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Article

Productivity Management of Road Construction in Thailand by EZStrobe Simulation System—Case Study: 0.15 m. Thick Subbase Course Construction

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Abstract. This research's objectives were to conduct a work study of subbase course of road construction and implement productivity analysis with EZStrobe simulation system. The study had divided construction process into 3 parts. Each part of the process was simulated with EZStrobe to find optimum construction team members with minimum unit cost. These optimum team members were used in simulation model of each part to determine basic time with 95% confident interval and 5% limit of error. Then, the standard time and productivity of each construction team was calculated in various units; production per hour (cu.m./hr., sq.m./hr.), daily production (cu.m./day, sq.m./day, m. of road/day), and number of hour required per section of subbase course construction (200 m. in length). After that, the overall process simulation model including Part1 to Part3 was created, representing for all 26 sections of subbase course construction. The analysis results showed that optimum team combination of Team1, Team2 and Team3 for the minimum unit cost of subbase construction was 2-1-2; and for the minimum duration of construction was 3-2-3. The outcomes of this research pointed out that, with EZStrobe simulation system, the productivity management could be done effectively by conducting work study at project site and simulating for alternative resources management plan to determine for optimum construction teams according to the desired project goals.

Keywords: EZStrobe, stroboscope, construction process simulation, productivity, resources management, road construction.

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1. Introduction

In construction industry, especially in heavy construction project, there is a need for various types of machineries and equipment which normally cost to contractor highly [1]. Good resources management at the work site will yield higher productivity [2] and consequently the profit margin of the project.

Successful contractors usually set the priority in productivity management. Some of them use financial incentive plan[3–5], while others utilize various methods of productivity analysis and management, so that their work could be done faster with lower cost [6, 7]. Many techniques had been introduced to construction industry for these purposes such as construction planning and scheduling [8], cost control and forecasting, and also work study techniques [9].

More than four decades, work study had been introduced to construction industry in USA [10] and the methods and tools have been continuously developed including construction process simulation. Many simulation systems were used for construction work study e.g. CYCLONE [11], Visual SimNet [12], and more advanced one as EZStrobe [13] which was designed to use simple interfaces as Microsoft Visio (© Microsoft Inc.) in creating a simulation model and transition to more advance tools STROBOSCOPE [14].

Damrianant and Wakefield [15] had studied PetriNet-Based methodology in construction-process simulation model and found it could be effectively use in process modelling with stochastic approach.

Matinez and Ioannou [16] presented the STROBOSCOPE as a programming language which could create realistic model for construction process and models that can make utilization, consumption, and production of resources stochastic; perform dynamic resource allocations; characterize resources created at runtime by combining other resources; and make dynamic decisions regarding the sequence of operations..

Ioannou and Matinez [17] had shown refined simulation models for the earth moving operations involved in the construction of a dam to illustrate the ease and effectiveness of modeling complex construction processes by using STROBOSCOPE.

Jiradamkerng [18] had applied Visual Simnet to study and analyze for basic times, standard times, and productivity of road construction in Thailand. The results showed that this discrete, stochastic simulation model could well represent road construction processes.

Jiradamkerng [19] studied and determined productivity of precast concrete slab installation work in Thailand by EZStrobe simulation system and found that this system was very effective, flexible, and user-friendly.

The above research works had shown that simulation models could be effectively applied for construction processes study and help constructors improving their productivity management by carefully simulate alternatives of construction processes and also resources planning.

2. Objectives and Scope of Work

The objectives of this research were to conduct work study of subbase course construction for rural road project in Thailand and implement productivity analysis with EZStrobe simulation system. The study had divided construction process into 3 parts: (a) subbase material transportation, (b) mixing at work site, and (c) compacting. Each part of the process was simulated with EZStrobe to find optimum construction team members with minimum unit cost, and then all parts of construction were combined into the whole process simulation model to determine optimum combination of teams from each part. The results of study would reveal better resources management at construction site to obtain higher productivity with lower unit cost of road construction.

3. Method and Results

This research work was done after Jiradamkerng [18] by adopting time study data from their earlier works. The standard rural road construction was normally used in Thailand in rural area. Construction works starting from clearing and grubbing work to set the route of constructing road and right of way, and next, compacted embankment course, subbase course, base course and finally wearing course or pavement. This study was done only in subbase course construction according to the available data.

The subbase course construction in this study was divided into 3 parts as mentioned above. Each part had details as follows:

Part1, Subbase material transportation, starting from an excavator at the borrow pit loaded subbase material into the trucks, which will transport it to construction site and dump along the route. The borrow pit was where constructor could get required material, in this study, it was located 12 kilometers away from construction site. So, the researcher had to plan for optimum team members as the optimum number of trucks to an excavator to keep them working with minimum delay time.

