# Force Majeure Weather Modeling

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## Abstract

Although adverse weather has impacted construction since before the pyramids, and when unusually severe is typically only deserving of a time extension without compensation, weather issues continue to generate their fair share of disputes. Even if not disputed, all significant grass root construction projects face weather impact issues that the parties may wish to recognize on an ongoing basis. Existing weather modeling methods can be cumbersome, overly technical and resource intense. In searching for practical approaches, the authors have developed new methodologies for modeling force majeure weather that provide objective evaluation of adverse weather impacts, for forensic as well as contemporaneous applications. Guidance for calculating normal adverse weather and force majeure weather day losses is provided, with examples to illustrate the new concepts. The focus of this paper is on the technical aspects of normal adverse weather and force majeure weather as opposed to the legal aspects.

## I. Adverse Weather

Construction is impacted by adverse weather, with the actual impact varying from project to project, the site location and the region. The greatest impacts of adverse weather are upon construction exposed to the elements, whether directly as in the case of earthwork, concrete, etc., or when working inside interior, non-conditioned spaces. Precipitation, high winds, cold and hot temperatures, high rates of snowfall, not to mention exceptional weather events (acts of God), can all adversely affect progress, the production rate of the workforce and worker productivity.

Weather issues generate their fair share of controversy between parties to construction contracts, as evidenced by litigation reported over the past ten years.[1] Not surprisingly, planning for normal adverse weather is receiving increased attention by planning and scheduling professionals. The "Weather Contingency" discussion that took place in late 2009 on the AACEI webpage–"Resources, Discussion Forums,"[2] which led to a webinar on planning for adverse weather in December 2009, illustrates how weather is taking center stage in planning and scheduling practice.[3]

In US contracts, it is common for contractors to assume the risk of normal adverse weather. Pursuant to the ConsensusDOC 500 Owner/Contractor Agreement,[4] normal adverse weather equates to reasonably anticipated adverse weather; no *reasonably anticipated* legal standard is provided, but, the average adverse weather during a ten year pre-contract time horizon is generally accepted.[5] In the FORMSPEC® model contract documents, the contractor does not bear the risk of failing to meet schedule due to "abnormal weather vs. the prior 5-year average."[6] Other specifications instead of abnormal adverse weather use "unusually severe weather" or "adverse weather that is unforeseeable." Unusually severe or unforeseeable weather are the opposite of normal adverse weather.

Often, civil works and highway specifications set forth the anticipated number of adverse weather days for each month.[7] The Corps of Engineers has issued a bulletin applicable to adverse weather policy for construction contracts. The bulletin describes the methodology to calculate monthly anticipated adverse weather delay workdays for a five-day work week based on National Oceanic and Atmospheric Administration (NOAA) data for the project location.[8]

Abnormal adverse weather is also commonly referred to in the US as force majeure weather (FM weather), with force majeure considered an event not caused by, and beyond the reasonable control of, the owner or contractor. The standard application of FM weather provisions is to grant the contractor a weather-related time extension when FM weather occurs, i.e., monthly actual weather-related day losses exceed those resulting from normal adverse weather; but not to make a deduction when, for a given month, actual weather was less severe than normal adverse weather.

Because adverse weather impacts occur intermittently, slowing the rate of progress without halting progress altogether, it is considered to cause embedded delay as opposed to discrete delay. Embedded delays are commonly subsumed within activity durations and are commonly modeled in the retrospective portion of a schedule.



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## II. Weather Conditions Criteria

Meteorological conditions that slow the rate of construction progress, i.e., cause *embedded* delay, are well documented in the literature and include:

- Precipitation (rainfall, snowfall, hail or ice) – There is general agreement amongst practitioners that 0.1 inch (2.5 mm) or more of precipitation (liquid equivalent) during a workday (or half a workday) will interrupt outdoor work[9] (in one specific file evaluated by the authors, a calculation using contemporaneous job records showed a high probability, i.e., ~70%, that outdoor work was suspended).
- Heavy Precipitation – Precipitation of 1 inch (25 mm) or more (liquid equivalent) is likely to impact work on the following workday, variously requiring *drying-out* time, snow removal, dewatering, wash-outs repair, etc.[10]
- Snowfall – Snowfall rates above 0.4 inches per hour of snowfall accumulation can reduce production, as demonstrated by data produced by the US Army Cold Regions Research and Engineering Laboratory.[11]
- Wind – High winds can adversely affect operations with tall cranes, lifts of large objects and/or other activities susceptible to blowing about or wind damage. Criteria for evaluating impact of high winds should be selected based on the activities planned for the project being evaluated and the intended means and methods. For example, lifting charts for a typical 200-ton crane equipped with 130 feet (40m) or more of boom and 120 feet (37m) or more of luffing jib length prohibit operation in a wind exceeding 30 mph (13 m/s).
- Cold Temperatures – Cold temperatures with wind chill have been shown by a wide variety of industry studies to adversely affect production. Cold weather affects workers psychologically and physiologically. Workers dislike working under adverse weather conditions. To protect from prolonged exposure causing tissue and non-tissue damage, workers wear adequate clothing, which slows the worker down. The National Electric Contractors Association (NECA) "The Effect of Temperature on Productivity"[12] and Koehn's paper "Climatic Effects on Construction" provide cold temperature weather factors.[13] NECA concludes that humidity above 70-80% significantly impacts productivity at temperatures below 10°F and above 80°F. Professor Koehn shows that below 35% relative humidity, productivity is basically not affected by changes in humidity; at high relative humidities, productivity decreases as the humidity increases.
- Hot Temperatures – Hot temperatures with high humidity have been shown by a variety of studies to adversely affect production. Like cold weather, hot weather affects workers psychologically and physiologically. Both the NECA and Koehn references provide hot temperature and humidity weather factors.[14]

