USING CONSTRUCTION PROCESS SIMULATION TO ASSESS PRODUCTIVITY OF LAYING WATER MAINS IN HONG KONG

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ABSTRACT

Construction process simulation has become a general technique in managing design and construction processes in the western world. However, there is a paucity of records on its practical application in Hong Kong and in the Greater China. Thus, it still remains as a tool for generating academic papers within the academic arena.

In Hong Kong, there is a plan to upgrade 45% of the existing 7,700 km of water mains, giving a total of 3,000 km of aged water mains to be replaced in the next couples of years. In managing this sheer amount of construction works, studying its productivity is of prime importance in order to complete the works on time and within budget. This study has applied one of the simplest simulation tools, Web-CYCLONE, to assess the productivity and explore ways to optimize it. The study reveals that Web-CYCLONE is user-friendly in assessing productivity. However, it has a number of shortfalls. For example, in running two consecutive programs, the system needs to be refreshed to renew the interface and trace the charts and diagrams generated. Besides, Web-CYCLONE has the limitation of inability in identifying the critical path of a project and thus the floats cannot be considered. Web-CYCLONE is also difficult in modeling projects with complex resource involvement.

Keywords: water mains construction, construction process simulation, productivity

1. INTRODUCTION

In Hong Kong, the fresh water and salt water supply networks are around 7600 km in length, providing Hong Kong people with a steady and clear water services for decades. However, about 45% of these mains are already 30 years old and have started to aging. The cost and difficulties in their maintenance are foreseen to increase sharply. In view of the out-of-service risk of the considerable length of those aging water mains and reduce the capital costs of the replacement and rehabilitation works, the act of replacement and rehabilitation of the 3000m Hong Kong underground aged water mains has been carried out in stages to prevent from further deterioration of the water supply network since 2008. In fact, the government has put in around HK$ 218.1 billion to carry out the 15 years replacement and rehabilitation programme of water mains. This large public construction project investment has been carried out in stages since early 2008 and believed that it can give a maximized effective usage of the citizens' money by minimizing the unnecessary water supply and traffic disruptions during construction works. Also, this can prevent the social impacts of the foreseeable accidental leakages and burst from the aged water mains as much as possible.

Under such a massive restoration scheme, a small saving can lead to huge economic benefits. Hence, it is worthy to study the construction process using construction process simulation. Use of simulation technique has become popular in managing design process in the western world (Hossain and Chua 2009). However, its practical application in construction in Hong Kong and the Greater China is limited. This study aims to apply the construction process simulation technique to optimize productivity of water mains renewal scheme in Hong Kong. Based on several case studies of the water mains laying construction process, a repetitive operation cycle has been established. A simulation engine - Web CYCLONE is then employed to model the water mains laying process. The works aim to find out the productivity, idleness of resources as well as the condition of resources deployment. It also targets to highlight the difficulties and problems encountered during the construction process. As Hong Kong construction practitioners rarely use simulation tools in planning construction works, this study also helps promote the application of construction simulation by demonstrating how the tool works and the ways to find out the productivity and idleness of resources in a construction process.

2. CONSTRUCTION PROCESS SIMULATION

Simulation is carried out using a computer application tool, normally associated with a simulation periphery such as simulation language, graphical modeling interface, or their combinations to facilitate model development by translating the abstracted model into what the computer can recognize (Zhang et al., 2005). The operation of process simulation requires the following steps:

- Problem formulation: definition of the production cycle and what to test, analyze and determine.
- Data collection: collection of raw data to model the variability of the production process.
- Simulation modeling: codifying the production cycle, resources deployment, and the stochastic nature of activities using the specific simulation language.
- Verification: checking if the model is developed right.
- Validation: checking if the model is accurate for the purpose.
- Simulation experimentation: performing “what if” analysis.