Part2, Subbase material mixing at site, was done to improve moisture content of the material to be the optimum value for next part compacting. In this part, at least one motor grader and one water-spraying truck were required to work together and optimum number of team members also had to be determined.

Part3, Compacting subbase course, was done by motor grader, pneumatic rollers compactor, and tandem vibratory rollers compactor, starting from all of them working together in sequence respectively. After the subbase course was well formed, the motor grader stopped and the 2 compactors would continue their compacting work for the surface finishing of subbase course, and finally, only tandem vibratory rollers would compact the course to meet required density.

Table 1. The main components of EZStrobe.

Elements	Function	Parameter	Description
Queue	Holds idle resource until used	1)Que name, 2)Number of Resources	
Combi	Constrained activity that can start whenever required resources are available	1)Combi name, 2)Probability distribution density function	
Normal	An activity that is not constrained and that can start whenever a preceding activity is complete	1)Normal name, 2)Probability distribution density function	
Fork	A probabilistic element to randomly select the path to follow	N/A	
Link	Connects different activities and queues	1)Condition necessary for the successor activity to start, 2)Number of resources to be consumed	
Fusion Queue	Breaks up a complex model into several pages, is assumed to be the same as the ordinary queue the are named after	N/A	

3.1. Determination of Optimum Construction Team Members for Each Part of Construction Process

The researcher had created simulation models for each part of subbase course construction by EZStrobe simulation system [13]. The main components of EZStrobe were the Queue, Combi, Normal, Fork, and Link elements. These components had their own function, parameter, and description as shown in Table 1.

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These elements were used to draw Activity Cycle Diagrams (ACDs) for representing any construction operation or process for simulation.

Part1 of construction process, subbase material transportation, could be simply illustrated in Fig. 1, starting from an excavator loaded subbase material into a truck at borrow-pit until it was full. The truck travelled to construction site, waited till dumping space was free, then dumped the material, and returned to borrow-pit waiting for next loading.

The simulation model of this Part1 was drawn by using Combi and Normal component in EZStrobe ACDs, which contained probability distribution functions of time durations (the time data of each activity had to be tested with statistic software package for the best fitted probability distribution function) as shown in Fig. 2.