In addition to conditions causing embedded delay, exceptionally severe weather events may cause identifiable and unanticipated *discrete* delay from job shutdowns due to blizzard conditions, hurricanes, tornados, storm damage or flooding. Unanticipated discrete delay in shipping of materials or equipment from overseas manufacturing facilities may also be caused by exceptionally severe weather events, such as typhoons.

## III. Frequency of Weather Conditions Criteria

Meteorological records, available from the National Climatic Data Center, provide a basis to evaluate the frequency of various adverse weather conditions a contractor could reasonably anticipate to encounter based on pre-contract conditions. Selection of a 10-year pre-contract time horizon to calculate mean frequencies (averages) allows a sufficient period to minimize skewing of the data from unusual conditions that may occasionally occur, while excluding older data that might obscure more recent climate shifts. Statistics should be obtained for a weather station that maintains the required data and is representative of weather conditions at the site. Data required consists of at least hourly readings of precipitation (liquid equivalent), temperature, relative humidity, wind speed and peak wind gust, and 6-hour snowfall amounts, for each calendar day, regardless of the weekly working schedule used at the site. Weekly or monthly conversion factors are used to convert calendar day weather data to working schedules. For instance, for a 5-day working schedule, the conversion factors are 5/7 (weekly) and 20/31 (monthly, May 2010).

To provide a reasonable evaluation of the extent to which the impact of actual weather conditions exceeds that which could have been reasonably anticipated, historical weather must be evaluated over periods comparable to the actual working schedule. Both the shift hours to be worked and the number of working days per week must be considered. A project working two ten-hour shifts, six days per week should reasonably be expected to encounter more adverse weather events in a calendar month than a project working five eight-hour days per week.



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Thus, for a project with a 7 a.m. to 3:30 p.m. shift, the average frequency of pre- contract weather events would only be considered for the period from 7 a.m. to 3:30 p.m. each day. In addition, if a five-day normal working schedule was to be used for the project, the pre-contract weather event frequency during each calendar month would be multiplied by 5/7 to convert from calendar to working days (if a weekly conversion factor is used).

In making calculations on NOAA data, the analyst must be cognizant that NOAA reports observations using Universal Coordinated Time; they must be correlated with the jobsite's local time zone, including any Daylight Saving Time adjustments. Also because many data elements are reported in metric units, a review of NOAA data definitions for each dataset is necessary to confirm where conversion is appropriate.

Because weather is seasonal, it would not be reasonable to assume that annual averages would prevail throughout the year or any combination of months. In northern climates the adverse winter weather will result in fewer available working days in January than in July. The accepted rule is to calculate the reasonably anticipated mean frequency of each type of weather condition for each calendar month.

The effect on construction of a weather event will depend not only on the activities in progress, but also the arrival time, duration and intensity of the weather. Rain near the start of the shift may cancel outdoor work for the entire day, whereas a storm that arrives near the end of a work day may leave production virtually unaffected. Gusty winds may preclude hoisting for an hour or two, with work resuming when the winds calm. To reflect this reality, the practice is to consider pre-contract precipitation in half-workday increments and wind effects on an hourly basis.

## IV. Calculating Normal Adverse Weather

A statistical analysis of local 10-year pre-contract NOAA data provides a reasonable basis for anticipating the number of workdays likely to be lost to precipitation during each month. For precipitation affecting exposed work, the calculation counts a minimum of one-half lost day for each precipitation event exceeding 0.1" during the workday with an additional one-half day lost if the precipitation exceeds 0.1" during the first half of the workday. An additional recovery workday is counted for each precipitation event exceeding 1 inch in any whole day, whether or not during the workday, as recovery is likely to be required during the next available workday.

Reasonably anticipated production loss due to cold ambient temperatures and wind chills or hot ambient temperatures with high humidity is calculated by applying data reported by Dr. Koehn (or NECA) to the pre-contract frequency of such conditions in each month reported by NOAA. An approach to this calculation is to establish a matrix of temperature ranges, in $10^{o}$F increments, and simultaneous relative humidities under 65%, between 65% and 85%, or above 85%. Wind chill is calculated in accordance with the standard NOAA formula and used in place of temperature if wind speed (V mph) is in excess of 3 mph and temperature ($T\,^{o}F$) is below $50^{o}$F).