CYCLONE, a discrete event simulation approach, has been used to analyze and design construction operations for over three decades. It is a well established simulation tool for studying construction productivity. The reason behind for not using the continuous approach was that the productivity value is just the variables change at discrete points of time but not the variable change continuously over time, while the discrete-event simulation technique provides an inexpensive way to test and evaluate different control strategies for operational systems (Odhabi et al., 1999). This technique has been proven to be effective for improving construction process planning (Halpin and Riggs, 1992; Zhang et al., 2005). Web CYCLONE, being a free ware available in the Internet developed by Purdue CEM Web-Cyclone Simulation Laboratory, is adopted for the study.

3. DEFINITION OF WATER MAINS LAYING CYCLE

The water mains laying procedure is worked out according to to the Manual of Main-laying Practice: Part 3 published by the Water Supplies Department of the Hong King Special Administrative Region on the Installation Method (Open Cut) Using Polyethylene Water Mains. The installation procedure is counter-checked using data collected and observed from three construction sites. The installation procedure is illustrated by a CPM network as shown in Figure 1.

As the study focuses on the laying of water mains, other auxiliary activities that do not fall into the cyclical operation are excluded from the simulation model such as the front-end works like application of excavation permit, site clearance underground cable detection, ground investigation, and the finishing-up works like sterilization of the pipes, service connection and hand-over. Some of these works are shown in the photos of Figure 2.

