ESTIMATING WEATHER DOWNTIME FOR OCEAN ENGINEERING USING SEQUENTIAL DOWNTIME ANALYSIS (SDA)

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Abstract

Ocean engineering activities are highly reliant on the metocean conditions meeting operational tolerances in order to safely complete required tasks. We present a process to simulate operational tasks that are affected by marine weather and provide a robust statistical basis for the estimation of downtime. The Sequenced Downtime Analysis (SDA) applies a time-domain simulation of a sequence of tasks within a long time-series of metocean data from measurements or hindcasts. SDA allows for an unlimited number of sequential tasks of fixed duration, variable duration and with delays between tasks. Job and task completion statistics can be determined for each year in the metocean database, providing inter-annual statistics as well as an assessment of the impact of start date slippages. SDA is an invaluable tool for the planning of marine operations, providing a realistic indication of the likely time a job will take to be completed. Further, SDA assists in identifying the specific tasks within a job-sequence that have the greatest downtime potential and the associated flow-on effects. SDA has been used successfully on five recent offshore engineering projects within New Zealand.

1 Introduction

The successful completion of coastal and offshore projects, on time and on budget, is highly dependent on the marine environment. Usually, marine engineering applications consist of numerous individual tasks, requiring consecutive scheduling, to be completed (often by different contractors), with each unique task having different operational safety tolerances. It is difficult for operators and contractors to evaluate the true cost of any marine construction due to the temporal variability in metocean conditions and the forecast weather downtime is often more expensive than expected.

Operational downtime is usually estimated from metocean statistics in the form of exceedence curves, monthly means or non-exceedence persistence tables (Anastasiou K. and Tsekos C., 1996, van der Wal and de Boer, 2004). However, these data do not consider the sequential nature of marine engineering projects or the effects that small cumulative delays can have on the overall project completion date. This is particularly important in regions with a strong seasonal modulation in the metocean conditions.

It is not possible to eliminate the uncertainty that a volatile marine environment creates in planning and delivering projects. However, by breaking down the project into discrete weather-sensitive components, the critical path for execution can be analysed.

We present a process to simulate operational tasks that rely on the marine weather and provide a robust statistical basis for the estimation of downtime (Sequenced Downtime Analysis). The Sequenced Downtime Analysis (SDA) applies a time-domain simulation of a sequence of tasks within a long time-series of metocean data. SDA can realise significant benefits to project planning and this paper presents a range of example applications for the system.

2 Methods

For a successful application of the SDA technique, a data time-series with no gaps is required. Usually SDA is applied using specifically-generated hindcast data; however it can easily be applied using a suitably long measured time-series.

2.1 Hindcast data

High resolution, accurate and site-specific hindcast data underpins the application and accuracy of the SDA technique, as usually numerical modelling is the only method of obtaining a suitably long time-series.

The MetOcean Solutions Ltd (MSL) hindcast system allows the meteorological and oceanographic conditions to be accurately hindcast at any location globally. Depending on the requirements, the hindcasting system can comprise of a coupled NWW3 / SWAN / POM / WRF (*N*OAA *W*ave*W*atch III, *S*imulating *WA*ves *N*earshore, *P*rinceton *O*cean *M*odel and the *W*eather *R*esearch and *F*orecasting model) system. The models characterise the full metocean conditions, including currents, tides, meteorological parameters and the directional wave spectra. The POM model provides hindcast depth-averaged current velocities. MSL's New Zealand implementation of WRF provides accurate prediction of localised weather conditions, important both for local winds and for forcing the wave / current model.

The MSL hindcast system can be rapidly deployed to any location, and currently provides >10 years of hindcast metocean data at hourly intervals (i.e. 1996 to present). The system has been validated for waves, winds and currents at numerous locations around NZ, which includes some of the world's most complex oceanography. Wave hindcasts have also been successfully validated at three locations in Western Australia and one site in the Middle East. An example wave validation example is presented for the Kupe Gas Field in New Zealand (Fig. 1).