Wind Chill ($^{o}$F) = $35.74+0.6215T-35.75V^{0.16}+.4275T(V^{0.16})$

The anticipated loss for each combination of temperature, wind-chill and humidity factors is established using NOAA data. This factor calculation is used as a look-up table to determine the loss applicable under conditions reported each hour by NOAA during workdays within the pre-contract period. Table 1 provides an example.

**Table 1** Productivity Loss for Varying Temperatures, Wind Speed and Humidities

| Temperature | < -10F | < -10F | < -10F | -10F - 0F | -10F - 0F | -10F - 0F | 0F-10F | 0F-10F | 0F-10F |
|---|---|---|---|---|---|---|---|---|---|
| Rel. Humidity | <65% | 65%-85% | >85% | <65% | 65%-85% | >85% | <65% | 65%-85% | >85% |
| Loss | 0.7 | 0.9 | 1 | 0.54 | 0.67 | 0.88 | 0.38 | 0.47 | 0.63 |
| | | | | | | | | | |
| Temperature | 10F-20F | 10F-20F | 10F-20F | 20F-30F | 20F-30F | 20F-30F | 30F-40F | 30F-40F | 30F-40F |
| Rel. Humidity | <65% | 65%-85% | >85% | <65% | 65%-85% | >85% | <65% | 65%-85% | >85% |
| Loss | 0.24 | 0.31 | 0.39 | 0.14 | 0.17 | 0.21 | 0.07 | 0.07 | 0.09 |
| | | | | | | | | | |
| Temperature | 80F-90F | 80F-90F | 80F-90F | 90F-100F | 90F-100F | 90F-100F | >100F | >100F | >100F |
| Rel. Humidity | <65% | 65%-85% | >85% | <65% | 65%-85% | >85% | <65% | 65%-85% | >85% |
| Loss | 0.04 | 0.1 | 0.15 | 0.18 | 0.24 | 0.34 | 0.45 | 0.59 | 0.79 |

Anticipated losses due to high winds are calculated by counting one hour loss for each hour during the working day in which NOAA records gusts above the threshold value to stop work (typically 30 MPH for hoisting with tall cranes.)

Experience indicates that, except in extremely snowy climates, production loss during rapid snowfall are small in comparison with other weather losses. Nevertheless, if it becomes necessary to evaluate these losses, three alternative approaches are available. One approach uses average hourly snowfall rates calculated using NOAA-reported 6-hour snowfall accumulations. A second choice uses hourly liquid-equivalent precipitation reports during periods with below-freezing temperatures and assume a standard ratio (typically 1 inch liquid = 10 inches of snow) to calculate the snowfall rate. A third option uses the hourly liquid-equivalent precipitation data to proportion the 6-hour snowfall report into hourly increments. Only snowfall periods during the workday are included in any of these anticipated loss calculations. Where snowfall rates have relatively minimal effects on production, a simplified calculation is justified in most instances. In any case, the production loss (in hours) for each hour with a high snowfall rate is calculated as follows (R represents snowfall rates):

| R (in/hr) | Loss |
|---|---|
| $R \leq 0.4$ | Lost hours = (0.25 x snowfall rate) x hours snowfall |
| $0.4 \leq R \leq 0.8$ | Lost hours = (1.25 x snowfall rate– 0.4 ) x hours snowfall |
| $R > 0.8$ | Lost hours = 0.6 x hours snowfall |

These losses are summarized for each calendar month and the results averaged for each month over the 10-year pre-contract period to determine the loss that can reasonably be anticipated from precipitation, cold and hot temperatures, winds chills and humidity, wind speed and high snowfall rates for each calendar month.

Table 2 provides a complete normal adverse weather calculation of production loss, accounting for precipitation, wind, hot/cold temperatures and snowfall rates. In making these evaluations it is important not to double-count adverse weather production loss. For example, it is not unusual for a day with high precipitation to also have high winds. Therefore, the analysis proceeds in sequence through precipitation, wind, temperature and snowfall rates. A period previously counted as lost due to weather (e.g., a rain day) is not counted again (e.g., as a wind day or with high temperature/humidity losses).

**Table 2** Sample Normal Adverse Weather Stated as Lost Production in Calendar Days

**Calculated Normal Adverse Weather Monthly Day Losses (Prior 10-year Standard)**

| Month | Precipitation ≥ (0.1") & Recovery | Wind (30 MPH) | Hot/Cold Lost Production | Snowfall Rate Lost Production | Monthly Schedule Lost Production |
|---|---|---|---|---|---|
| Jan | 2.1 | 2.0 | 8.4 | 0.5 | 13 |
| Feb | 1.7 | 2.1 | 5.9 | 0.3 | 10 |
| Mar | 2.5 | 3.6 | 2.7 | 0.2 | 9 |
| Apr | 3.9 | 3.7 | 0.6 | - | 8 |
| May | 3.9 | 2.2 | 0.1 | - | 6 |
| Jun | 3.8 | 0.9 | 0.1 | - | 5 |
| Jul | 3.1 | 0.4 | 0.3 | - | 4 |
| Aug | 3.7 | 0.6 | 0.3 | - | 5 |
| Sep | 2.5 | 0.7 | - | - | 3 |
| Oct | 2.4 | 2.5 | 0.3 | - | 5 |
| Nov | 2.4 | 2.8 | 2.3 | - | 8 |
| Dec | 1.2 | 1.5 | 6.0 | 0.2 | 9 |