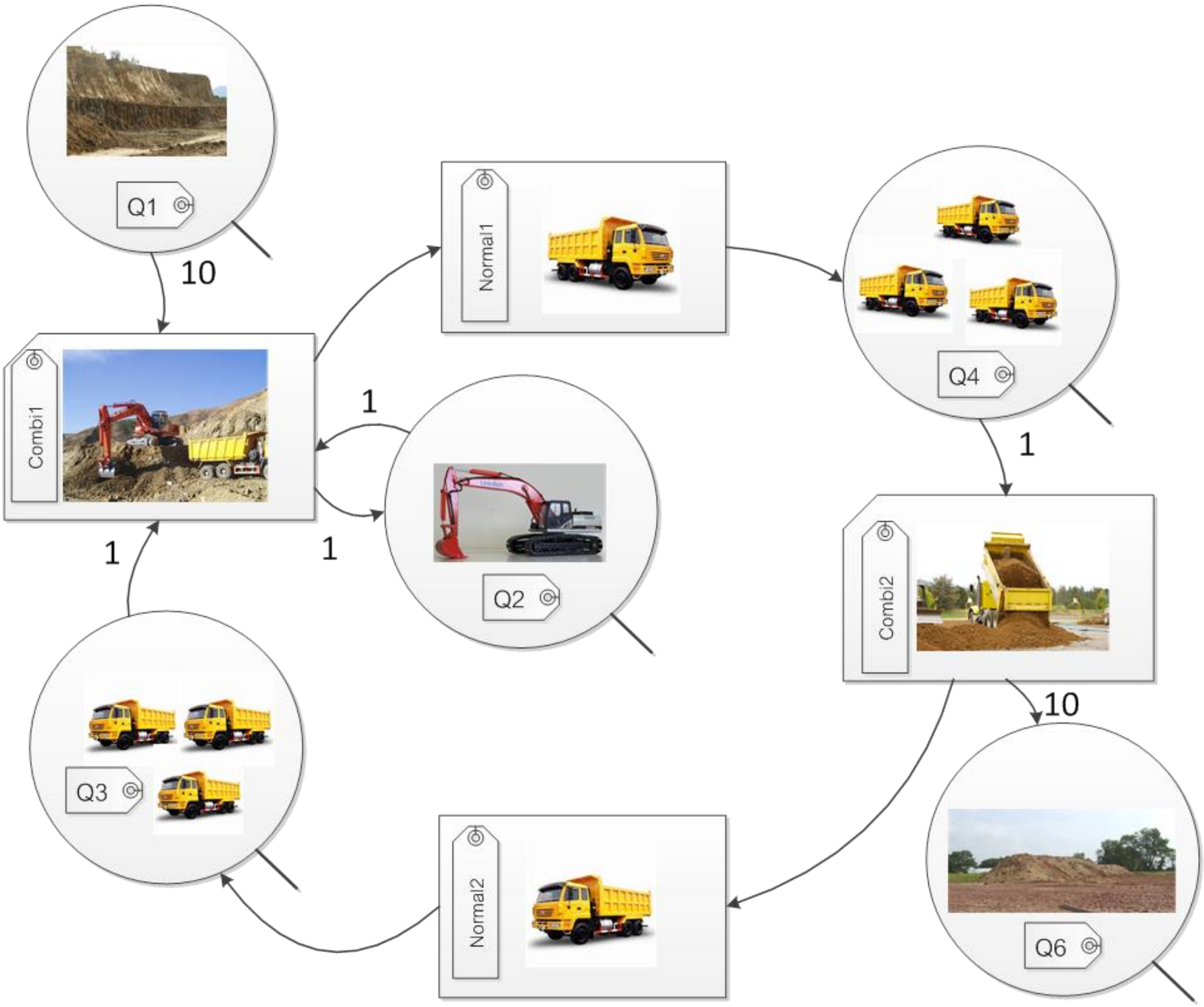

Fig. 1. Simple illustration showing subbase material transportation.

The required results from running the model could be reported by adding boxes of "Parameter" and "Result" as shown in the top right of Fig. 2. In the "Parameter" boxes, the number of excavator and truck were represented by variable "nExcvtr" and "nTruck" which had initial number of 1 and 7, cost per hour of excavator and truck (including operators) were 2,000 Baht and 1,000 Baht respectively.

For the "Result" box, we could enter calculation formulas for the results required; in this part, "UnitCost" was cost per cu.m. of transported material (Baht/cu.m.). We could change the numbers in Parameter box to see what-if scenarios for optimization of team members which would yield for the minimum unit cost.

UnitCost	Cost per cu.m. of transported subbase material	((nExcvtr*cphExcvtr+nTruck*cphTruck)*SimTime/(60*60))/795

nExcvtr	Number of Excavator	1
nTruck	Number of 15 cu.m. Truck	7
cphExcvtr	Cost per hour of Excavator	2000
cphTruck	Cost per hour of Truck	1000

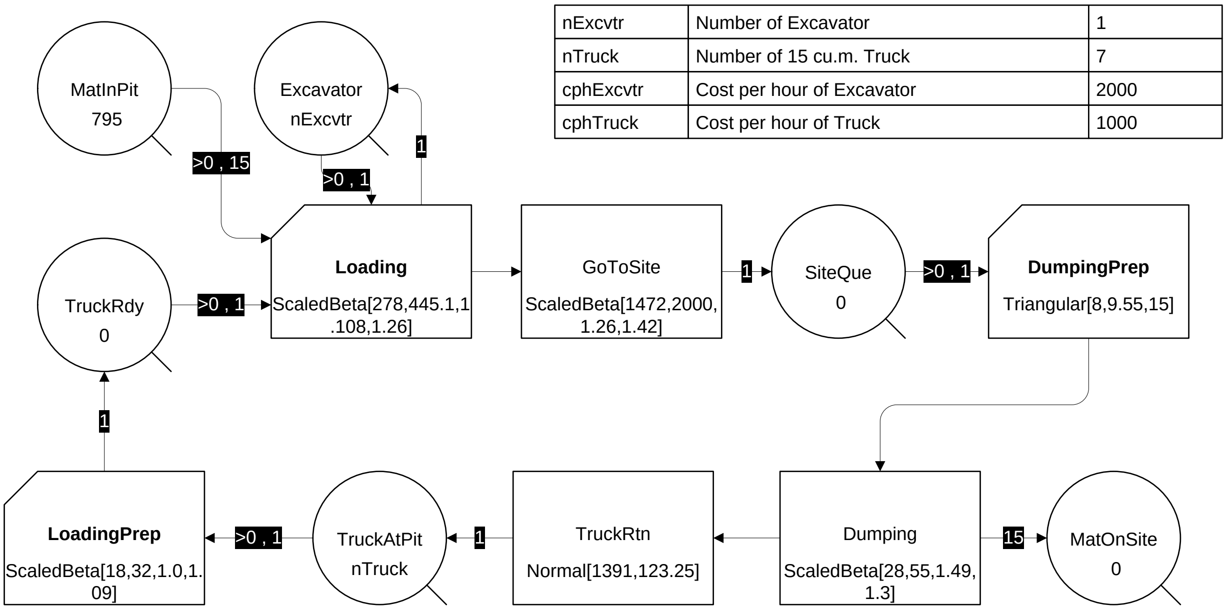

Fig. 2. EZStrobe ACDs showing Part1: Subbase material transportation.