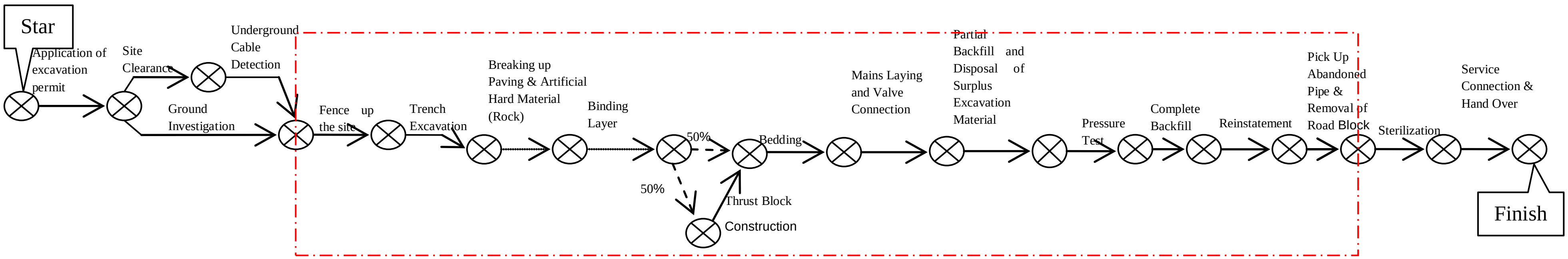

Figure 1: CPM of Water Mains Laying Cycle – Open Cut

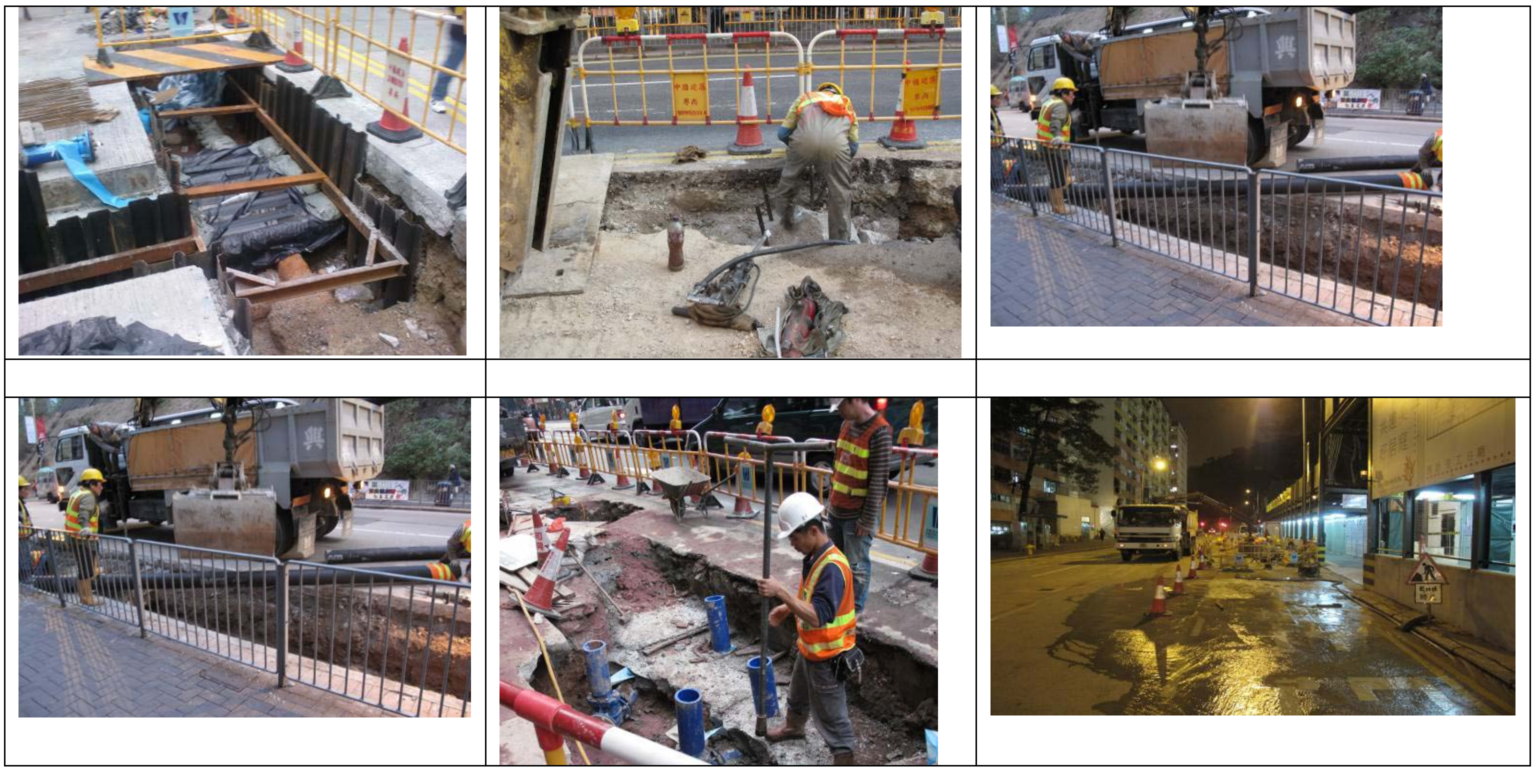

Figure 2: Photos showing some of the Pipe-laying Activities

4. SIMULATION MODEL

Employing the Web CYCLONE, two models are developed which consist of several sub-cycles with certain specific resources (plant and labor). First, the model of laying water mains without thrust block construction and the other is the model with thrust block construction. Thrust block is a reinforced concrete block applied at the turning angle of a pipeline to resist the longitudinal stresses formed at bends or closed ends of pressurized pipeline. The concrete thrust blocks are normally casted at bends of the water mains pipeline so that the full thrust can be withstood. In the water mains laying construction, the thrust block may not be necessary in some working order within the alignment if there is no bend or closed end at the section. Around 50% of the water mains working order being study is necessary to construct the thrust blocks. Therefore, two models are built. Figures 3 and 4 show the Web CYCLONE simulation models for water mains pipeline construction with and without thrust block construction.

