Tower Crane Productivity Analysis On Apartment Development Projects

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ABSTRACT

The development of infrastructure technology in Indonesia has seen a significant and rapid growth. Along with this advancement, the number of construction projects has also increased, thanks to the availability of advanced tools and equipment. In construction projects, it is crucial to adhere to the agreed-upon design and complete the work within the designated timeframe. This ensures that there are no setbacks or delays in the construction process. The objective of this study is to determine the types of Tower Crane heavy equipment used, assess the productivity of the Tower Cranes, and identify the optimal positioning for the Tower Cranes. This research was conducted on the Juanda-Bekasi Transpark Area Development Project. Based on the analysis results, it was found that the project utilizes three Tower Cranes of the C7030-12T type. Tower Crane 1 exhibited the highest productivity, with a value of 3326.3881 kg/hour. Tower Crane 3 had a productivity value of 3286.3825 kg/hour, while Tower Crane 2 had a productivity value of 2069.2752 kg/hour. The highest productivity value for Tower Crane 1 was recorded on September 28, at 4662.57 kg/hour. For Tower Crane 2, the highest productivity value was observed at 2919.52 kg/hour. Tower Crane 3 achieved its highest productivity value on September 8, at 5341.45 kg/hour. Among the three simulations conducted in this study, the optimal configuration for Tower Crane placement was obtained in the second simulation, which involved using two Tower Cranes.

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1. INTRODUCTION

The development of infrastructure technology in Indonesia has experienced a rapid and significant increase. This growth has led to an increase in construction projects, supported by the use of sophisticated tools and equipment. In construction projects, it is crucial to adhere to the agreed-upon design and complete the work within the designated timeframe. Failure to do so can have detrimental effects, including additional costs and potential delays. Making poor decisions during the construction process can amplify these negative impacts [1].

The purpose of utilizing heavy equipment is to assist human workers in their tasks, enabling them to achieve desired results more efficiently and within a shorter timeframe. Heavy equipment is considered to have high capacity if it produces high or optimal output at low cost [2].

The Tower Crane is a material handling equipment that is employed to transport objects or materials from one location to another within a construction site. It is designed to be adjustable in both vertical and horizontal directions, making it suitable for handling tasks at varying heights and distances [3].

Productivity is a combination of the words "*product*" and "*activity*" which means the result of a process and an activity for a specific purpose. Production refers to the act of creating or making something, typically in a manufacturing or industrial setting, and it involves the use of resources such as labor, raw materials, and machinery to produce goods or services. Activity refers to the state or quality of being active, It encompasses various actions, movements, operations and be broad diverse, ranging from physical tasks to intellectual pursuits [4].

In Olivia Tamara's research (2018) titled "Optimization and Productivity of Tower Crane Heavy Equipment on the Caspian Tower Grand Sungkono Lagoon Project," the objective was to determine the optimal positioning of the Tower Crane, evaluate its productivity on the Caspian Tower Grand Sungkono Lagoon Project, and assess the operational costs associated with the Tower Crane [5].

The author selected the Transpark Juanda-Bekasi development project as the research location. The Transpark Juanda-Bekasi area is the first Superblock in Bekasi City, encompassing 4.7 hectares and offering various facilities such as residential land, educational land, shopping centers, and recreational land. The author focused on an apartment within the area, which incorporates a green building concept and comprises 32 floors. Every 16th floor is designated as a green space functioning as a sky park. The Tower Crane lifting equipment is essential in the construction of this apartment, facilitating the distribution of materials from the supply area to the demand area within the Transpark Juanda-Bekasi Area Development Project, both vertically and horizontally.