From Fig. 2, the parameters in the model were retrieved from case study project; 4-lane road construction (each lane 3.25 meters wide), with 1.5 meters shoulder on both sides that made overall road width of 16 meters, and the total length of road was 5200 meters. The model represented transportation work of 795cu.m. subbase material which calculated from the 16 meters wide with one section of 200 meters in length (totally 26 sections to 5200meters) and 0.15 meters thick.

Table 2. The optimum number of truck in Part1: Subbase material transportation.

Team Member		Cost per cu.m.(theoritical)
Number of Excavator	Number of 15-cu.m. Truck	(Baht/cu.m.)
1	3	114.66
1	4	105.19
1	5	99.78
1	6	95.24
1	7	94.78
1	8	94.01
1	9	94.45
1	10	97.81
1	11	101.13

By changing number of truck from 3 to 11, the simulation results in Table 2 showed that the minimum unit cost came with the optimum number of 8 trucks working with an excavator. This optimum team would be consecutively applied in simulation model for next step productivity analysis.

In the same way, the optimum team members for Part2 (Subbase material mixing at site), and Part3 (Compacting subbase course) of construction processes were determined by simulation model in Fig. 3 and Fig. 4.

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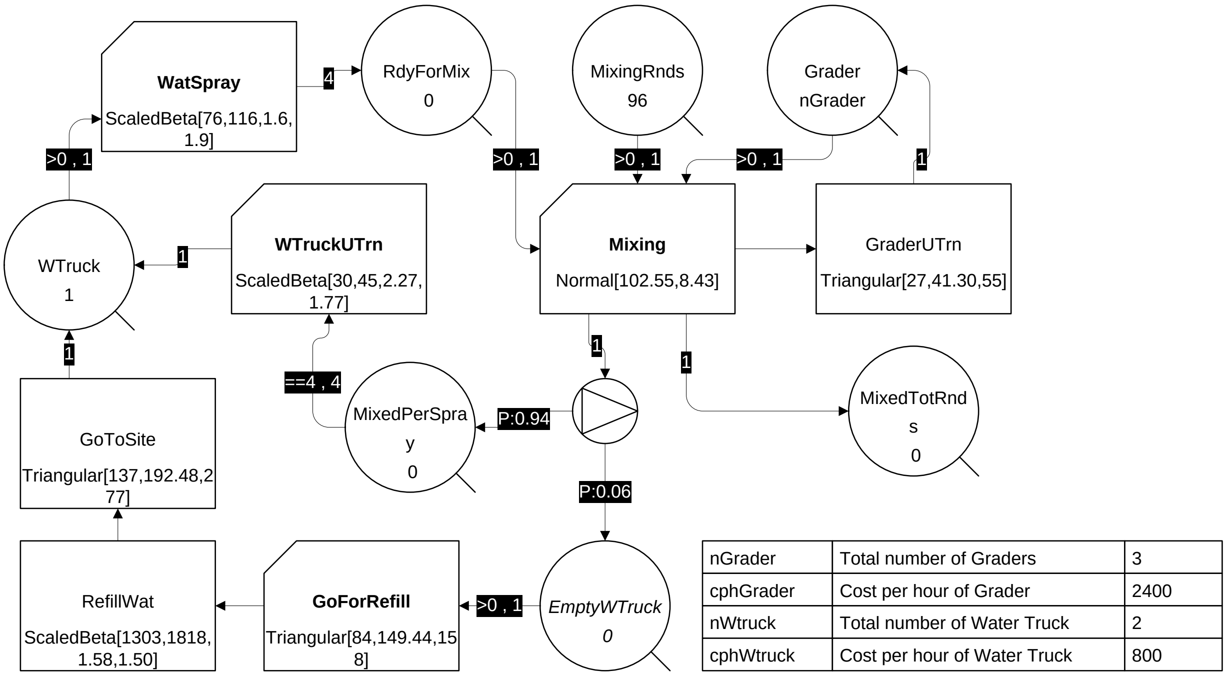


nGrader	Total number of Graders	3
cphGrader	Cost per hour of Grader	2400
nWtruck	Total number of Water Truck	2
cphWtruck	Cost per hour of Water Truck	800