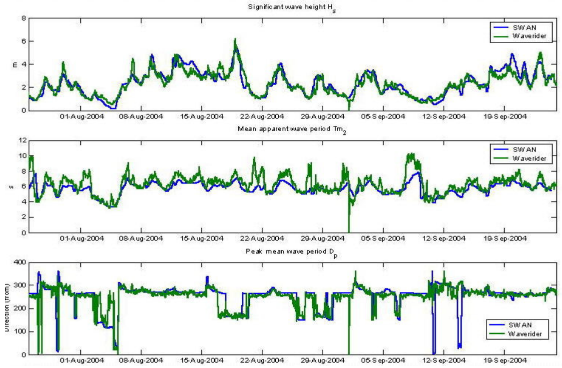

Figure 1 Hindcast time-series validation plot showing the measured and modelled wave data over a two-month period in 2004. Location is the Kupe Gas Field, South Taranaki, NZ.

Resolution is an important feature for hindcast data, and the spatial and temporal scales need to be sufficient to resolve the regional and local energy gradients. To achieve this, the MSL system uses a series of nested grids that start at an open ocean (~ 5km) and reduce to the 500 m scale for typical coastal applications (Fig 2), or 25 m in complex locations such as a harbour entrance.

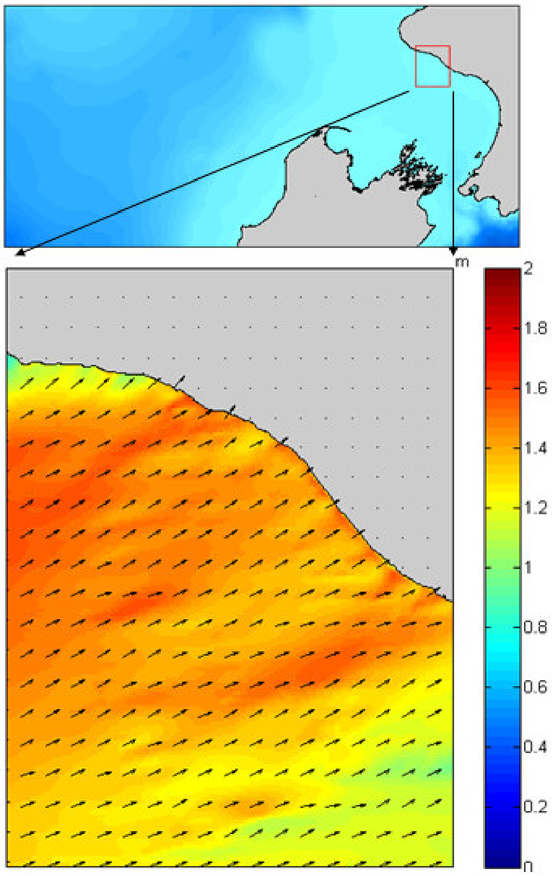

Figure 2 Example use of the nested grids to achieve a high-resolution hindcast data output

2.2 SDA theory and operation

The Sequenced Downtime Analysis (SDA) toolbox operates in a MATLAB environment and applies a time-domain simulation of a job consisting of an unlimited number of SDA 'tasks' which are required to be completed sequentially in a 'job sequence'.

The SDA system analyses the start date and duration of each task in sequence, given the conditions it requires for execution; it then analyses how long the task will take and the downtime as defined from the metocean hindcast, then moves on to the next dependent task. The mob/demob for each task can be included, usually as a weather-independent task. The first part of the simulation has zero-lag between tasks plus mob/demob as required. The project schedule is usually slipped by one day at a time over the likely start period (e.g. two months). Subsequent simulations include a Monte Carlo approach in which some chaos is added to test the cumulative effect of small, random delays to the overall project schedule; the results are analysed to produce the P50 and P90-P99 job sequence completion date certainty levels, corresponding to each of the likely project start dates.

Each task within the job sequence is defined as having a:

- Duration,
- Percent variation in the task duration (either randomly assigned or based on a Raleigh distribution),
- Potential delay in starting the task (randomly selected based on potential maximum),
- Fixed delay between starting the next task in the sequence,
- Daylight dependency (i.e. yes or no),
- Criteria that limits the possibility of completing each of the tasks (the existing version of the MetOcean SDA allows for up to 3 different limiting criteria to be considered either inclusively (*and*) or exclusively (*or*)).
- Associated unique time-series data file.

