, it was attempted to visualize the trend and characteristic in various ways. Table 1 shows the average rainy days for the past 20 years throughout the year by month for the cities. Three levels of rain amount (DP01, DP05, and DP10) were considered for this data analysis. From the table, it was found that the total number of rainy days throughout the year with DP01, DP05, and DP10 in any of the three cities is overall approximately 70, 30, and 14, respectively. The change of the number of rainy days month by month becomes clearer when the data is placed in a bar chart. In Figure 2, the data is graphically illustrated in a bar chart, to show the fluctuation of the number of rainy day with DP01 to DP10 in month by the cities. In this figure, it is interesting to observe that the number of rainy days with DP01 is higher in the Savannah area during the summer time, while the number decreases during the winter time and until April. A similar pattern is seen with DP05 and DP10 as well. It seems that the rainy season begins in May in GA and especially construction in the Savannah area may be heavily affected by the rainy season as opposed to construction in the Atlanta and Macon areas.

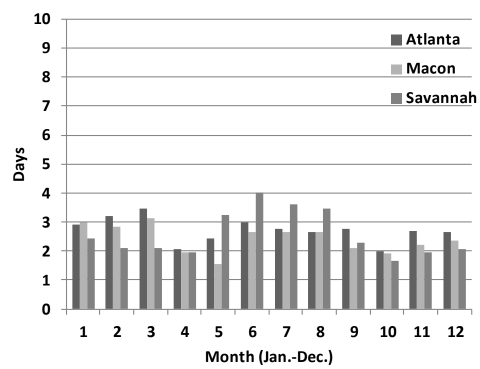
Table 1

Number of days with rain greater than or equal to 0.1 in., 0.5 in., and 1.0 in. for three major cities in Georgia

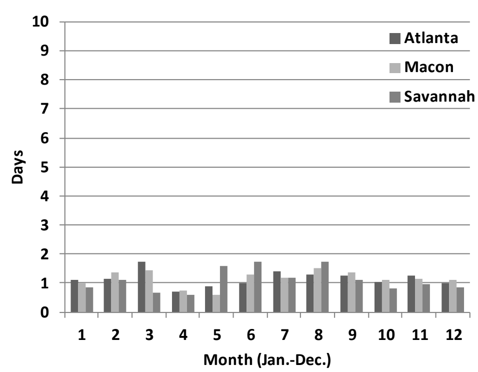
Month	DP01			DP05			DP10		
	ATL	MAC	SAV	ATL	MAC	SAV	ATL	MAC	SAV
1	7.2	6.7	5.8	2.9	3.0	2.5	1.1	1.0	0.9
2	6.5	6.1	5.0	3.2	2.9	2.1	1.2	1.4	1.1
3	6.6	6.4	4.6	3.5	3.2	2.1	1.8	1.5	0.7
4	5.9	4.8	4.2	2.1	2.0	2.0	0.7	0.8	0.6
5	5.9	4.6	7.4	2.5	1.6	3.3	0.9	0.6	1.6
6	7.0	6.8	8.6	3.0	2.7	4.0	1.0	1.3	1.8
7	7.3	7.3	8.1	2.8	2.7	3.6	1.4	1.2	1.2
8	6.2	6.1	7.1	2.7	2.7	3.5	1.3	1.5	1.8
9	5.0	4.7	5.3	2.8	2.1	2.3	1.3	1.4	1.1
10	4.5	4.1	3.6	2.0	1.9	1.7	1.1	1.1	0.8
11	6.3	4.7	5.2	2.7	2.2	2.0	1.3	1.2	1.0
12	6.5	5.9	5.3	2.7	2.4	2.1	1.0	1.1	0.9
SUM	74.8	67.9	69.9	32.6	29.0	30.9	13.9	13.9	13.2