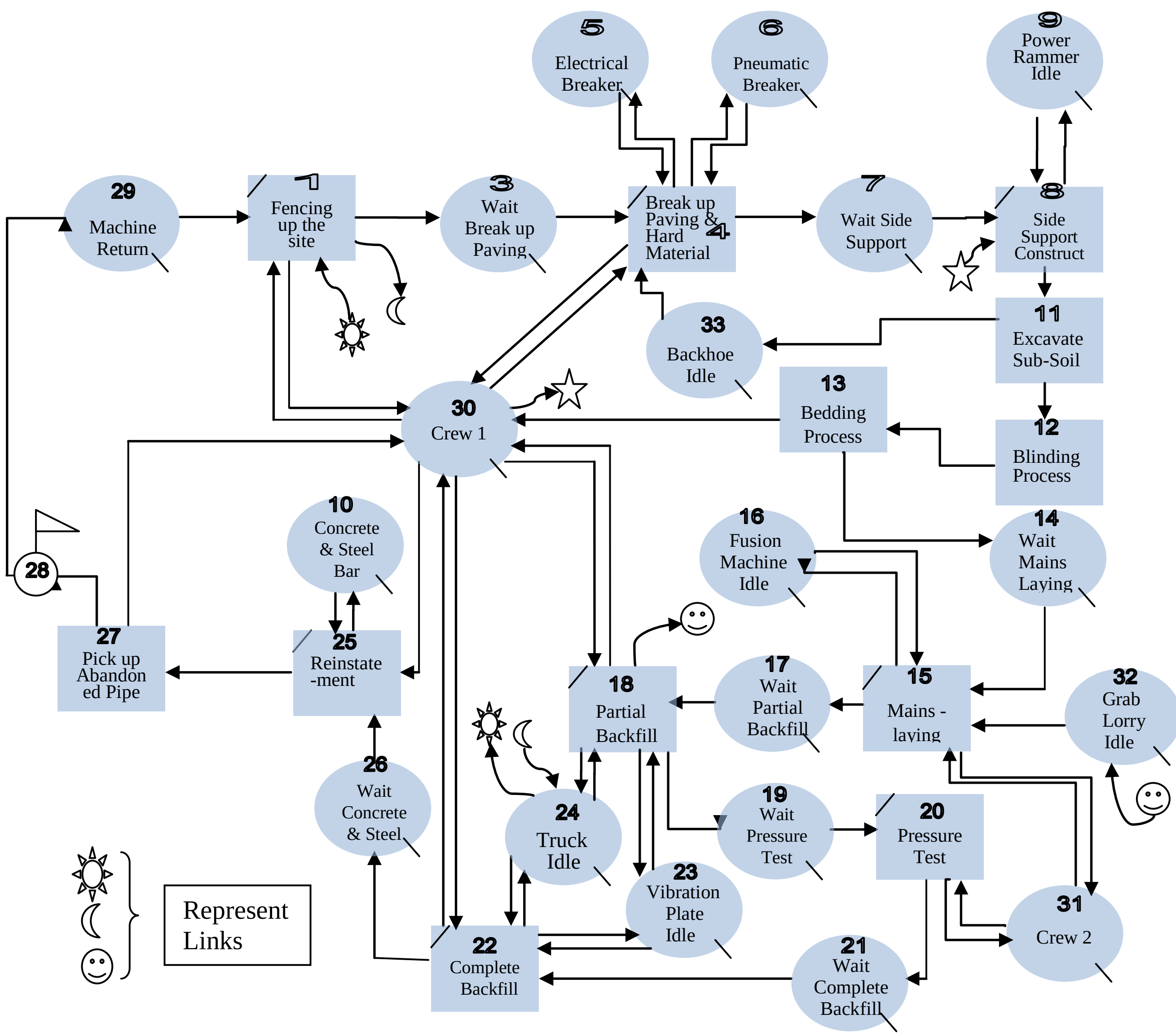

Figure 3: Web CYCLONE Model for Water Mains Laying without Thrust Block Construction