Source: NOAA Data – Metro Airport and Industry Data

## V. Baseline Weather Modeling Validation

Baseline validation requires establishing how normal adverse weather is modeled and verifying the calculations. Some contracts specify the extent of normal adverse weather to be assumed.[15] If unclear what weather factors are accounted for in the specification, obtaining clarification from the specifier is recommended for two reasons:

1) To verify that the specification considers adverse weather days for all weather conditions that may impact the work. A case in point; a study performed on behalf of the South Dakota DOT excludes the effect of high winds.[16]

2) To ensure an apple-to-apple comparison is made when calculating actual weather schedule loss and determining FM weather (when actual weather conditions are more severe than normal weather conditions).

If allowances for normal adverse weather are not identified in the baseline schedule, or are incompletely specified in the contract (e.g., weather days include only precipitation), it will be necessary to develop reasonably anticipated weather production loss due to normal adverse weather using guidance provided in Sections II – IV.

The next step following calculation of lost production is to validate the normal adverse weather allowances originally modeled in the baseline. Four prospective methods and one retrospective method are commonly used by schedulers to plan for normal adverse weather. The retrospective method uses weekends as make-up weather days; it requires approval of overtime for the craft workforce and supervision and weekend testing and inspection, which tends to increase costs. This method is not relied upon except for anticipated losses of less than 2-3 days per month.

### [A] Prospective Weather Modeling

A baseline may rely on four different prospective methods to model normal adverse weather. One method inserts a weather contingency activity as a predecessor to the project completion milestone. Considering Table 2, for a 30-month project starting March 1st, with critical path work exposed to weather conditions through June of the following year, the weather contingency activity preceding the completion milestone calculates to a 81-working day duration (e.g., using a weekly conversion factor). A variation of this method adds granularity by inserting weather contingency activities as predecessors to interim milestones. In either method, the intent is for the weather contingency activity or activities to be depleted periodically, using the monthly anticipated or actual weather loss, whichever is lower.

A third method the analyst may encounter increases durations of weather-sensitive activities using the specific month(s) in which scheduled and the anticipated weather day losses for that/those month(s). If this method is used, the analyst should be aware that the duration for a weather-modeled activity has to be recalculated every time the activity shifts to a different month, or the activity duration is increased or decreased, or both.

A fourth method uses a weather calendar(s) available as software settings. If used, the analyst should verify that 1) weather calendars are accurate (randomly chosen weather days are identified, totaling, in each month, the number of weather days required to account for lost production), 2) each calendar is assigned only to activities sensitive to the corresponding impacts modeled by the calendar. A study of total floats may also be required because multiple calendars can lead to breaks in the zero-total float critical path.

## VI. Force Majeure Weather Modeling

### [A] Weather Condition Calculations

As depicted in Table 2, for planning purposes, applicable losses due to precipitation, recovery days, high winds, hot and cold temperatures (accompanied by winds and humidity) and high snowfall rates are totaled for each calendar month. However, to determine if FM weather justifies a time extension, it is recommended that actual loss due to ***each weather condition*** be compared with the normal adverse weather for that condition. Thus, unusually frequent precipitation may constitute a FM condition justifying a time extension that would not be subject to offsetting by other better than anticipated conditions, even if, for example, temperatures during the month were unusually moderate, resulting in lower than planned losses due to high temperatures.

The same criteria and methodology used to evaluate pre-contract meteorological records to determine normal adverse weather days is applied to actual conditions to determine whether actual conditions rise to the level of force majeure. This analysis is restricted to critical path activities that are impacted by weather, condition-by-condition.



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After evaluation, the resulting actual weather should be compared condition by condition (e.g., precipitation, temperature, etc.), month by month, without offsetting.[17] Schedule gain, if any, resulting from less severe weather accrues to the contractor. Better than anticipated weather for a single condition may not shorten the schedule. Unusually good weather may allow foundations to complete early, but the gain may be lost if the steel to be set on the foundation does not arrive until the date previously anticipated, based on normal adverse weather. Following this example, if unusual high winds arise after steel erection begins, the resulting loss will delay the project and may justify a FM weather extension, even though preceded by work exposed to weather less severe than normal adverse weather.

It is common for contracts to require demonstration of unusual conditions and that the conditions actually caused a critical path delay to justify a force majeure time extension. In this instance, it will be necessary to consult field records or other sources to determine actual work stoppages and production losses that accompanied the unanticipated adverse weather. These losses can be compared month by month and parameter by parameter with those that should reasonably have been anticipated as calculated from the pre-contract data using an appropriate methodology.

