Submerged Geotextile Breakwater Construction Modeling

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Abstract

Construction of a sand-filled geotextile submerged breakwater was being considered at Kahului Harbor, Maui, to reduce wave energy and increase harbor tranquility. By reviewing the construction methods used in similar submerged structures, a CYCLONE (CYClic Operations Network) model was developed and could be extended to Kahului Harbor, pending final design. The model was created in EZStrobe, adjusted to optimize costs, and reduced the construction time. A utility function had been employed to compare the same model under sensitivity analysis and assists in optimizing various parameters intrinsic to production processes. This study reviewed several projects in Australia, Mexico, South Korea, New Zealand, India, and the United Kingdom and provided recommendations for future submerged breakwater construction.

Keywords
Process Simulation, Coastal Engineering, Submerged Geotextiles

1. Introduction

To accurately examine work tasks and their associated resource allocation, a process simulation model was prepared in CYCLONE (CYClic Operations NEtwork) simulation language and entered into EZstrobe, a user-graphic interface. This study examined five construction projects involving the installation of submerged geotextile breakwaters. The models were further broken down as critical subtasks were identified to identify where efficiencies in resources could be gained. The resources considered include time, equipment, manpower, and construction materials.

Identifying resource intensive tasks will allow for the development and/or implementation of improved methods to optimize processes. Optimization can be as simple as reducing one forklift as it may be idle 90% of the time and not adversely impact production if it is not used. A process may already be optimized and might require an innovation to increase its productivity. This paper considered these factors when examining each process.

To improve the harbor protection at Kahului, Maui, a submerged breakwater solution was proposed. This solution should cost less and work effectively compared to the originally planned break-wall extension. This paper will review possible construction methodologies, conduct modeling of these methods using CYCLONE, optimize each methodology to maximize the utility factor, and recommend the best overall method for constructing the proposed breakwater. Furthermore, this paper will examine five documented projects with similar characteristics to that of the desired Kahului breakwater. Lastly, this paper will consider the sensitivity to weather for each method as each method has different tolerances to less than optimal weather.

2. Utility Function

The Utility Factor (UF) for this paper will indicate the total resources required to complete the entire project. The UF used in this paper is based on the UF defined by Gowda, Singh, and Connolly (1998) regarding the enhancement of bituminous paving operations. Because the dollar cost for each resource remains undefined, it is not considered, though it is known that the parametric cost is less than the original breakwater extension. However, the time and feasibility of construction serve as the primary factors at this stage. Thus,

$$UF = \text{Production Rate} / (ARI \times AWT \times ATT) \quad (1)$$

The Production Rate (PR) will be measured by cubic meters of geotubes completed per hour. ARI is the average resource idle percent time. AWT is the average wait time at the queues in hours. ATT is the average throughput time of the units from start to finish in hours.

This project aims to determine which optimized method is the most efficient.

Weather will impact the productivity of the divers, the barge, the dredge pump, and the accuracy of the geotube deployment. The ocean current can impact diver safety as well as increase the difficulty in attaching tubes to the seafloor. The ocean current will also impact the barge as it requires the ocean to be smooth during deployment when using tubes in a grid. The dredge pump also needs a relatively smooth surface when dredging material from the seafloor. The split-hull hopper barge is the most resilient piece of equipment in the open ocean, but the weather will decrease the accuracy of deploying tubes as they do not have a controlled descent.

The primary method investigated will be the Rapid Accurate Deployment (RAD) method developed by ASR Limited and used in New Zealand, India, and the United Kingdom.

3. Earlier Projects Studied: Young-Jin, Mt. Maunganui, and Kovalam

Earlier projects studied the shore stabilization submerged breakwater at Young-Jin Beach, South Korea, completed in 2004, and the Mt. Maunganui of New Zealand. The successful Young-Jin project extended the beach that it was protecting by 2.4-7.6m. However, since this project had a very different design than what is practical at Kahului Harbor, the pump rate of a cutter section dredge acts as the only generic part of the modeling applied here.

The writers discovered the Mt. Maunganui breakwater of New Zealand to be similar to that of the breakwater constructed in Boscombe, United Kingdom, which this paper models in detail. However, funding was not procured in time, and the reef was not completed. The breakwater in Boscombe now serves as marine habitat and a good diving and snorkeling location. One of the more recently submerged geotextile breakwaters was constructed with the same methodology in Kovalam Beach. This structure was not as deep as Boscombe or Mt. Maunganui, and a single layer greatly reduced its construction time and exposure to weather delays.