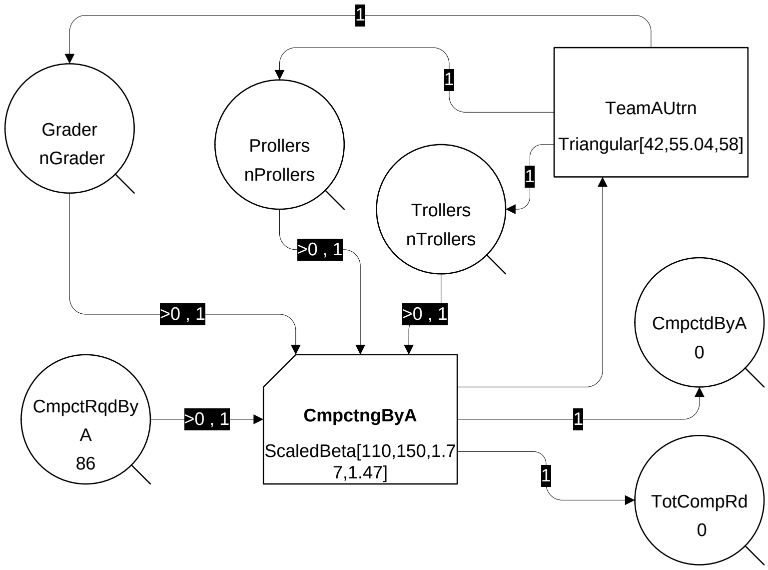
BasicTime	Basic Time(Hours) of Material mixing work for 0.15m. Subbase (3200 sq.m.)	SimTime/3600
UCmixing	Cost per sq.m. of Material Mixing Work for 0.15 m.Subbase	((SimTime/3600)*(nGrader*cphGrader+nWtruck*cphWtruck))/3200

Fig. 3. EZStrobe ACDs showing Part2: Subbase material mixing at site.

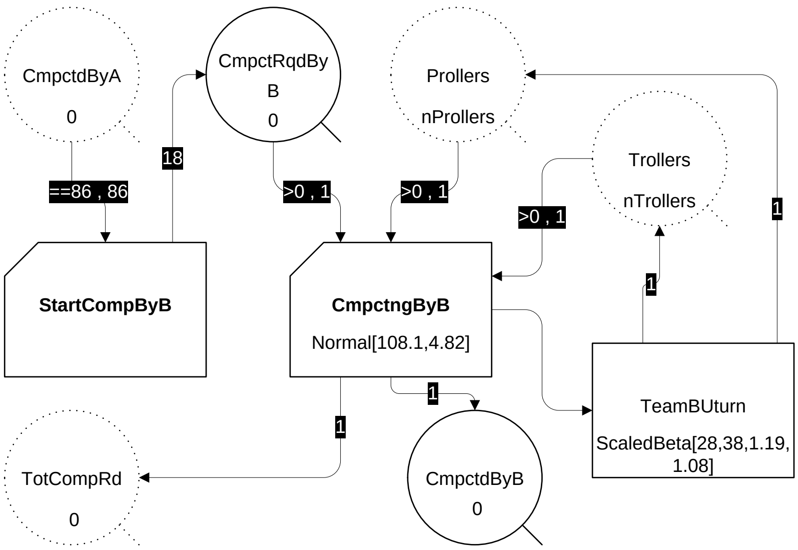
The simulation model in Fig. 4, showing Part3: Compacting subbase course, had been divided in 3 phases according to heavy equipment used as shown in Fig. 5. Phase1, in Fig. 4(a), compacting work was done by team of Motor Grader, Pneumatic Rollers and Tandem Vibratory Rollers, after that Phase2, in Fig. 4(b), of compacting work was carried out with the 2 types of Rollers, then final compacting in Phase3, in Fig. 4(c), would be finished by Tandem Vibratory Rollers only. Number of rounds for each compacting phases were collected from work site of the sample project.

It should be noted that model of Part3 is more complex than the earlier 2 parts, so it was divided into 3 pages connecting with few couples of “Fusion Queue” with table of Parameter and Result in Fig. 4(d).

The results from running simulation models of Part2 (Fig. 3) and Part3 (Fig. 4) showed optimum construction team members in Table 3 and Table 4 respectively. For Part2, it was found that the optimum team included 2 Motor Graders and 1 Water Truck, and the optimum team for Part3 consisted of 1 Motor Grader, 1 Pneumatic Rollers and 1 Tandem Vibratory Rollers.

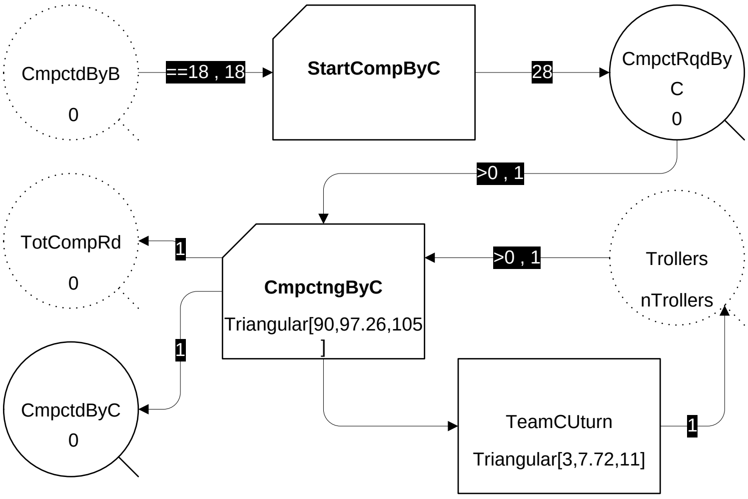


(a) Part3-Phase 1 : Compacting work by Grader, Pneumatic Rollers and Tandem Vibratory Rollers