Contractor pre-job planning does not typically anticipate exceptionally severe events such as time required to repair tornado or hurricane damage; these are risks that may be insured but are not typically factored into baseline schedules. Any discrete delays caused by such exceptionally severe weather events would justify force majeure time extensions to the extent the critical path of the project is affected, however critical path float may be dealt with in the contract.

Methods for modeling FM weather impacts rely on the assumption that FM weather entitles the contractor to relief from liquidated damages, without compensation for the extension, even if concurrent contractor delay occurs on other parallel paths. This is the common technical principle that applies to concurrent contractor and excusable delay.[18]

### [B] Recommended FM Weather Modeling Methods

Table 3 lists four FM weather modeling methods. Three methods are introduced: weathered as-planned (WAP), *weather path* and *weather* impact analysis. The first two methods employ *what if* simulations on the as-planned schedule and critical path, respectively, and filter FM weather delays from all other delays, known or unknown.

**Table 3** Alternative Approaches to Modeling Force Majeure Weather

| Modeled Method | Factors to Consider |
|---|---|
| Weathered As-Planned (What if Analysis) | Acceptable because FM weather delays are excusable ▪ Limited to weather delays only ▪ Serial effect of weather may require WAP analysis in windows |
| Weather Path (What if Analysis) | Percent of working days during each month that critical path activities were subject to adverse weather ▪ Automatically accounts for shifts in critical paths |
| Weather Impact Analysis (WIA) | A time impact analysis (TIA) variant ▪ Requires an accepted as-planned and monthly windows ▪ FM weather modeled before progress is introduced |
| Collapsed As-Built (CAB) | Conceptually suitable as weather is modeled through subtractive techniques ▪ Windows CAB permits contemporaneous as-built FM weather modeling |

### [C] *Weathered* As-Planned Analysis

Weathered as-planned (WAP) is an impacted as-planned method that substitutes FM weather calendars for normal adverse weather calendars. The as-planned, if it follows common practice, already includes weather impacts; more precisely, it portrays the contractor's intentions with the assumption of *normal adverse* weather. With actual weather known, replacing FM weather for normal adverse weather answers this fair *what if*: With actual weather known, what would the corresponding as-planned completion date and critical path be if FM weather was modeled instead of normal adverse weather? WAP analysis includes neither impact of actual delays nor progress–as the baseline does. Nonetheless, because WAP excludes consideration of what actually occurred (as impacted as-planned analysis does), use of WAP should be limited to the following conditions applying:

1) Impacted as-planned analysis for calculating weather time extensions is not barred by contract specification.

2) The as-planned schedule submitted by the contractor either was accepted by the owner as a reasonable baseline, or, based on independent validation (and subject to appropriate rectifications) by the analyst, represents a reasonable baseline as the starting point for FM weather modeling.

3) Monthly updates and progress report narratives support that the as-planned critical path remains as the critical path for the project, and that the project is generally progressing according to the as-planned schedule.

With these predicates, consider the following WAP step-by-step protocol:

1) *Validate* the normal adverse weather modeling (specific conditions and accuracy) upon which the as-planned schedule was premised (assuming the criteria and calculations are available). This requires confirming the method (make-up days, in as-planned durations, contingency activities or weather calendars, whichever applies).

2) Independently calculate and tabulate for each month (as-planned start to completion date), normal adverse weather loss, condition-by-condition (loss in January is the same for every year). Condition-by-condition is required because not all work is affected by all conditions.

3) Calculate actual adverse weather for each month, in each year, for the very same meteorological conditions, separately, using the guidance provided in Sections II through IV above.

4) To the extent normal adverse weather was modeled in the as-planned schedule, remove the normal adverse weather modeling calculations used in the as-planned schedule, whether based on weekend makeup days, weather contingency activities, increased weather durations activity durations or weather calendars.

5) Using the scheduling software, modify the baseline weather calendar(s), if existing, or create WAP normal weather calendars for each independently-calculated normal adverse weather condition. Apply each weather calendar, condition-by-condition, to those activities sensitive to the condition. Recalculate the as-planned schedule and compare to the baseline (i.e., weather as originally modeled in the as-planned schedule).

6) For the WAP normal weather calendar for each condition, substitute actual weather production loss if higher than the respective normal weather loss. No changes are made if FM is less severe than normal adverse weather.

7) Recalculate the as-planned schedule with the WAP FM weather calendars vs. the WAP normal weather calendars; compare to the as-planned completion date and critical path. If weather serial effect or unusual recovery is apparent, recalculate the as-planned schedule in windows, each closing date coinciding with the end of each quarter (3-month windows) or end of May and November (6-month windows).