4. Narrowneck, Australia

The multi-functional artificial reef at Narrowneck, Australia, was the first multi-functional artificial reef to be constructed using geotextile tubes (Jackson, 2012). This reef was designed as part of a comprehensive shoreline restoration project completed in 2000. The breakwater primarily aimed to compliment and stabilize the beach nourishment efforts started in 1999. Its secondary objective was to improve surfing conditions without becoming a safety hazard for surfers. The breakwater also provided a habitat for marine life, which was not a planned, but was a desirable, outcome. This project met its objectives, but the surf break was smaller than the design parameters. This was attributed to the inaccuracy of the bag deployment method, which resulted in spaces between the bags (Jackson and Corbett, 2007). This site has similar characteristics to Kahului Harbor, which attracts even more interest in reviewing this site. The depth of the breakwater varies from 2-10m because of the sloped seafloor. The average wave height is 1m with swells observed up to 11m. The proposed breakwater at Kahului will be from 3-12m deep with a sloped seafloor and typical wave heights from 6-10m.

The Narrowneck breakwater was constructed using a total of 450 geotextile tubes that measured 20m long and on average 3.14m in diameter. The volume of one bag was 155 cu.m., and a bag was filled and placed using a split-hull hopper dredge. The total volume of geotubes used was 69,750 cu.m. at a cost of $3.6M (Shand, 2011) for $51.61 per cu.m. of geotube placed. Dragging a pipe along the seafloor, the barge dredged the fill sand directly from the ocean floor.

It is assumed to take approximately 10 minutes to load each bag on the ship with a forklift when the ship could store five bags at a time. The rate of dredging can vary based on the size and shape of the drag-pipe as well as the size of the pump (Marine Board, 1987). For this simulation, a dredge and fill cycle of 23 minutes will serve as a baseline assuming the system can fill 6.81 CM per minute, based on the pumping rate of the cutter dredge in the South Korea model. An EZStrobe model was prepared and used to calculate production parameters.

This model required 541 hours to install all 450 geotextile tubes excluding any preparation or break time. The barge and boat crew will never be truly idle as they were engaged in all steps of the process. The AWT came at 3.12 hours. ARI did not act as useful statistics in this model and was set at 1. The ATT was calculated as 1.20 hours. The UF for this model was observed and calculated to be 34.57 using eqn. 1. The cost per hour for this project with the baseline model was $6,661/hour using the total cost and excluding any preparation, design, and staging time. However, this method was determined to be too inaccurate with the placement of the geotubes to be suitable for use at Kahului Harbor and thus was not taken further.

5. Yucatan, Mexico

Geotextile tubes served as submerged breakwaters along the Yucatan coast in Mexico for a project in 2005. The tubes were placed parallel to the coastline near the shore to restore the beach. This project primarily aimed to eliminate perpendicular structures (groins to enhance the beach), increase beach nourishment, and reduce the hydraulic load on specific sections of the coastline (Alvarez et al., 2007). The installed tubes were not fully submerged. As the beach grew, sand eventually covered them.

Unlike the previous case studies, this project was installed from the coastline, and the tubes all connected to one another end to end for approximately 4km. The beach was prepared using an excavator, and the tubes were placed by hand, and then filled using a land-based pump with a slurry of water and sand. At the rate of 1,000 gal/min, 4" and 6" slurry pumps filled the tubes, where the slurry used between 10-30% solids and filled 70% of the tubes. The fill rate of a geotube was limited to 30% of the pump rate due to the slurry concentration. The tubes were 1.85m in diameter and linked together to extend a total of 4km, taking approximately 5.5 min. to fill one linear meter of geotube. The fill rate assumed that no stoppages or maintenance cycles were included in the pump work time. The pump would need to move, and various stockpiles would need to be staged along the coastline. It was assumed that the tubes must be filled in order because they would not effectively connect if they were not filled that way. Installing the breakwater from shore limited its practicality toward Kahului, but the study can still provide lessons especially with the slurry pump rates.

6. Boscombe, United Kingdom

The multipurpose submerged breakwater installed at Boscombe in the United Kingdom used the Rapid Accurate Deployment (RAD) method. This breakwater aimed to add an additional surf break further from shore with right-hand waves (Surfer, 2010). As the first artificial surfing reef in Europe, this breakwater has drawn a great deal of media attention. This breakwater was installed 280m offshore at a depth of 3-5m, following the seafloor slope. Here, the tide averaged between 1-2m.