2. METHODS

In this research, both primary data and secondary data are required. Primary data is obtained directly from field observations and surveys conducted at the Transpark Juanda Bekasi Area Development Project. The primary data consists of Tower Crane productivity data, Tower Crane coordinate data, and data related to supply and demand points.
Secondary data is used to complement and reinforce the primary data. It includes site plan data, Tower Crane manuals, apartment work drawings, documentation, and other relevant supporting data. This data was obtained through observation during the observation process and also through interaction with workers at the project site.
During the initial observation phase, field observations were conducted for 20 working days to collect the necessary data. The collected data is then processed, which involves calculations of productivity and simulations to determine the optimal positioning of the Tower Crane.
Tower Crane productivity is greatly influenced by cycle time, which refers to the time required for the Tower Crane to complete one rotation. This rotation involves vertical (hoist), horizontal (trolley), and rotating (swing) movements. The entire rotation consists of six stages: material binding, lifting, rotating, lowering, releasing the material, and returning to the material supply location.
The research is conducted in the heart of Bekasi, specifically in Transpark Juanda. This location is renowned as the largest and finest superblock area, introduced by Mr. Chairul Tanjung, which has become a prominent landmark in Bekasi, West Java. Transpark Juanda offers more than just apartments. It features the esteemed London School of Public Relation (LSPR) university, shopping centers, the popular entertainment venue Trans Snow World, hotels, and shop houses, making it a fully integrated residential complex within a single superblock area.

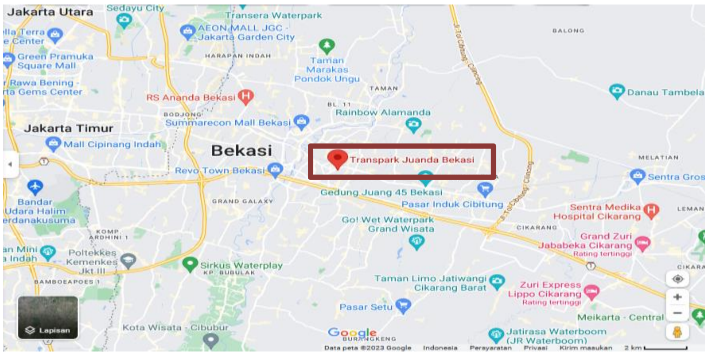

Figure 1. Research Sites
Source: Google Earth, 2023

3. RESULTS AND DISCUSSION

This thesis, the specific location that will be analyzed and discussed is Jl. Insinyur H. Juanda No.19, Bekasi City, West Java, Indonesia. Data collection occurred over 20 working days, focusing on the heavy equipment Tower Crane involved in steelwork. In the primary data collection phase, observations were made regarding the movement cycle time of the Tower Crane, starting with the type of lifting equipment used.

3.1 Tower Crane Specification

The Transpark Juanda-Bekasi area is a comprehensive superblock residential development that encompasses various facilities, including residential land, educational land, shopping centers, and recreational land. The entire area spans a total land area of 4.7 hectares. Within this superblock, there are five apartments, each consisting of 32 floors. The height of each apartment is 114 meters. Considering the height requirements of the apartments, the Tower Crane type C7030-12T, which is produced in China, meets the criteria. This particular type of Tower Crane has a height range limit of 230 meters, making it suitable for the apartments with a height of 114 meters.

3.2 Productivity Tower Crane

The productivity value of the Tower Crane is determined by comparing the load weight capacity of the Tower Crane with the cycle time required to complete a load movement. The work volume value is obtained from project data and is recorded in the table below. The cycle time is derived from the time required for various stages of the load movement process, including loading, lifting, slewing, unloading, and returning. Each Tower Crane performs four cycle times per day.