Provided the as-planned schedule models normal adverse weather according to step 5, WAP analysis can be applied contemporaneously. Following the end of each month, if actual adverse weather is more severe than the normal adverse weather, condition by condition, the weather calendars for that month would be revised to reflect actual weather production losses, and the as-planned schedule would be re-calculated on that basis, with consideration given to revising the weather calendar downstream for weather serial effect. If actual adverse weather was less severe than normal adverse weather, no revisions would be required. For each monthly ***what if*** simulation, the data date would remain on the project start date, which means that *no progress would be introduced*. Such contemporaneous WAP analysis would be for the limited objective to determine at the end of each month whether a time extension for FM weather is warranted, without consideration for any other events possibly impacting actual schedule performance.

Using RP 29 lexicon,[19] WAP is a modeled/additive/single base technique, if performed in one simulation, and a modeled/additive/multiple base technique, if in multiple simulations. When carried out in windows, the model for each window is the prior window as impacted by FM weather. No progress or other time impacts are introduced during WAP modeling. An example of a single-base WAP analysis for a project is illustrated in Figures 1 and 2. For simplicity, weather conditions are combined as anticipated weather day losses for each month, as shown in Table 4.

**Table 4** Normal Adverse Weather and Actual Adverse Weather Monthly Day Losses

| Month | Precip. | Wind | Hot/Cold | Snowfall Rate | Anticipated Normal Adverse Weather | Actual Adverse Weather | Max of Anticipated and Actual | Difference of Max & Normal (monthly) | Difference of Max & Normal (cumulative) |
|---|---|---|---|---|---|---|---|---|---|
| March | 2.5 | 3.6 | 2.7 | 0.2 | 9 | 6 | 9 | 0 | 0 |
| April | 3.7 | 3.7 | 0.6 | 0.0 | 8 | 15 | 15 | 7 | 7 |
| May | 3.7 | 2.2 | 0.1 | 0.0 | 6 | 6 | 6 | 0 | 7 |
| June | 2.8 | 0.9 | 0.1 | 0.0 | 4 | 4 | 4 | 0 | 7 |
| July | 2.4 | 0.4 | 0.3 | 0.0 | 3 | 7 | 7 | 4 | 11 |
| August | 3.1 | 0.6 | 0.3 | 0.0 | 4 | 3 | 4 | 0 | 11 |
| September | 2.2 | 0.7 | 0.0 | 0.0 | 3 | 1 | 3 | 0 | 11 |
| October | 2.2 | 2.5 | 0.3 | 0.0 | 5 | 10 | 10 | 5 | 16 |
| November | 1.9 | 2.8 | 2.3 | 0.0 | 7 | 7 | 7 | 0 | 16 |
| December | 1.2 | 1.5 | 6.0 | 0.2 | 9 | 14 | 14 | 5 | 21 |
| January | 2.1 | 2.0 | 8.4 | 0.5 | 5 | 15 | 15 | 10 | 31 |
| February | 1.7 | 2.1 | 5.9 | 0.3 | | 6 | 6 | 6 | 37 |

Notes: All are in calendar days
Work impacted by weather was planned to finish on 1/12/10.