(a) DP01



(b) DP05

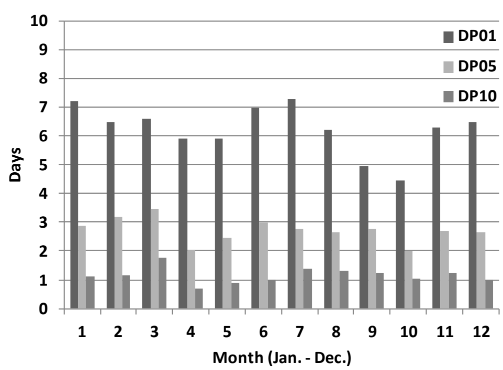


(c) DP10

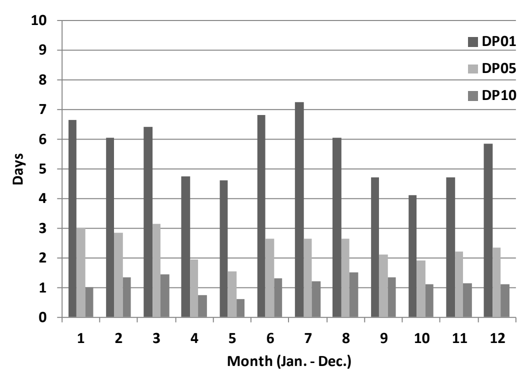
Figure 2: Average Number of Rainy Days in Month with (a) DP01 (Greater Than or Equal to 0.1 in.), (b) DP05 (Greater Than or Equal to 0.5 in.), and (c) DP10 (Greater Than or Equal to 1.0 in. for Three Major Cities in Georgia

Another type of data presentation was also attempted to depict the difference between the amounts of rain in each city. Figure 3 is used to clearly show the difference of the number of rainy days between the levels of precipitation. The figure presents the average number of rainy days in each area, with the three different precipitation levels in Savannah, GA. In this figure, the difference in the number of rainy days at the different levels can be directly compared by each month. It was observed that the difference in the number of rainy days between DP01 and DP05 is about 3 to 4 quite constantly for all cities and the difference between DP05 and DP10 is 1 or 2 days throughout the year for all cities.

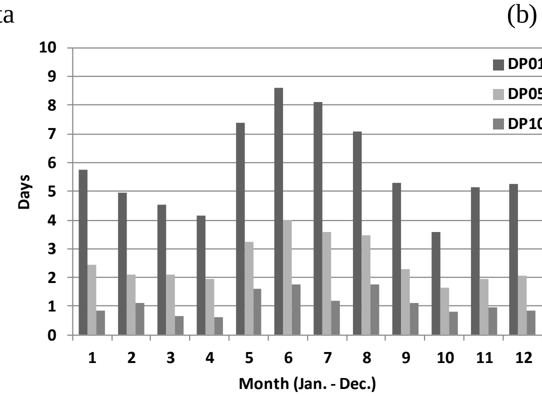
Since the rainy day data was collected for 20 years, it was feasible to calculate the standard deviation value for each month. The combination of average and standard deviation leads to a useful solution in calculating the probability along with a frequency distribution function. In this research, the Gamma density function was employed to present the data in terms of a cumulative frequency distribution. The biggest benefit of using the Gamma function as opposed to the Normal function is that the starting point of the Gamma function is zero and thus the function does not include the negative region. The negative region is commonly included when the Normal function is used, which frequently results in an unrealistic frequency distribution. For example, the number of rainy days can't be a negative number, but with the Normal function, it would be the case for the distribution to cover the negative region, especially with a large standard deviation data. In Figure 4, as an example, three frequency distribution curves with DP01, DP05, and DP10 in June and October in the Savannah area are presented using the cumulative Gamma density function. Similar graphs were developed for all 12 months and for the three cities. The interpretations and discussions for these graphs are presented in the following section.