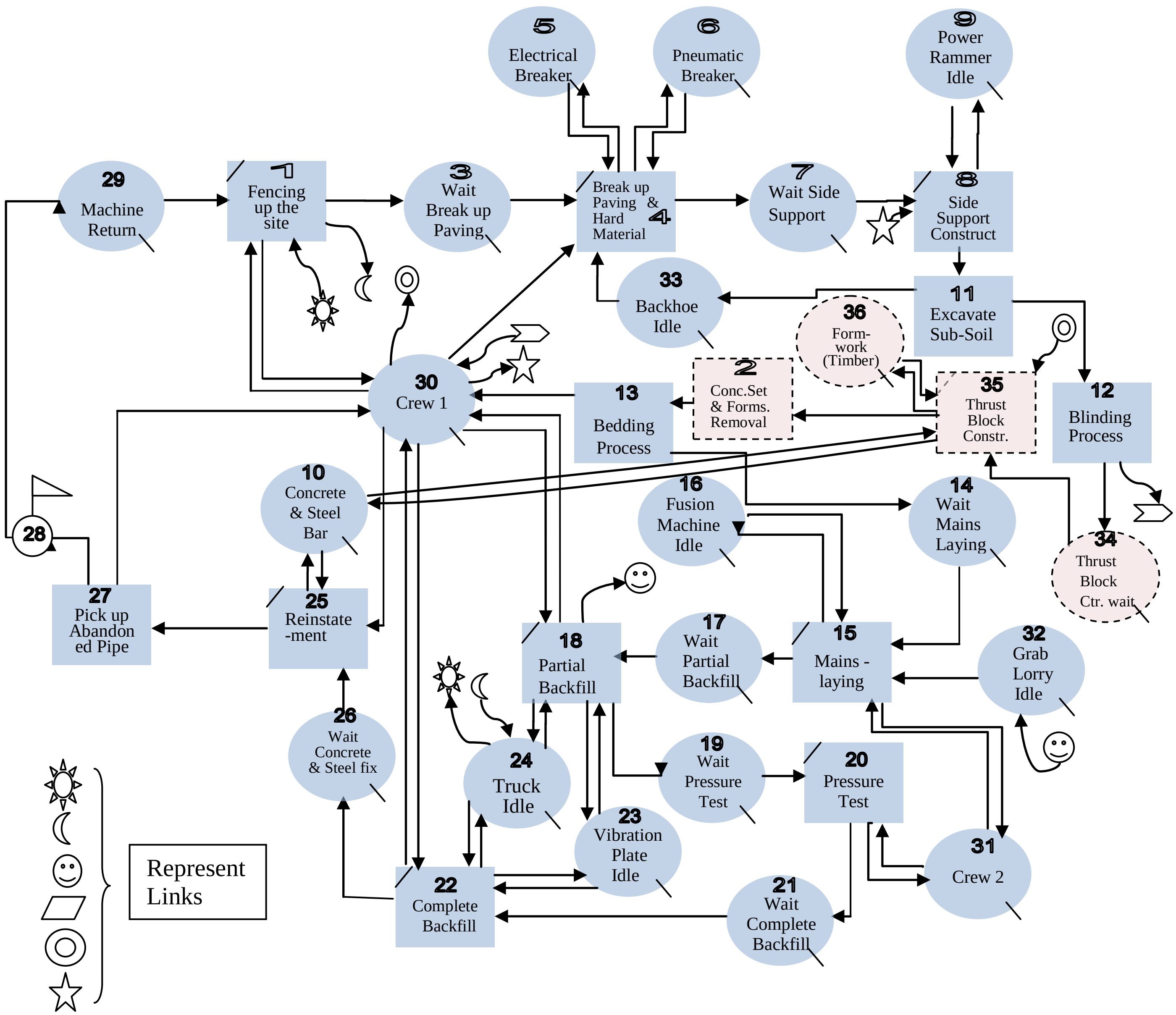

Figure 4: Web CYCLONE Model for Water Mains Laying with Thrust Block Construction