In excess of 1000 iterations per start time are usually simulated, with variations in the total time to complete a task (i.e. percent variation) and a random delay between tasks (i.e. potential delays in starting task) able to be accounted for in each of the tasks within the job sequence, and for each iteration.

Latitude and longitude co-ordinates and time-zone are required if daylight dependency is specified for any task within the job sequence. The SDA system uses complicated algorithms to determine the zenith of the sun relative to the job location; thereby identifying the daylight hours at the job site.

An number of dependent tasks at varying locations can be simulated if necessary, with each task able to having its own unique location specific time-series of metocean data.

Graphical and tabular outputs enable the user to understand project duration at differing levels of certainty, and increase awareness of key milestone dates to minimize “knock on” slippage. The job sequence can be repeated for each year that time-series data is available, allowing annual and inter-annual statistics on job completion times to be determined. The time-series length achievable using the MSL hindcasts means that the impact of ENSO signals (e.g. Southern Oscillation Index (SOI) or the Multivariate ENSO Index (MEI)) on job completion can be evaluated.

SDA has been used successfully in the decision making processes of various offshore and coastal projects in New Zealand, including; the Pohokura Gas Platform installation and piling (Fig. 3), the Maari WHP installation and FPSO hook-up, a 50,000 m^3 pipeline berm for the Kupe Gas project, and variety of ocean towing activities.

Figure 3 Installation and piling activities for the Pohokura Gas Platform were simulated using SDA for 8 individual years. The results were used to assess the impact of project slippage and to ensure the optimum use of the available weather windows.

2.2.1 Example 1 – FPSO Hook-up operations

Installation of a jacket and FPSO at an offshore drilling site is a complicated undertaking consisting of several jobs with unique task requirements in terms of duration and limiting criteria. The complexity in such jobs often leads to difficulty in budgeting; however SDA provides a clear, statistically-robust assessment of the impact of project delays, allowing more transparent reporting to project sponsors. The SDA system was used successfully in the PPB jacket installation at Pohokura, New Zealand and FPSO hook-up operations at the Maari site

A job sequence for an example FPSO Hook-up is presented in Table 1. The job task list was simulated for 8-years, with the job sequence scheduled to commence anywhere within the months of December to January (i.e. commencement 1-day slippage beginning 1st Dec, finishing 31st Jan of the following year). Significant wave height was defined as the only limiting criteria. In total, 1000 iterations were simulated, with each task having a potential duration variation of up to 5%, determined using a Raleigh distribution. Further, a potential delay of up to 6 hours was randomly assigned to each task for each of the iterations. There was no daylight dependency for any of the task within the job sequence. The wave data time-series are shown on Figure 4, illustrating the energetic and variable nature of the environment.

Table 1 Job task list – Job sequence for an aspect of an offshore Jacket installation. Total duration for this job sequence is 13.79 days.

task No	Description	Duration (days)	H_s limit (m)
1	Transit and mobilise	2.58	none
2	Install umbilical	1.13	2.5
3	Install No.1 production line	1.33	2.5
4	Install No. 1 test line	1.33	2.5
5	Transit and re-mobilise	1.5	none
6	Install Flowline / Riser	2.1	2.5
7	Install No. 2 Flexible Riser	1.44	2.5
8	De-mob to Port	2.38	none

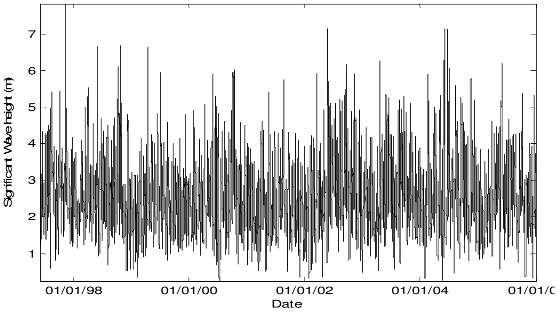

Figure 4 Eight-year hourly wave height time-series from the MSL hindcast model.