(b) Part3-Phase 2 : Compacting work by Pneumatic Rollers and Tandem Vibratory Rollers

Fig. 4. (a),(b). EZStrobe ACDs showing Part3: Compacting subbase course.



(c) Part3-Phase 3 : Compacting work by Tandem Vibratory Rollers only

Parameter

nGrader	Total number of Motor Grader	1
nProllers	Total number of Pneumatic Rollers	1
nTrollers	Total number of Tandem Vibratory Rollers	2
cphGrader	Cost per hour of Grader(Baht)	2400
cphProllers	Cost per hour of Pnuematic Rollers(Baht)	800
cphTrollers	Cost per hour of Tandem Vibratory Rollers(Baht)	1000

Result

BasicTime	Basic time for the 0.15m. Subbase Compacting(3200 sq.m.),Hours	SimTime/3600
UnitCost	Cost per sq.m. of 0.15m. Subbase Compacting, Baht/sq.m.	((SimTime/ 3600)*(nGrader*cphGrader+nProllers*cphProllers+nTrollers*cphTrollers))/ 3200

(d)

Fig. 4. (c), (d) EZStrobe ACDs showing Part3: Compacting subbase course.

Motor Grader Pneumatic Rollers Tandem Vibratory Rollers

Fig. 5. Equipment working in 3 phases of Part3: Compacting subbase course.

Table 3. The optimum number of Equipment in Part2: Subbase material mixing at site.

Team Member		Cost per cu.m.(theoritical)
Number of Motor Grader	Number of WaterTruck	(Baht/cu.m.)
1	1	5.00
2	1	4.83
3	1	6.62
2	2	6.90
3	2	6.72

Table 4. The optimum number of Equipment in Part3: Compacting subbase course.

Team Member			Cost per cu.m.(theoritical)
Number of Motor Grader	Number of Pneumatic Rollers	Number of Tandem Vibratory Rollers	(Baht/cu.m.)
1	1	1	7.75
2	1	1	12.24
1	2	1	9.18
1	1	2	8.93

3.2. Preparation of Basic Time and Productivity of Subbase Course Construction

The above determined optimum team members yield minimum unit cost for each part of subbase course construction and was further used in deriving basic time, standard time and productivity of each part.

$$N = \left[\frac{\frac{k}{s} \times \sqrt{n' \Sigma x_i^2 - \left(\Sigma x_i \right)^2}}{\Sigma x_i} \right]^2 \quad (1)$$

This could be done by running simulation model of each part (Fig. 2, Fig. 3 and Fig. 4) with the optimum number of team member. According to requirement of 95% confident interval and 5% limit of error for the basic time [20], each model had been run for 30 times and the results were checked with equation (1), provided that N was Required number of samples (must equal or less than n'), n' was actual number of sample (30), and k was the standard score from normal curve for 95% confidence (1.96), s was limit of error +/-5% (0.05). If the computed N value was less than the number of sample (30 samples), the results were reliable and acceptable for further uses. In the other hand, If N value was larger than 30, the researcher had to run for more samples until the new calculation passed the requirement.

After getting reliable results, the average basic time (Simulation time) was calculated to the standard time by adding relaxation allowances [21] of 28% according to Harris&McCaffer's suggested scale [22] and contingency allowances of 10%.

From Table 5, productivity of all 3 parts of construction could be derived in terms of production per hour (cu.m./hour, sq.m./hour), daily production (cu.m./day, sq.m./day), and also productivity of 0.15m.subbase course (16m. width) in meter/day.

The time required per section(200m. in length) of subbase construction was calculated as shown in the bottom line of Table 5: 10.36 hours for Part1, 4.08 hours for Part2, and 8.10 hours for Part3. So, at construction site, all 3 parts worked in line-process manner, starting from Part1, material transported to stock along the construction route, then, subbase material would be mixed as in Part2, after that Part3 would start its compacting work.

Table 5. Basic time for 1 Section of 0.15m.Subbase Course Construction (W=16m., L=200m., Area=3200 sq.m.) and productivity of each Part.