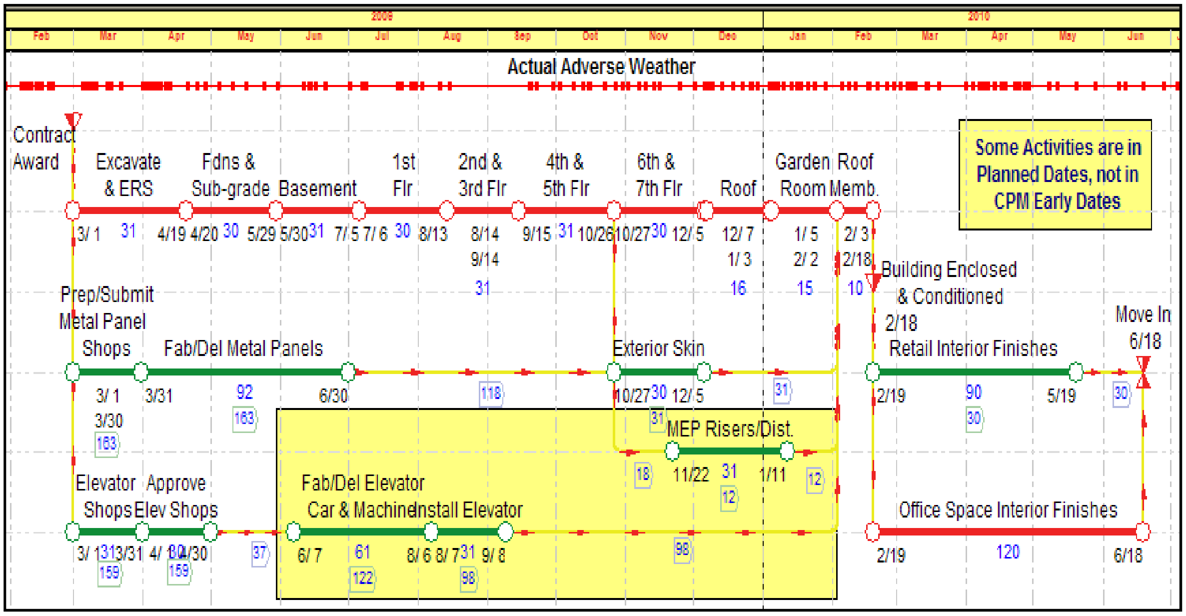
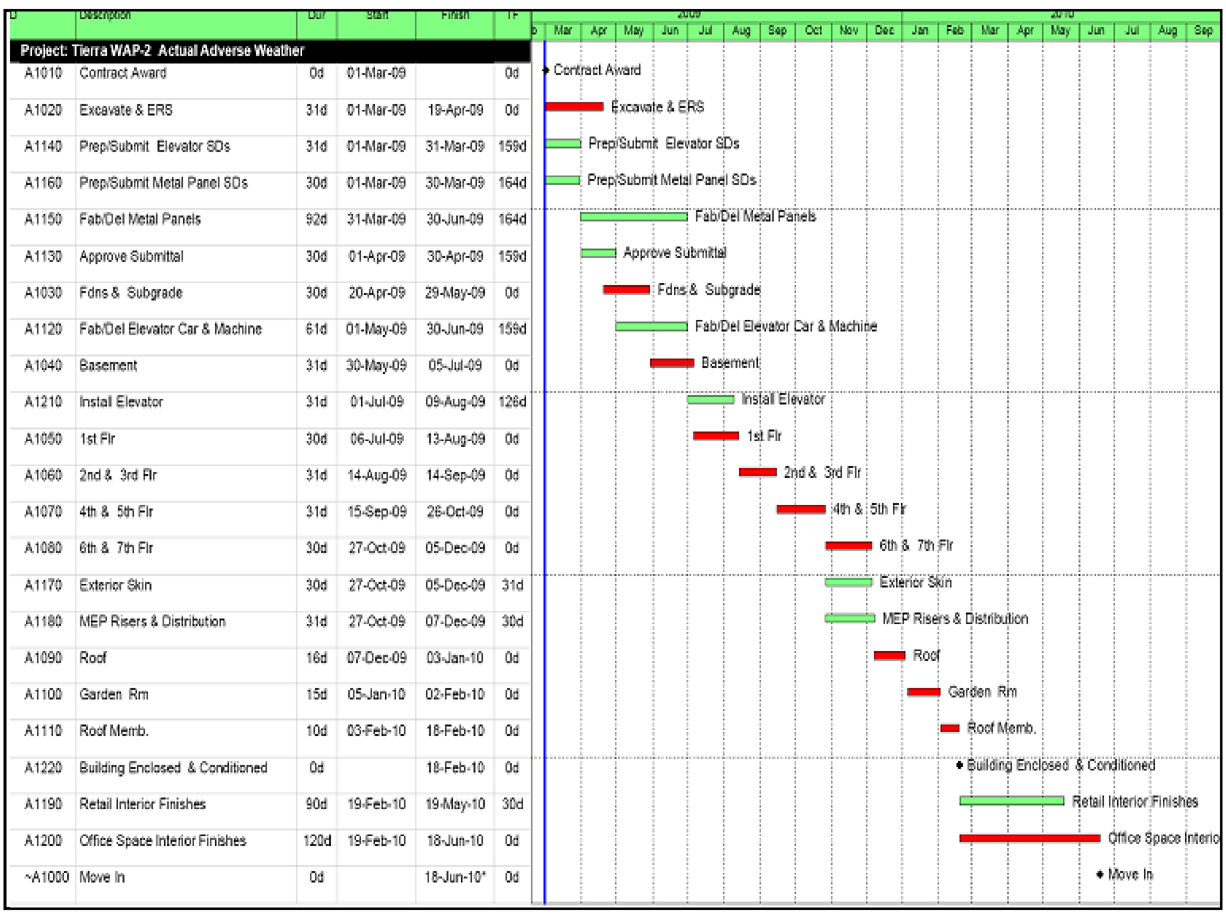



Figure 1 FM Weather-Impacted Schedule, Completion Extended From 12 May 10 to 18 June 10

The weather-impacted as-planned schedule in Figure 1 is calculated and displayed using the NetPoint® software. FM weather causes a time extension of 37 calendar days, from 12 May 10 to 18 Jun 10. The weathered as-planned schedule in Figure 2 is calculated and printed using Primavera/6 software, and supports the same time extension.