(a) Atlanta

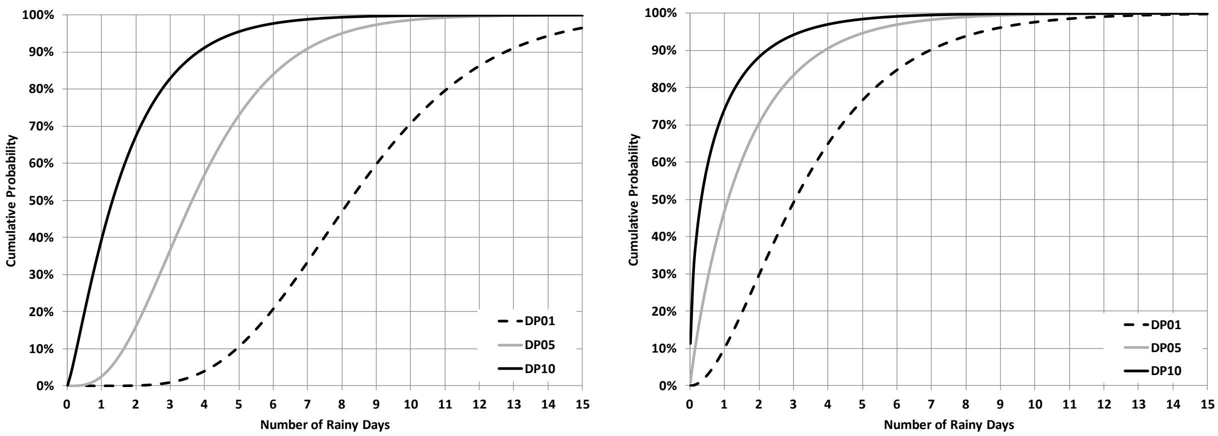


(b) Macon



(c) Savannah

Figure 3: Average Number of Rainy Days in Month with DP01, DP05, DP10 in (a) Atlanta, (b) Macon, and (c) Savannah, GA



(a) June (b) October

Figure 4: Cumulative Gamma Distribution for Number of Rainy Days in (a) June and (b) October for Savannah, GA

Data Interpretation and Discussion

Table 1 and Figures 1 to 3 presents the average numbers of rainy days based on the past 20 years and the numbers are straight forward, thus can be readily considered by the owner and contractors, and accordingly can be applied for scheduling or planning in their potential highway construction projects. By applying the numbers of the table and figures to a project schedule, the planners could establish a more realistic scheduling system for a given project. Not only does the estimation of the rainy days by month help the pre-construction project scheduling and alleviate the potential contract conflict between the parties, it is also beneficial for a project manager to effectively manage the construction progress during construction with respect to handling resources such as labor, equipment, and materials on a monthly and yearly basis. Therefore, more effective and efficient construction management could be amenable with the data presented. Another advantage of using the predicted number of rainy days is that it is helpful to create a more accurate bidding document by taking the prediction into consideration.

However, it is of particular importance to remind that, in statistics, the average value of a sample group simply implies that chances of having the actual occurrence less than the average are approximately 50% and chances greater than the average is also approximately 50%. As Figure 4(a) indicates, for example, the cumulative Gamma distribution in Savannah, GA shows that DP01 in June at the 50% level of probability is approximately 8 days. The implication is that there are 50% chances that it could rain less than 8 days in the month of June in the next year and the same chances that it could rain more than 8 days in the month in the Savannah area. This inference may be deemed to be very critical to some construction managers or owners if they plan to execute a vital construction project in terms of construction duration. In the case of dealing with a high-important, schedule-sensitive project, the owner may want to assure that the construction be finished with an initially set-up time. By having the contract document to exclusively include the construction duration and relevant penalty or disincentive terms due to possible delay of the project, the owner may be eager to use a high reliability level such as 90%, i.e., in the same example as above, there are only 10% chances that the rainy days with DP01 could be greater than 13 in June in Savannah, according to the cumulative Gamma distribution shown in Figure 4(a). Therefore, setting up a different reliability level depending upon the level of importance of a given project provides a great flexibility for the owner as well as the contractors.

To test the effectiveness and accuracy of the proposed method, a simple case comparison was conducted between projected numbers of rainy days based on the 20 years (1992 – 2011) and the actual rainy days observed in the Savannah area in 2012 at two difference reliability levels: 50% and 90%. Table 2 shows the case comparison in Savannah. In the table, it is found that the projected rainy days at 50% levels for each of the three rain amounts

(DP01, DP05, and DP10) are very close to the actual rainy days. The difference between projected and actual rainy days ranges from approximately 5% to 17%. The difference could be reduced by differently setting the reliability level. In this simple example, however, it should be noted that the numbers of rainy days doesn't specifically consider the real world construction scheduling where there are many variables that need to be incorporated. Some drawbacks and challenges that need to be considered in regard to use of the proposed approach are described in the following part of this section.