Item	Description	Part 1		Part 2		Part 3	
1	Average Basic Time(Cycle time, second)	27,016		10,639		21,133	
2	Relaxation Allowances,%	28		28		28	
3	Contingency Allowances,%	10		10		10	
4	Total Allowances,%.	38		38		38	
5	Standard Time (second)	37,282		14,682		29,163	
6	Production per hour	76.77	cu.m./hour	194.93	cu.m./hour	98.14	cu.m./hour
		309.00	sq.m./hour	784.61	sq.m./hour	395.02	sq.m./hour
7	Daily Production(8 hours)	614.13	cu.m./day	1,559.42	cu.m./day	785.10	cu.m./day
		2,471.98	sq.m./day	6,276.90	sq.m./day	3,160.14	sq.m./day
8	Unit Cost, Baht/cu.m.	130.26	Baht/cu.m.	28.73	Baht/cu.m.	50.95	Baht/cu.m.
9	Unit Cost, Baht/sq.m.	32.36	Baht/sq.m.	7.14	Baht/sq.m.	12.66	Baht/sq.m.
10	Productivity for 0.15m.Subbase Course of 16 m. total width	154.50	m./day	392.31	m./day	197.51	m./day
11	Productivity as Time duration(hour) for 1 section of construction (200 m. in length)	10.36	hour	4.08	hour	8.10	hour

This kind of line-process should be carefully studied to plan for balanced construction teams that work together in order to maximize overall productivity with lower unit cost, which could be illustrated in next simulation model.

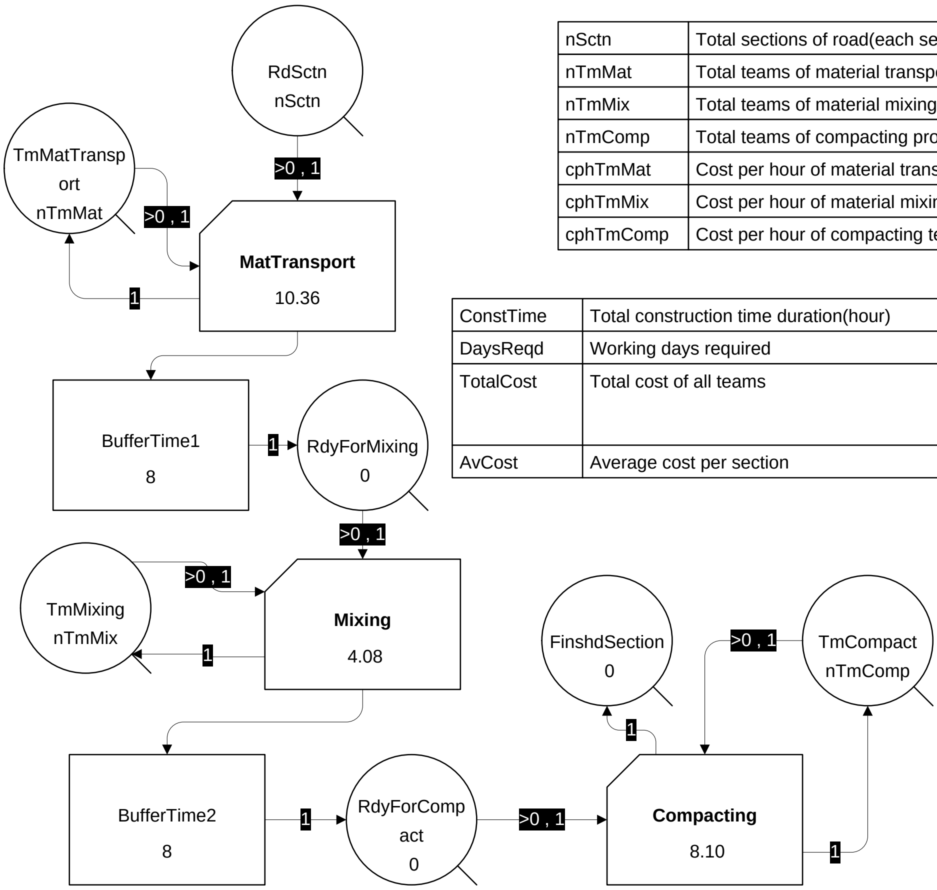
3.3. Productivity Management at Construction Site

The model in Fig. 6, showing overall construction process of subbase course, used the productivity values in term of time required (hour) for each part of construction by its optimum team. Since construction at work site was done by Team1(for Part1), Team2(for Part2) and Team3(for Part3) consecutively. The management at site had to plan for optimum combination of Team1, Team2 and Team3 for the best productivity which could be evaluated by the lowest unit cost of subbase construction.

The Combi named "MatTransport", represented Part1 of construction process by Team1, required 10.36 hours per section, and "Mixing" for Part2 by Team2 required 4.08 hours, and the last Combi in model "Compacting" for Part3 used 8.10 hours for 1 section work. The researcher had added buffer time (8 hours) between Parts of construction to prevent crashing of construction teams in line-process.