| ID | Description | Dur | Start | Finish | TF |
|---|---|---|---|---|---|
| Project: Tierra WAP-2 Actual Adverse Weather | | | | | |
| A1010 | Contract Award | 0d | 01-Mar-09 | | 0d |
| A1020 | Excavate & ERS | 31d | 01-Mar-09 | 19-Apr-09 | 0d |
| A1140 | Prep/Submit Elevator SDs | 31d | 01-Mar-09 | 31-Mar-09 | 159d |
| A1160 | Prep/Submit Metal Panel SDs | 30d | 01-Mar-09 | 30-Mar-09 | 164d |
| A1150 | Fab/Del Metal Panels | 92d | 31-Mar-09 | 30-Jun-09 | 164d |
| A1130 | Approve Submittal | 30d | 01-Apr-09 | 30-Apr-09 | 159d |
| A1030 | Fdns & Subgrade | 30d | 20-Apr-09 | 29-May-09 | 0d |
| A1120 | Fab/Del Elevator Car & Machine | 61d | 01-May-09 | 30-Jun-09 | 159d |
| A1040 | Basement | 31d | 30-May-09 | 05-Jul-09 | 0d |
| A1210 | Install Elevator | 31d | 01-Jul-09 | 09-Aug-09 | 128d |
| A1050 | 1st Flr | 30d | 06-Jul-09 | 13-Aug-09 | 0d |
| A1060 | 2nd & 3rd Flr | 31d | 14-Aug-09 | 14-Sep-09 | 0d |
| A1070 | 4th & 5th Flr | 31d | 15-Sep-09 | 26-Oct-09 | 0d |
| A1080 | 6th & 7th Flr | 30d | 27-Oct-09 | 05-Dec-09 | 0d |
| A1170 | Exterior Skin | 30d | 27-Oct-09 | 05-Dec-09 | 31d |
| A1180 | MEP Risers & Distribution | 31d | 27-Oct-09 | 07-Dec-09 | 30d |
| A1090 | Roof | 16d | 07-Dec-09 | 03-Jan-10 | 0d |
| A1100 | Garden Rm | 15d | 05-Jan-10 | 02-Feb-10 | 0d |
| A1110 | Roof Memb. | 10d | 03-Feb-10 | 18-Feb-10 | 0d |
| A1220 | Building Enclosed & Conditioned | 0d | | 18-Feb-10 | 0d |
| A1190 | Retail Interior Finishes | 90d | 19-Feb-10 | 19-May-10 | 30d |
| A1200 | Office Space Interior Finishes | 120d | 19-Feb-10 | 18-Jun-10 | 0d |
| ~A1000 | Move In | 0d | | 18-Jun-10* | 0d |

Figure 2 FM Weather-Impacted Schedule, Completion Extended From 12 May 10 to 18 June 10

## VII. Other FM Weather Modeling Methods

### [A] Weather Path Analysis

The authors intend to describe this method in detail in a separate paper.

### [B] Weather Impact Analysis

Weather impact analysis is a time impact analysis (TIA)[20] variant that proceeds in monthly windows and that modifies TIA analysis to make it suitable for modeling FM weather after actual weather has occurred, but before progress is introduced.[21] As with conventional TIA analysis, with the prior monthly update statused with progress through the prior month data date, FM weather delays in the current monthly update are modeled through FM weather calendars and the schedule is recalculated before or concurrently with other delays before progress is introduced.

This method may be more sensitive to critical path shifts as well as actual vs. as-planned progress, but, besides an accepted as-planned, it requires monthly updates accepted by the owner as reasonable for use as a current baseline for the balance of the work going forward. On the other hand, this method is susceptible to manipulation and involves repeated judgment calls relative to calculating remaining durations and the reasonableness of non-progress revisions.

### [C] Windows Collapsed As-Built

Windows collapsed as-built[22] (windows CAB) analysis performs subtractive simulations on periodic schedule models representing intervals of the as-built schedule. Each model creates a period of analysis for the quantification of delay impact and reconciles schedule extension to time impacts to the critical paths existing in each window.

The application of windows CAB to FM weather modeling requires monthly windows, and the prospective portion of the schedule beyond the monthly window data date to be current with the plan for the balance of the work going forward. Windows CAB FM weather protocols are similar to WIA analysis, except FM weather modeling is carried out after progress is introduced into the monthly window. FM weather delays subsumed within the activity as-built durations are extracted and the monthly window collapsed through subtractive techniques.

## VII. Summary and Conclusions

Nearly all grass-root construction and civil works projects face the likelihood of abnormal adverse weather impacts the parties may wish to recognize on an ongoing basis. The WAP methodology enables an objective, network logic-based, real time evaluation of weather impacts and is also a reliable approach to retrospective analysis of weather impacts in the context of dispute resolution. Weather calculations include production loss due to loss of a workday (or half a workday) and working through the weather at reduced productivity instead of cancelling work for the day.

Reliance on the as-planned schedule is technically appropriate,[23] provided the predicates itemized on page 6, §VI.[C] apply, because WAP analysis calculates the sensitivity of the as-planned schedule to alternate weather (force majeure vs. reasonably anticipated weather) without considering progress and any other delays, known or unknown.

The authors advocate making timely determinations on weather impact issues throughout the course of construction. The modeling methods in Table 3 are suitable for real-time evaluation though the updating process. This paper describes in detail the WAP method due to its ease of use, without advocating the method to be superior to other methods for all applications. Any method acceptable to the parties that is applied during the course of construction will go a long way to allowing owners and contractors to cooperatively resolve weather-related time extensions.

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