Since the quality of the surf break acted as the major focus, the placement of the geotubes had to be much more accurate than that of Narrowneck reef. To achieve this, the three layers required a total of 54 geotubes. The base layer consisted of a mat with webbing and smaller geotubes, and the top layer and ramp layers were made from grids containing 14 geotubes and large individual tubes that varied in size from 15-70m in length and 1-4m in diameter. The largest, 70m tubes, were deployed and filled individually.

6.1 CYCLONE Model

For the CYCLONE model, three sets of 14 tubes were deployed in grids, and twelve of the 760m tubes were deployed individually. Divers using GPS guidance placed 11 five-ton anchor blocks to hold the geotubes in place before they were filled. Along the beach was a stockpile of grated sand with a land-based pump to fill the geotubes. On the bottom of the structure, the smaller geotubes were first attached to a geomat to form three separate grids. One grid at a time was then hoisted onto a barge and towed into position. Divers then attached the base grid to seafloor anchors, and the barge slowly moved away, deploying the grid. Once a layer was attached to the seafloor, the land-based pump would fill each geotube to specification.

This process would then repeat for the following two grids. The large, 70m tubes were modeled to be loaded four at a time onto the barge, then individually attached to the existing grids and filled in place, repeating the process to fill a total of 12 tubes. The distribution for the size of tubes was not documented, but the literature states 54 total tubes were used. Aerial photos of the completed reef show at least 10 of the 70m tubes on top. According to a short documentary about the reef, it took between 1-4 hours to fill each tube (O'Connell, 2009). The 70m tubes were estimated to take between 3-4 hours to fill. The time required to place both the grid and individual tubes was also estimated. The approximate total volume of the Boscombe reef was 13,000 cu.m. (Shand, 2011). It was assumed that the large tubes were 70m long and 4m diameter. If these were filled to 80% capacity, the volume per tube would be 704 cu.m., and the total volume of the twelve tubes would be 8,446 cu.m.

The small tubes were of different sizes, but were treated like they were of the same size, a volume of 109 cu.m. If the pump rates were used from the Mexico example, each bag would take between 5-103 hours, which was not practical. The windows of time described in the documentary would be used with a uniform distribution as described above.

6.2 Model Sections

The CYCLONE model contains six sections:

1. Unpacking and inspecting the geotubes
2. Assembling the smaller grids with 14 geotubes
3. Placing the anchors
4. Staging of the sand for the pump
5. Placing the three grid sections with the smaller tubes
6. Placing the large tubes

Sections 1, 3, and 4 can start simultaneously. Section 3 cannot progress past the second combi until section 1 has completed the first small tube. Section 5 cannot start until section 3 is complete, section 4 is ready to pump, and one grid is ready from section 2. Section 6 cannot begin until section 5 is complete and section 4 is ready to pump.

6.2.1 Geotube Unpacking and Staging

The first section of the model begins when the materials arrive on site and are ready to unpack **(Figure 1).** The small and large tubes are unpacked, inspected, and staged for the next step in the process. The big tubes require a forklift and two laborers to unload, and the small tubes require two laborers. Two sets of laborers at a time can unload based on the workspace availability. This space could be modified in the future.

6.2.2 Small Tube Grid Assembly

The second section of the model, assembling the grids **(Figure 2),** can begin once the small tubes have been unpacked and inspected. The other materials are assumed to be available. Laborers using a forklift unroll the grid mat in the designated workspace. The small tubes are then unrolled, and the webbing is stitched in place. The tubes are tied to the webbing until all 14 that make up the grid are complete. Two cranes lift the completed grid and load it onto a barge for deployment.

6.2.3 Anchor Placement

The anchor placement does not have any prerequisites and should begin as soon as possible (**Figure 3**). Eleven 5-ton anchors are loaded onto the barge, moved into position using a GPS, and deployed. All the equipment required to accurately deploy the anchors is assumed to be on the barge. The anchors are deployed one at a time with the barge repositioning between each deployment. Once all the anchors are in place, the barge is free to load the grids.