A typical SDA graphical output is shown in Figure 5, illustrating the period over which each task within the job sequence can be completed (based on each tasks limiting criteria and the hindcast time-series). When the limiting criteria is reached or exceeded the task is postponed until conditions abate sufficiently to allow work to proceed. Figure 6 illustrates the effect of project slippages on the time to complete the specified job sequence (Table 1) illustrating that if the job sequence had started within the period 1st Dec 1997-31st Jan 1998 the Job could have potentially taken > 25 days to complete (i.e. > 11 days downtime).

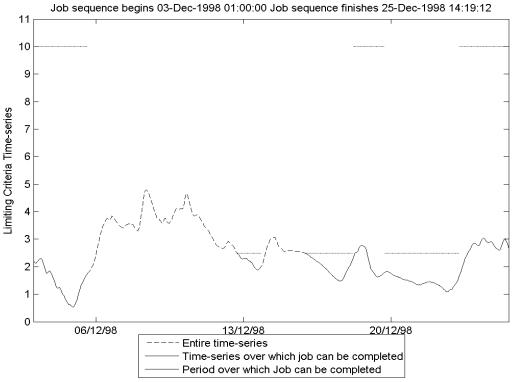

Figure 5 Typical SDA graphical output

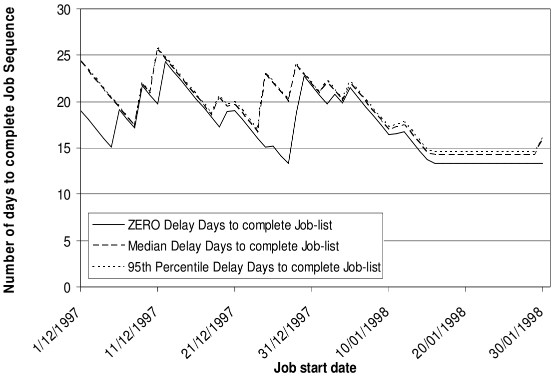

Figure 6 Duration to complete job sequence for different start dates; for a start period between 1st Dec 1997 and 31st Jan 1998

Table 2 Job sequence completion statistics for part of the work-scope for a Jacket emplacement.

Start date slippage period	Average completion time	Maximum completion time
01/12/97 to 31/01/98	18.86	25.55
01/12/98 to 31/01/99	17.72	28.72
01/12/99 to 31/01/100	21.57	30.00
01/12/00 to 31/01/101	25.69	41.44
01/12/01 to 31/01/02	18.47	24.58
01/12/02 to 31/01/103	21.96	30.99
01/12/03 to 31/01/104	20.90	33.65
01/12/04 to 31/01/105	19.36	29.44
All years Average	20.56	30.55
MEI -ve period	21.66	33.39
MEI +ve period	19.91	28.84

Completion statistics for the each of the years available within the metocean hindcast are given in Table 2. Also presented are statistics on the duration the job sequence would take to complete for all years simulated and for years with a positive and negative Multivariate ENSO Index (MEI). On average the job sequence will take approximately 1 day longer during a year with a negative MEI, but could take up to 3 days longer in extreme years. Also, when the project is began in a positive phase of the MEI the total job sequence duration is expected to be slightly less than the average duration (Table 2).

2.2.2 Example 2 – Construction of an offshore detached sub-tidal berm using geo-textile bags.

This example consists of the construction of a detached nearshore sub-tidal berm in South Taranaki, NZ. The berm consists of 7 geo-textile bags and the project start date is January 12th. The wave climate in this region is very energetic (McComb, 2001) and represents a challenging environment for marine operations. In this hypothetical project the geo-textile bags are transported to the site via barge and require controlled placement, assisted by SCUBA diver, prior to filling. The filling of the geo-textile bags is achieved via pumping from an adjacent dredge hopper. The work scope also includes a post-lay survey to ensure satisfactory completion of the project.

Limiting criteria include a combination of significant wave heights and wind velocities; with the magnitudes varying between tasks in the job sequence (Table 3). 1000 iterations have been simulated, with each task having a potential duration variation of up to 5%, determined using a Raleigh distribution. The deployment and filling of each bag is required to be completed during daylight hours only. The wave height and wind velocity time-series for the site is given in Figure 7. The total job duration is only 10.7 days, excluding weather effects.