Table 2

Comparison of projected and actual number of days with rain greater than or equal to 0.1 in., 0.5 in., and 1.0 in. for Savannah

Month	DP01			DP05			DP10		
	Projected Rainy Days at		Actual Rainy Days in 2012	Projected Rainy Days at		Actual Rainy Days in 2012	Projected Rainy Days at		Actual Rainy Days in 2012
	50%	90%		50%	90%		50%	90%	
1	6	10	6	3	5	3	1	3	1
2	5	9	5	2	5	2	1	3	1
3	5	8	6	2	5	3	1	2	2
4	4	8	4	2	5	2	1	2	1
5	7	12	5	3	6	3	2	4	1
6	9	13	9	4	7	4	2	4	2
7	8	13	9	4	7	5	1	4	2
8	7	12	9	3	7	4	2	4	2
9	5	10	7	2	6	3	1	3	2
10	4	7	5	2	4	3	1	3	2
11	5	9	4	2	4	2	1	3	1
12	5	8	5	2	4	2	1	3	1
SUM	70	119	74	31	65	36	15	38	18

Note. The rainy days are rounded up from the original number.

Despite of the fact that the estimation of the rainy days with various reliability levels could help the construction managers realistically plan and schedule their project, there are still several challenges to be addressed as follows:

Construction delay may be shorter than the estimated number of rainy days. In other words, even if there are some predicted rainy days in the next month, the actual construction schedule may not be affected by the rainy days in case of following instances:

It only rains on non-working days such as weekends or holidays within a month.
It only rains when the scheduled work activities that are not affected by weather are executed.
It only rains during the night time when no work activities are executed.

Construction delay may be longer than the estimated number of rainy days. In fact, it commonly happens in the field. For example, if it heavily rains today, some field work activities such as subgrade soil compaction won't be able to be executed next day due to a wet condition in the field. Waiting time until having a dry condition may last several days.
The impact level by the precipitation among construction processes varies and may have different influence to forthcoming processes indirectly and directly.

These challenges should be addressed in detail in the future research with several case studies. The discussion with regard to the future research is presented in the following section.

Concluding Remarks and Future Research

This study explores the potential rain effect on highway construction at different reliability levels to recognize possible construction delay in conjunction with construction planning, scheduling, and estimating; and statistically describes an approach toward successful database development that can achieve a high level of rainy day prediction. The study presented in this paper attempted to utilize a similar weather model that was developed in one of the previous weather-construction interaction studies, and apply it to the three major cities of Georgia. The three regions are geographically representing the state of Georgia in order to recognize adverse weather condition that directly affects the delay of construction processes. The database collected for this study could be easily utilized by the parties who are engaged in developing a construction contract. The probability distribution curves using the Gamma frequency density function could provide valuable information associated with reliability for the owner and the contractors, especially for scheduling and bidding. Three different threshold values in terms of the amount of rainfall enable the owner and contractors to consider how individual work activities can interact with the rain quantity and to define what activity can be affected by adverse weather. As a consequence, construction planners may be able to establish a relatively more realistic schedule for a construction project.

Although this study is limited to a precipitation analysis only, the study does promise that future studies with additional weather-related factors (e.g., wind, temperature, intervals between rainy days, etc) could provide more sophisticated analysis on project management for construction industry. Additionally, inclusion of more locations within the state of Georgia will have a significant impact in further understanding of construction process in terms of construction scheduling. Additionally, for validation of the presented study, it is required to investigate the actual and realistic impact of weather factors on the construction scheduling by conducting case studies. Observation and analysis of actual construction delay associated with adverse weather and receiving comments from the owners and contractors will be critical for further validation of this research as a part of the future study.

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