6.2.4 Grated Sand Transport to Pump

The next section of the model, the preparation of the pump for filling the geotubes **(Figure 4),** can also start independently from the other sections of the model. However, the pump must be ready by the time the first grid is attached to the seafloor. The dump trucks are loaded with grated sand then moved to the dump site where a spotter directs where to dump. The bulldozer manages the sand into a stockpile. This project requires 14,300 cu.m of sand needing a conical stockpile radius of 24 m. However, all the sand does not need to be in place to begin pumping, and only enough sand to keep up with the demand at the filling end is required.

6.2.5 Placement of Small Tubes in a Grid

This section requires the anchors to be complete and the first grid to be ready for deployment **(Figure 5).** The grid will be loaded onto the barge and moved to site. Divers will ratchet one end to the anchors, and the barge will slowly move away as the grid sinks. The divers will attach the rest to the anchors, and then each tube will be filled using the land pump. The pump must be ready by the time the placement of the grid is complete. This process will repeat until all three grid sections are deployed and filled.

6.2.6 Placement of Big Tubes

To begin the last step, the placement of the big tubes **(Figure 6),** all grids must be filled, the pump must be ready, and the tubes all unpacked and inspected. The tubes will be loaded onto the barge, and the process will occur very similarly to that of emplacing the grids. Once the last tube is filled, the project is complete.