In the parameter table, "nSctn" represented the total sections of subbase course construction; in this case, there were 26 sections, each section had 0.15m. thick, 16m. wide, and 200 m. long, total length to 5200 meters.

The number of Team1 was presented by "nTmMat", Team2 by "nTmMix" and Team3 by "nTmComp" which could be numbered according to trial combination of construction teams. And also, the cost per hour of each construction team was set as parameter to determine for overall unit cost of subbase construction. The optimum team combination would give minimum unit cost (cost per section), which was used for resources management purposes.



nSctn	Total sections of road(each section = 200 m.long)	26
nTmMat	Total teams of material transport	1
nTmMix	Total teams of material mixing process	1
nTmComp	Total teams of compacting process	1
cphTmMat	Cost per hour of material transport team	10000
cphTmMix	Cost per hour of material mixing team	5600
cphTmComp	Cost per hour of compacting team	5000

ConstTime	Total construction time duration(hour)	SimTime
DaysReqd	Working days required	ConstTime/8
TotalCost	Total cost of all teams	ConstTime*(cphTmMat*nTmMat +cphTmMix*nTmMix+cphTmComp*nTmComp)
AvCost	Average cost per section	TotalCost/nSctn

Fig. 6. EZStrobe ACDs showing overall process of subbase construction (Part1 to Part3).

After series of different number of team combination were input to the model, the results were showed in Table 6. The optimum number of Team1, Team2 and Team3 for minimum unit cost was 2, 1 and 1 respectively, but for the shortest duration optimum number was 3, 2 and 3 respectively.

The project management team could use these outcomes for effective resources planning to cope with project objectives. For this case study, if the project had some spared time, the first combination (2-1-2) would yield higher benefit in term of the lower unit cost. On the other hand, if the management team had to finish the work as soon as possible, the second combination (3-2-3) would be more interesting.

Table 6. Overall unit cost of 0.15m.subbase course construction and estimated duration.

No. of Team (Team1-Team2-Team3)	Av. Cost per Section (Baht)	Av.Cost per sq.m. (Baht/sq.m.)	Estimated Duration (day)
2-1-2	228,579.00	71.43	20.87
1-1-1	235,743.00	73.67	37.19
3-1-2	246,486.00	77.03	17.57
2-2-2	258,070.00	80.65	20.36
2-1-3	260,683.00	81.46	20.87
3-2-3	262,454.00	82.02	15.18
3-1-3	273,512.00	85.47	17.57
2-1-1	283,686.00	88.65	30.13
3-3-3	288,606.00	90.19	15.18
2-2-3	289,390.00	90.43	20.36
2-3-3	324,467.00	101.40	20.36
3-1-1	376,393.00	117.62	30.13

4. Conclusion

This research's objectives were to conduct a work study of subbase course of road construction and implement productivity analysis with EZStrobe simulation system. The study had divided construction process into 3 parts. Each part of the process was simulated with EZStrobe to find optimum construction team members with minimum unit cost.

The results showed that optimum team members of Team1 (for Part1: Subbase material transportation) consisted of 8 trucks working with an excavator, Team2 (for Part2: Subbase material mixing at site) was 2 Motor Graders and 1 Water Truck, and Team3 (for Part3: Compacting subbase course) was 1 Motor Grader, 1 Pneumatic Rollers and 1 Tandem Vibratory Rollers.

These optimum team members were used in simulation model of each part of construction to determine for basic time, which was verified for the reliability requirement of 95% confident interval and 5% limit of error.

Then, standard time of each part was calculated by adding relaxation and contingency allowances to the derived basic time. After that, the productivity of each construction team was determined in various units; production per hour (cu.m./hr., sq.m./hr.), daily production (cu.m./day, sq.m./day, m.of road/day) , and number of hour required per section of subbase course construction (200 m. in length).

The last productivity values were used in overall process simulation model including Part1 to Part3. This model was set for 26 sections of subbase course construction by varying the number of team in each part, with additional 8hours of buffer time between parts to prevent crashing between consecutive construction teams.

The analysis results showed that optimum team combination of Team1, Team2 and Team3 for the minimum unit cost of subbase construction was 2-1-2; and for the minimum duration of construction was 3-2-3. These outcomes could be use as guidelines for project management team to develop highly effective resources planning of similar construction projects.

For subbase course construction with different parameters, some input data must be amended to yield more accuracy of results for each specific condition. In addition, if the construction work was carried out in the bad weather area, the effects of weather conditions should be also put into consideration. The author hopes that more studies should be done in various types and steps of road construction, which would be benefits for all involved parties of road construction projects in Thailand.

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using for productivity analysis and management. The integrated user-friendly Microsoft Visio© interfaces were truly enhanced the system performances, especially in creating the models.

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