At the beginning, a section of the site of water mains laying would be fenced up as in COMBI (1). QUE (30) is Crew-1 and the truck at QUE (24) waiting for works. After fencing up, the surface of the site is ready to break up as shown in QUE (3). Then, trench excavation begins and the excavating activities are sub-divided into several smaller packages. They are “breaking up paving”- COMBI (4), “side support of the trench” - COMBI (8) as well as “excavating sub-soil” - COMBI (11). The electrical and pneumatic breaker at QUE (5) and (6) operate with the backhoe QUE (33) to break up the road paving as shown in COMBI (4). COMBI (4) also represents the breaking up of the rock or hard materials just below the concrete paving. Crew-1 at QUE (30) is waiting for works. After the paving and the rock/hard material have been broken up, the trench is ready to receive steel sheet piling as side supports as shown in QUE (7). Construction of the side supports is shown in COMBI (8) with the availability of Crew-1, power hammer and the backhoe. To construct the side supports of the trench, it requires a powered rammer to drive the sheet piles. The sheet piles and the power hammer are assumed to be available at QUE (9). The backhoe at QUE (33) would be available for nodes (4) till (11) and return to QUE (33) after excavation of sub-soil with the availability of Crew-1. Nodes (11) to (13) represent the activities of excavating sub-soil, blinding layer construction and the bedding construction of the trench with the availability of Crew-1. Then the grab lorry and fusion machine at QUE (32) and QUE (16) are ready prior to mains laying COMBI (15). Crew-2 in QUE (31) also helps in mains laying. After mains laying COMBI (15), partial backfill is ready to start in QUE (17). To carry out the partial backfill in COMBI (18), Crew-1 at QUE (30), the truck at QUE (24), the grab lorry at QUE (32) as well as the vibration plate at QUE (23) have to be available. The pressure test waits to be started at QUE (19) before complete backfill. Crew-2 at QUE (31) has to be available for the pressure test as shown in COMBI (20). After completion of pressure test, the trench is ready for complete backfill at QUE (21). Truck at QUE (24), the vibration plate at QUE (23) and Crew-1 at QUE (30) have to be ready prior to complete backfill at COMBI (22). For reinstatement at QUE (26), it can be started when concrete and steel bar at QUE (10) and Crew-1 at QUE (30) are available. After picking up the abandoned pipes at QUE (27), Crew-1 will return to the pool. Finally, the plant and labour will return and start laying another water mains section. Available resources are assumed as follows:

- One electrical breaker at QUE (5)
- Two pneumatic breaker at QUE (6)
- One Power Rammer at QUE (9)
- One fusion machine at QUE (16)
- One grab lorry at QUE (32)
- One vibration plate at QUE (23)
- One Truck at QUE (24)
- Two Backhoe at QUE (33)
- Two set of Concrete and steel bar are available at QUE (10)
- One general labor crew is available at QUE (30) and one mains layer crew is available at QUE (31)

To build up the duration distribution patterns of various work packages, data from ten completed water mains laying projects have been collected from the Water Services Department of the Hong Kong SAR government. These data were used to describe the probabilistic occurrence of duration for the simulation purposes.

5. SIMULATION RESULTS

After building up the CYCLONE networks for the water mains laying, the networks are transformed into programs codified in the CYCLONE language and run in the computer. The network is run for 10 cycles and 100 cycles for water mains laying with or without thrust block construction. The results are shown in Table 1 and Table 2. Information on duration of each activities is shown Table 3 and Table 4.

Water-mains laying without thrust block process		
PRODUCTIVITY INFORMATION		
Total Simulation Time Units	Cycle No.	Productivity (meter run per time unit)
46.9	10	0.213
412.0	100	0.243

Table 1: 10 and 100 Cycles of Water Mains Installation without Thrust Block Construction

Water-mains laying with thrust block process		
PRODUCTIVITY INFORMATION		
Total Simulation Time Units	Cycle No.	Productivity (meter run per time unit)
13.8	10	0.725
98.6	100	1.014

Table 2: 10 and 100 Cycles of Water Mains Installation with Thrust Block Construction

Water-mains Laying without Thrust Block Construction						
CYCLONE ACTIVE ELEMENTS STATISTICS INFORMATION						
Activity Type	No.	Name	Access Counts	Average Duration	Maximum Duration	Minimum Duration
COMBI	1	Fencing up the site	99	0.2	0.2	0.2
COMBI	4	Break up Paving & Hard Materials	100	1.0	1.0	0.9
COMBI	8	Side Support Construction	100	0.2	0.2	0.2
NORMAL	11	Excavating Sub Soil	100	0.7	0.8	0.5
NORMAL	12	Blinding	100	0.5	2.6	0.0
NORMAL	13	Bedding	100	0.5	2.6	0.0
COMBI	15	Mains Laying & Valve Connection	101	0.4	0.5	0.3
COMBI	18	Partial Backfill	101	0.3	0.4	0.2
COMBI	20	Pressure Test	102	0.2	0.2	0.2
COMBI	22	Complete Backfill	103	0.3	0.5	0.1
COMBI	25	Reinstatement	100	0.4	0.5	0.3
NORMAL	27	Pick up Abandoned Pipe & Removal of Road Block	100	0.1	0.2	0.1