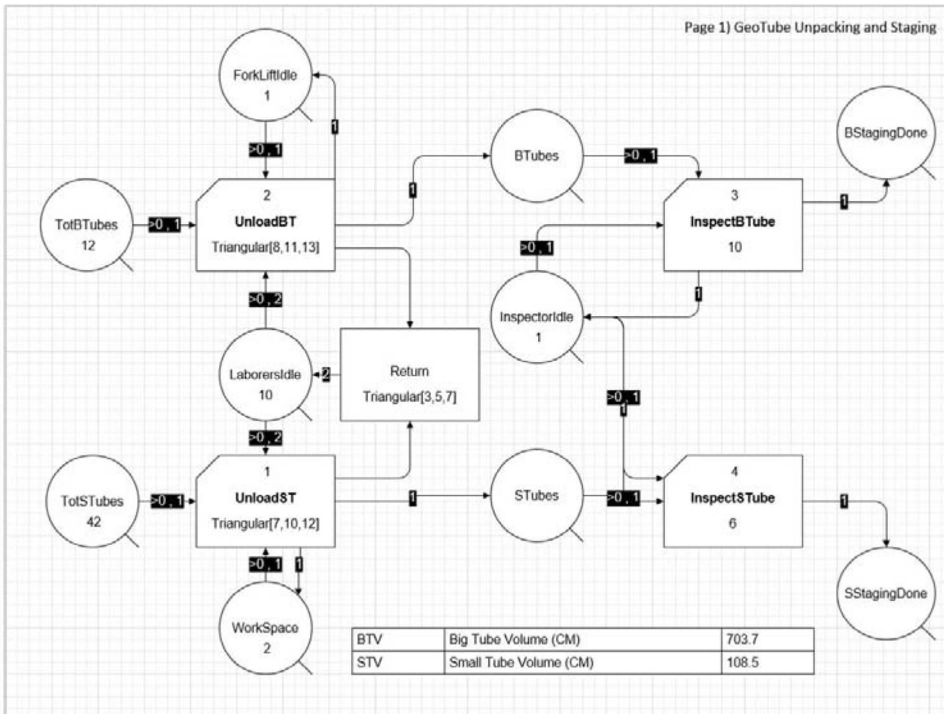

Figure 1: Geotube Unpacking and Staging

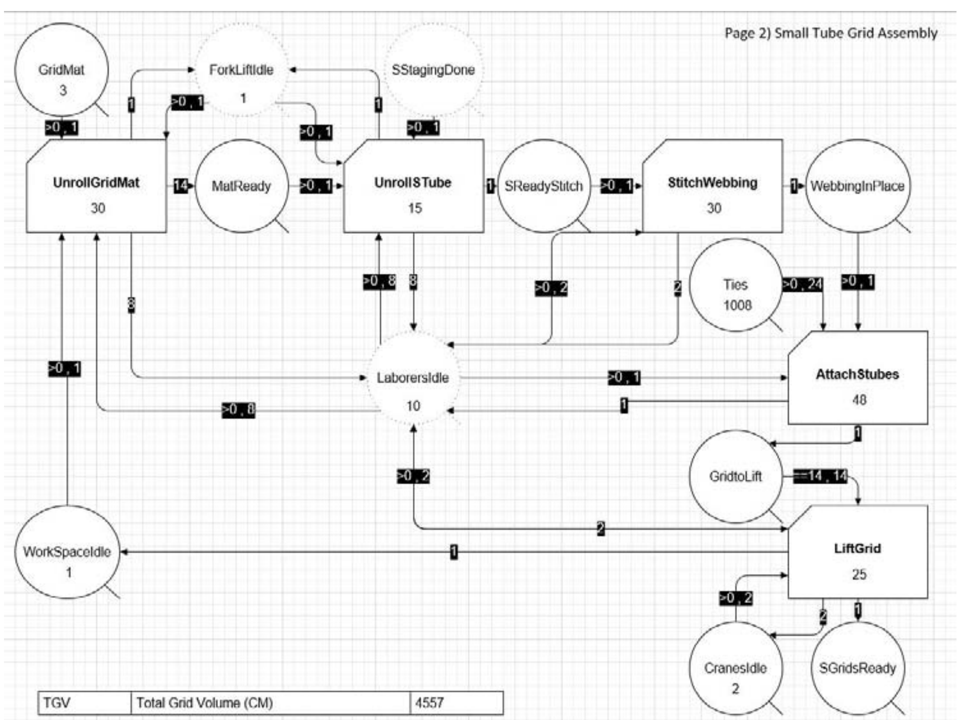

Figure 2: Small Tube Grid Assembly

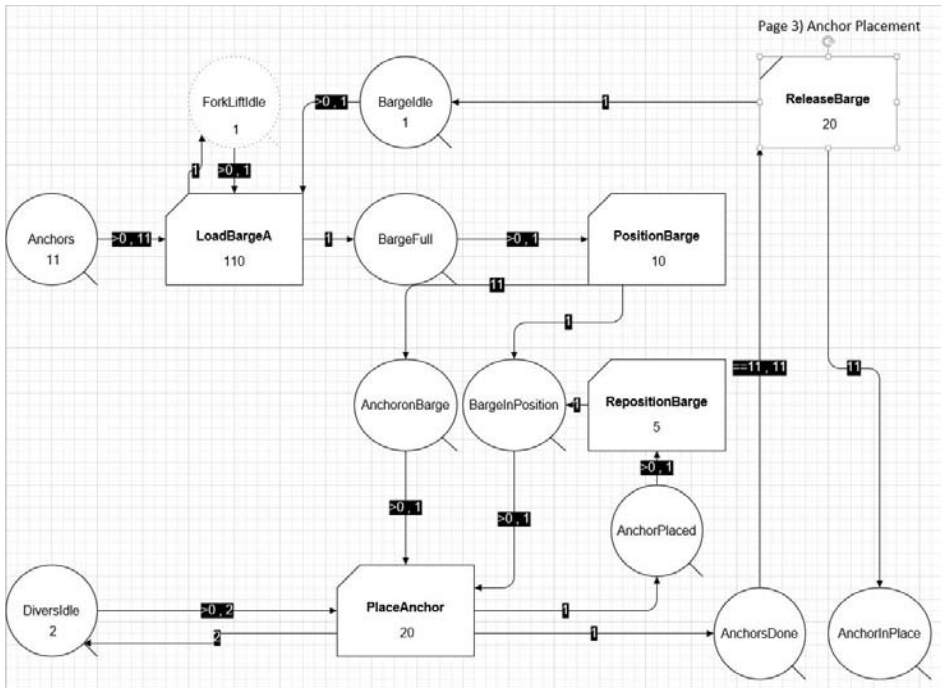

Figure 3: Anchor Placement

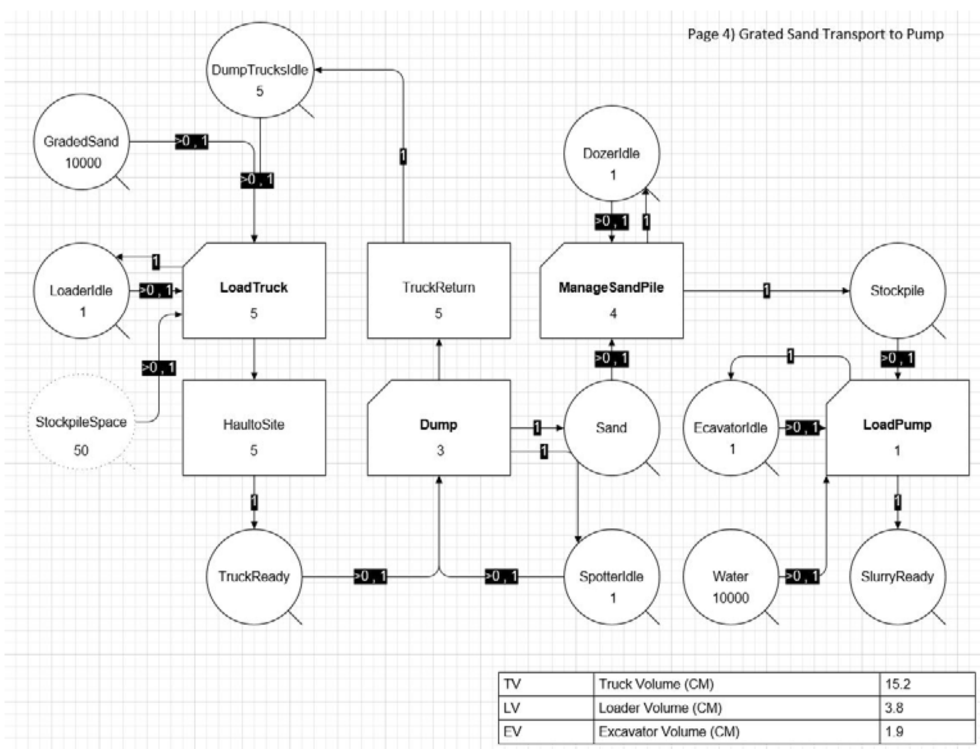

Figure 4: Grated Sand Transport to Pump

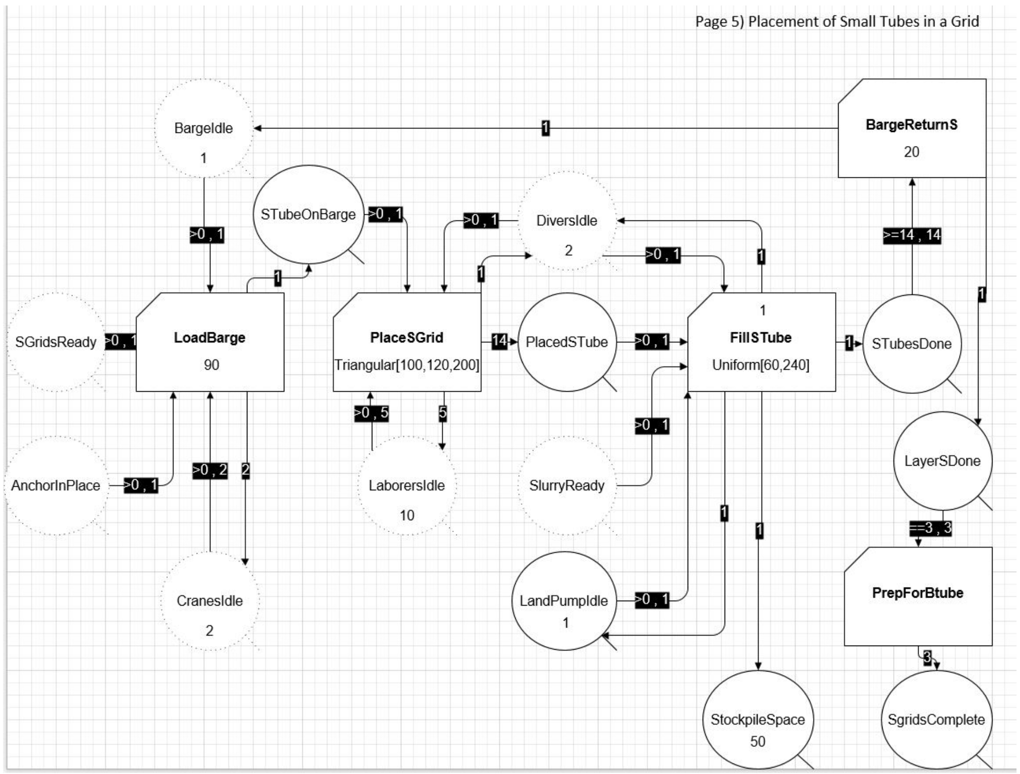

Figure 5: Placement of Small Tubes in a Grid

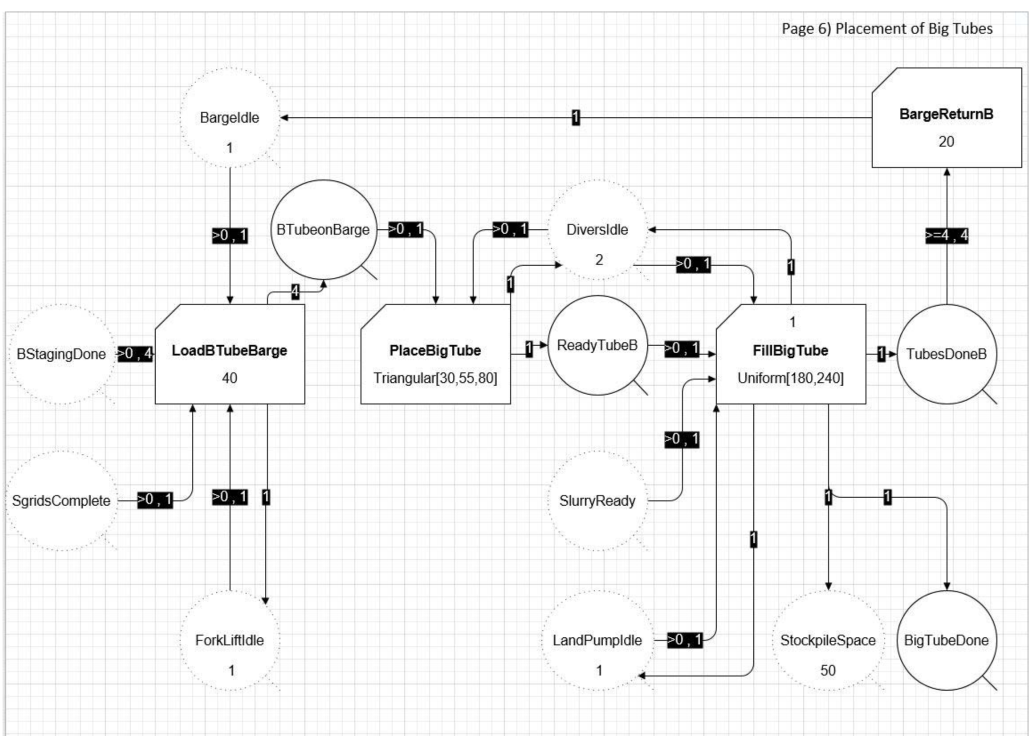

Figure 6: Placement of Big Tubes

7. RAD Method Results

The baseline model required 178 hours to prepare and install all 54 of geotextile tubes excluding break time and weather delays. Three runs with the same parameters varied the time by more or less than 5 hours, which is equivalent to more than four and a half 40-hour work weeks to emplace the tubes using the RAD method. The total cost of this