Table 3 Job task list – job sequence for construction of a hypothetical offshore breakwater using geo-textile bags

task No	Description	Duration (days)	H_s limit (m)	Wind limit (m/s)
1	Mobilise	2.0	n/a	n/a
2	Transit to site	1.0	3.00	15
3	Deploy B1	0.2	1.75	10
4	Fill B1	0.4	1.50	10
5	Deploy B2	0.2	1.75	10
6	Fill B2	0.4	1.50	10
7	Deploy B3	0.2	1.75	10
8	Fill B3	0.4	1.50	10
9	Deploy B4	0.2	1.75	10
10	Fill B4	0.4	1.50	10
11	Deploy B5	0.2	1.75	10
12	Fill B5	0.4	1.50	10
13	Deploy B6	0.2	1.75	10
14	Fill B6	0.4	1.50	10
15	Deploy B7	0.2	1.75	10
16	Fill B7	0.4	1.50	10
17	Post-lay survey	1.5	2.00	10
18	Transit back	1.0	3.00	15
19	Demobilise	1.0	n/a	n/a

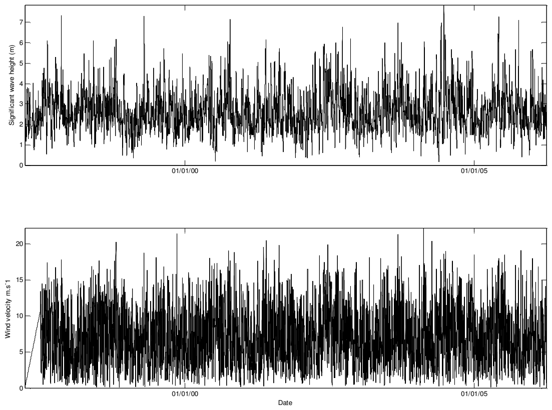

Figure 7 Eight year time-series of sig. wave height and wind speeds for Opunake, South Taranaki, NZ.

An example of the SDA graphical output for the berm project is given in Figure 8. The energetic nature of the environment makes it difficult to complete the tasks given their comparatively low limiting criteria (i.e. $H_s < 1.5\text{-}1.75$ m), and while the job sequence is only 10.7 days in duration, the actual time taken to complete the job has the potential to extend out significantly more (Figure 9). Also, as the start date is slipped further from the initial proposed starting date (i.e. 12th Jan) the number of days attributed to weather down-time tends to increase and the completion time conversely increases as a result of the period required to complete the job sequence extending into a typically more energetic period of the year (in terms of metocean conditions).

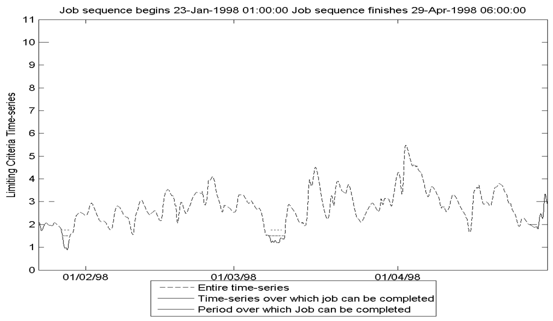

Figure 8 A Typical SDA graphical output for the berm construction

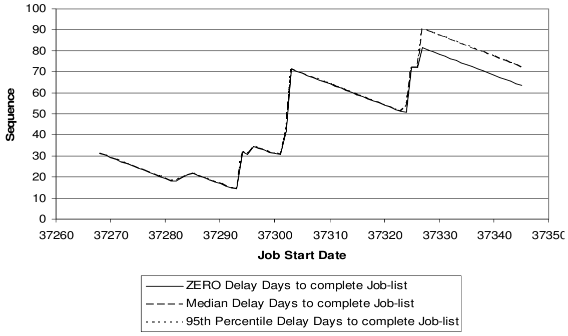

Figure 9 Duration to complete job sequence for different start dates; for a start period between 12th Dec 1997 and 31st March 1998

The average and the maximum of the 50th percentile completion times for each year are presented in Table 4. While there is some variability between the years, the average time to complete the job sequence is approximately 86 days, suggesting that in an average year there could be as much as 75 days of down time associated with the this job scope. During the more energetic years, the median total job sequence could extend out to more than 138 days, i.e. ~127 days downtime (Table 4).