Table 3 – Duration Information from CYCLONE Simulation without Thrust Block Construction

Water-mains Laying with Thrust Block Construction						
CYCLONE ACTIVE ELEMENTS STATISTICS INFORMATION						
Activity Type	No.	Name	Access Counts	Average Duration	Maximum Duration	Minimum Duration
COMBI	1	Fencing up the site	99	0.2	0.2	0.2
NORMAL	2	Concrete Hardened & Formwork Removal	73	0.5	2.2	0.0
COMBI	4	Break up Paving & Hard Materials	74	1.0	1.0	0.9
COMBI	8	Side Support Construction	74	0.2	0.2	0.2
NORMAL	11	Excavating Sub Soil	73	0.7	0.8	0.5
NORMAL	12	Blinding	72	0.6	2.3	0.0
NORMAL	13	Bedding	144	0.5	2.6	0.0
COMBI	15	Mains Laying & Valve Connection	145	0.4	0.5	0.3
COMBI	18	Partial Backfill	98	0.3	0.4	0.2
COMBI	20	Pressure Test	99	0.2	0.2	0.2
COMBI	22	Complete Backfill	100	0.3	0.5	0.1
COMBI	25	Reinstatement	100	0.4	0.5	0.3
NORMAL	27	Pick up Abandoned Pipe & Removal of Road Block	100	0.1	0.2	0.1
COMBI	35	Thrust Block Construction	73	0.2	0.4	0.1

Table 4 – Duration Information from CYCLONE Simulation with Thrust Block Construction

The idling times of the various resources for the two models are shown in Figure 5. It is obvious that for the one with thrust block construction, the idling times of resources are much less than those without thrust block construction, which explains the difference in productivity; i.e. 0.213 to 0.243 meter run per time unit for water-mains laying without thrust block and 0.725 to 1.014 meter run per time unit for the one with thrust block.