project was $3.5M with $250k of improvements pending litigation. Using the base price, this project cost $288.46 with the CM geotube filled. The cost per hour for this project with the baseline model was $21,067.40/hour, using the total cost and excluding any design, shipping, or harbor closure time.

The ARI was collected for the divers, laborers, inspector, forklift, and dump trucks. It was not realistic to vary the number of resources for the barge, cranes, land pump, bulldozer, excavator, loader, and spotter because doing so would be unfeasible in cost and not noticeably change the PR. The ARI was calculated by summing the products of the above resources' average wait time in queues and their average count in the queues. This was an assumption that all wait queues weigh equally; alternately, the designer could assign suitable weights in the utility function. Each product was divided by the total time that the resource could be used. **Table 1** depicts the ARI for the baseline of the model.

Table 1: ARI of Baseline Model

	ARI (% time)
Divers	0.0115
Laborers	0.365
Inspector	0.477
Forklift	0.013
Dump Trucks	0.214
Average	0.216

The AWT was collected for the time when the big tubes, small tubes, and completed grids were in a queue waiting for the next step. **Table 2** depicts the AWT for the baseline model.

Table 2: AWT of Baseline Model

	AWT (hours)
Big Tubes	146.89
Small Tubes	12.87
Grids	35
Total	194.76

The ATT was collected only for the small tube grid placement and the big tube placement. The time started with the loading of the grids/tubes onto the barge and until the grid or tube was complete. **Table 3** depicts the ATT for the baseline model.