Table 4 Job sequence completion statistics for a hypothetical offshore breakwater, South Taranaki.

Start date slippage period	Average completion time	Maximum completion time
12/01/98 to 31/03/98	122.95	156.59
12/01/99 to 31/03/99	87.38	221.48
12/01/00 to 31/03/00	131.95	165.79
12/01/01 to 31/03/01	44.93	64.79
12/01/02 to 31/03/02	49.88	90.33
12/01/03 to 31/03/03	77.13	165.33
12/01/04 to 31/03/04	85.71	112.62
12/01/05 to 31/03/05	86.13	127.35
All years Average	85.76	138.03
MEI -ve period	88.09	150.68
MEI +ve period	84.36	130.45

The impact of a positive and negative MEI on the duration required to complete the work scope is also shown on Table 4. Typically, negative MEI periods (i.e. the strongly El Nino phase) will result in an increase in the duration required to complete the work scope; with weather related downtime predicted to be on average 77 days during normal years and as much as 140 days during more energetic years (i.e. 150.68-10.7 days). The converse is true for when the work scope is conducted over months with a positive MEI (Table 4), with the work scope predicted to take approximately 1 day less for average years, and 8 days less for less energetic years (i.e. 84 days and 130 days respectively).

3 Discussion

The SDA technique has been applied successfully to several offshore and coastal projects including; the Pohokura Gas Platform installation and piling (Fig. 2), the Maari WHP installation and FPSO hook-up, a 50,000 m^3 pipeline berm for the Kupe Gas project, and variety of ocean towing activities. .

Historically, in the marine environment operational downtime has usually been estimated from exceedence curves, monthly statistics or non-exceedence persistence tables. The sequential completion of tasks in a job sequence is not accounted for in these methods, nor is the effect that small cumulative delays can have on the overall duration of the complete job. The SDA technique was developed in order to overcome these deficiencies in the traditional analysis methods techniques routinely used for establishing likely downtime.

For SDA to be effective, it is vital that a high quality, long time-series of each of the relevant limiting criteria be available. Usually site-specific measured data of this duration is not readily available, and hindcasting techniques such as described in this paper can be usefully applied.

The SDA technique provides information on the timing of a proposed work scope, assisting critical decisions in the initial phases of project planning. The technique gives valuable information to the cost engineers/project managers in assessing likely duration of operational schedules. Generally, project sponsors want to make rational economic decisions on very long term capital investments, and knowing the range of likely project costs is a key driver. High costs may be acceptable if expected and risk-managed early in a project's life. If the SDA shows a high risk of costly operational delays, the project sponsor may take a different attitude to the commercial structure - the data from the SDA analysis provides an objective benchmark to weather or duration related component of any risk-reward arrangement with the lead or sub-contractors. For example, sharing this risk may be sufficient to make the projects risk program viable. As the project moves through its life and schedule changes occur, SDA can be re-applied to reduce uncertainty in possible impacts of weather downtime. In the final stages of operational deployment, SDA can be used in conjunction with forecasts to assist in operational planning.

4 Summary

Sequenced Downtime Analysis (SDA) is a technique for determining the likely downtime and total duration associated with a sequence of operational ocean engineering tasks SDA applies a time-domain simulation of a sequence of tasks within a long time-series of metocean data from measurements or hindcasts and estimates the likely completion time of the complete job. Unlike typical downtime estimation techniques, SDA uses a Monte Carlo approach in which the cumulative effect of small, random delays to the overall project schedule are tested. Limiting criteria (e.g.. wave height, wind velocity) for each of the dependant tasks is considered in the simulation.

The application of SDA to a work schedule requires a high quality data time-series with no gaps; usually only achievable using site-specific numerical hindcast data.

SDA provides valuable information to engineers and managers, particularly during the initial start-up phase of a project, allowing project sponsors to make rational, well-informed economic decisions.

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