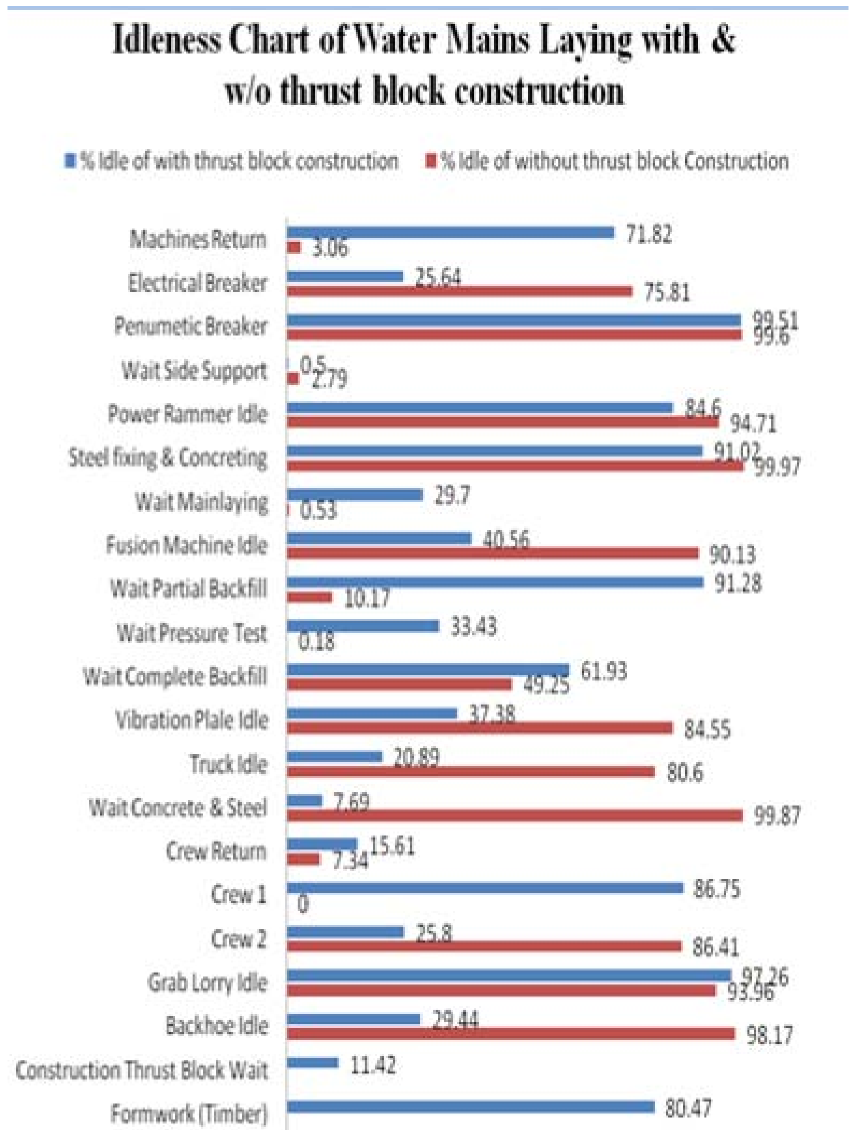

Figure 5: Idling Times of Various Resources for Water Mains Laying with and without Thrust Block Construction

6. DISCUSSION

6.1 Productivity

Looking at the simulation results of 100 cycles, it can be observed that the productivity of water mains laying without thrust block construction (0.213 to 0.243 meter run per time unit) is relatively lower than those with thrust block construction (0.725 to 1.014 meter run per time unit). Further, the idling time of resources in water mains laying without thrust block construction are generally higher and thus the production costs are higher. In order to achieve a higher productivity, stricter supervision on pipe laying in the simpler water mains laying project is recommended, especially in the working stages of break-up of paving and excavation which take the longest duration.

6.2 Idling time of machine

The idleness times of electrical breakers and pneumatic breakers are high compared to the others. The percentages of idleness for Crew-1 and the grab lorry are high as well. These high idleness values imply the construction works have not been properly coordinated and resulted in wastage. The waiting time for ‘wait concrete & steel’ and ‘steel fixing & concreting’ at the water mains construction with thrust block installation is long as these activities need to “wait” for setting of concrete. Hence, the use of quick setting cement/concrete can reduce the waiting time and thus improve the productivity.

The above example has demonstrated that Web CYCLONE is a user-friendly tool in finding out the productivity of construction works. It simplifies the simulation modeling process, making it accessible to construction practitioners with limited simulation background. It can highlight the efficient and inefficient elements of a construction process and hence facilitate derivation of improvement measures.

7. CONCLUSION

With the advent of simulation methods in construction, simple networking concepts were introduced as a modeling framework for studying construction operations. In this study, Web CYCLONE is used to evaluate the productivity of the water main laying process, which has shown to be a user-friendly tool in finding out the productivity of construction works. Web CYCLONE simplifies the simulation modeling process and makes it accessible to construction practitioners with limited simulation background.

The simulation results show that there is a big difference in productivity of water mains laying with and without thrust blocks due to the high idling time of resources for those without thrust block construction resulted from the poor supervision of work, incorrect manning level and resource deployment. This is the first time ever applying construction simulation to study productivity of the water mains laying process in Hong Kong and the findings are astonishing. It shows that the use of construction simulation can highlight the inefficient parts of construction planning and facilitate productivity improvement in the construction industry of Hong Kong.

However, Web CYCLONE is incapable of running two consecutive different scripts continuously, it requires user to “refresh” the window before the second script is “run” so that the interface can be renewed. Besides, Web CYCLONE is just the evaluator but not a solution generator. The CYCLONE network is also difficult to identify the critical path of a project. With the absence of late time information (allowable activity delay float), the critical path of a construction process is difficult to explore. Furthermore, plenty of time is needed to differentiate the multiple types of CYCLONE modelling elements, e.g. NORMAL, COMBI…etc, as well as arrangement of entity flows. This tool is also difficult to model complicated resource involvement (Zhang and Tam, 2002).

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