Table 3: ATT of Baseline Model

	ATT (hours)
Big Tubes	3.98
Grids/Small Tubes	39.96
Total	43.94

By dividing the ARI, AWT, and ATT into the production rate, the Utility Factor (UF) was 0.027. This UF appeared much lower than that of the Australia model, but the detail and complexity of the RAD model made comparing the utility factors between the models impractical. The UF would serve as the overall comparison used to optimize the RAD model where the highest UF was the best.

7.1. Modifications to the RAD Model Resource Quantities

According to **Table 1**, the divers had the least idle time, followed by the forklift. The number of divers in the water could not increase due to safety reasons. The resource quantities would be modified to increase the productivity rate and decrease the utility factor. The first modification (MOD 1) would increase the number of forklifts to two. The original simulation already showed that ARI was very low, so an option appeared available to increase the resource quantities. The second modification (MOD 2) would increase the number of laborers by six to sixteen, since sixteen was double the requirement for the task needing the most laborers. The third modification (MOD 3) would reduce the number of dump trucks to three. **Table 4** shows the modification component results, and **Table 5** shows the total results.

Modification 1, increasing forklifts, did slightly increase the PR, but decreased the UF significantly. The small tubes had much less wait time, but the increase in the idle time for the forklifts and the workers increased the ARI and reduced overall efficiency.

Table 4: Modification Results for ARI, AWT, and ATT

Resource	**Baseline**	**MOD 1**	**MOD 2**	**MOD 3**
ARI (% time)				
Divers	0.0115	0.011	0.012	0.011
Laborers	0.365	**1.19**	**0.439**	0.367
Inspector	0.477	0.46	0.475	0.474
Forklift	0.013	**0.057**	0.013	0.013
Dump Trucks	0.214	0.213	0.214	**0.075**
Average	0.216	**0.388**	0.231	**0.188**
AWT (hours)				
Big Tubes	146.89	142.62	146.78	147.47
Small Tubes	12.87	**7.07**	10.33	12.77
Grids	35	39.5	35.7	33.83
Total	194.76	185.2	192.76	194.07
ATT (hours)				
Big Tubes	3.98	4.03	3.93	3.87
Grids/Small Tubes	39.96	39.49	39.05	40.286
Total	43.94	43.52	42.99	44.16

Table 5: Summary of Model Results

		Australia	**United Kingdom / New Zealand**			
		Baseline	**Baseline**	**Mod1**	**Mod2**	**Mod3**
Total Volume (cu.m.)		69750	13000	13000	13000	13000
Total Hours		541	178.4	174.5	178.1	178
Cost $ in Millions		3.6	3.75	N/A	N/A	N/A
Production Rate (CM/hr)	PR	128.9	49.2	50.3	49.2	49.3
Ave Resource Idle (%time)	ARI	1	0.216	0.388	0.231	0.188
Ave Wait time at Queues (hr)	AWT	3.12	194.8	185.2	192.76	194.07
Ave Throughput Time (hr)	ATT	1.195	43.9	43.52	42.99	44.16
Utility Factor	UF	34.57247	0.026635	0.016084	0.025702	**0.030599**

Modification 2, increasing laborers, only impacted the wait time for time for the small tubes, increasing overall laborers' idle time and the forklift's idle time. The net change to the PR and UF was not significant.

Modification 3, reducing the dump trucks, had the best overall results by increasing the UF. The PR did not change, but the reduced idle time for the trucks in the sand-staging section of the model was significant. The best of all the attempted modifications, this modification illustrated that the best way to increase the UF for this model was to look at each section and to optimize them independently.

8. Conclusion

To improve this model, the sensitivity was increased to identify the times that each resource was needed. Deactivating a resource when it was first needed and releasing it as soon as it was no longer needed would more accurately represent the idleness of the resource. More importantly, identifying a reasonable pump rate to fill the grids and large tubes would allow for better modeling. The pump rates identified in the literature for the South Korea and Mexico models were not within the expected pump rates needed for the RAD method. The time given for filling the tubes was "1-4 hours," which was too broad to accurately model the filling of the geotubes. It was necessary to identify the actual pump rate to better model this task as it had the greatest variance in the COMBIs.

The fill-in-place method has the best accuracy but also the highest cost per cubic meter. The method that deploys tubes in a grid has the greatest number of cyclic actions and variables that can be optimized, but that also means there are more parts than human error. This method is also very sensitive to weather and can be stopped frequently for extended periods of time. The Australia Split Hull method is more efficient, but its inaccuracies in deployment make it infeasible to use at Kahului Harbor.

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Biography

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