Table 1. Work Volume TC 1

Date	Time	Work volume (kg)	Cycle time (hh:mm:ss)	Total cycle (mm)
06-Sep-21	08:00-12:00	17115	01:11:04	71,06
07-Sep-21	08:00-12:00	11294	01:09:52	69,86
08-Sep-21	08:00-12:00	13003	01:10:40	70,66
09-Sep-21	08:00-12:00	15240	01:09:44	69,73
10-Sep-21	08:00-12:00	10404	01:09:28	69,46
13-Sep-21	08:00-12:00	9074	01:05:12	65,2
14-Sep-21	08:00-12:00	14872	01:06:16	66,26
15-Sep-21	08:00-12:00	17464	01:09:28	69,46
16-Sep-21	08:00-12:00	19372	01:10:00	70
17-Sep-21	08:00-12:00	15129	01:09:04	69,06
20-Sep-21	08:00-12:00	13722	01:09:16	69,26
21-Sep-21	08:00-12:00	12128	01:09:24	69,4
22-Sep-21	08:00-12:00	15252	01:08:40	68,66
23-Sep-21	08:00-12:00	11281	01:08:52	68,86
24-Sep-21	08:00-12:00	9029	01:09:20	69,33
27-Sep-21	08:00-12:00	12576	01:10:04	70,06
28-Sep-21	08:00-12:00	19222	01:09:16	69,26
29-Sep-21	08:00-12:00	12897	01:09:48	69,8
30-Sep-21	08:00-12:00	13972	01:09:40	69,66
01-Okt-21	08:00-12:00	11221	01:08:56	68,93
total	4800	274267	23:04:04	1384

Table 2. Work Volume TC 1

Date	Time	Work volume (kg)	Cycle time (hh:mm:ss)	Total cycle (mm)
06-Sep-21	08:00-12:00	9105	01:44:04	104,06
07-Sep-21	08:00-12:00	8016	01:43:36	103,6
08-Sep-21	08:00-12:00	9918	01:43:00	103
09-Sep-21	08:00-12:00	11746	01:43:48	103,8
10-Sep-21	08:00-12:00	8105	01:43:40	103,66
13-Sep-21	08:00-12:00	9329	01:43:44	103,73
14-Sep-21	08:00-12:00	8158	01:43:48	103,8
15-Sep-21	08:00-12:00	10192	01:44:16	104,26
16-Sep-21	08:00-12:00	7164	01:43:28	103,46
17-Sep-21	08:00-12:00	8093	01:43:44	103,73
20-Sep-21	08:00-12:00	7019	01:44:24	104,4
21-Sep-21	08:00-12:00	9639	01:44:16	104,26
22-Sep-21	08:00-12:00	8140	01:43:36	103,6
23-Sep-21	08:00-12:00	7483	01:43:24	103,4
24-Sep-21	08:00-12:00	9114	01:43:52	103,86
27-Sep-21	08:00-12:00	10921	01:43:52	103,52
28-Sep-21	08:00-12:00	8020	01:43:44	103,73
29-Sep-21	08:00-12:00	9318	01:45:56	105,93
30-Sep-21	08:00-12:00	7181	01:44:16	104,26
01-Okt-21	08:00-12:00	8983	01:43:36	103,6
total	4800	175644	34:38:04	2078.06

Table 3. Work Volume TC 3

Date	Time	Work volume (kg)	Cycle time (hh:mm:ss)	Total cycle (mm)
06-Sep-21	08:00-12:00	18021	00:55:56	56,93
07-Sep-21	08:00-12:00	16782	00:55:20	55,33
08-Sep-21	08:00-12:00	18776	00:46:24	46,4
09-Sep-21	08:00-12:00	14729	00:57:08	57,13
10-Sep-21	08:00-12:00	14298	00:55:28	55,46
13-Sep-21	08:00-12:00	14938	00:55:36	55,6
14-Sep-21	08:00-12:00	18552	00:55:52	55,86
15-Sep-21	08:00-12:00	15292	00:55:20	55,33
16-Sep-21	08:00-12:00	11605	00:56:04	56,06
17-Sep-21	08:00-12:00	11922	00:57:44	57,73
20-Sep-21	08:00-12:00	15014	00:56:32	56,53
21-Sep-21	08:00-12:00	17124	00:57:08	57,13
22-Sep-21	08:00-12:00	14923	00:56:28	56,46
23-Sep-21	08:00-12:00	14591	00:57:04	57,06
24-Sep-21	08:00-12:00	8052	00:55:04	55,06
27-Sep-21	08:00-12:00	9185	00:56:00	56
28-Sep-21	08:00-12:00	11952	00:56:52	56,86
29-Sep-21	08:00-12:00	10261	00:55:56	55,93
30-Sep-21	08:00-12:00	9024	00:55:40	55,66
01-Okt-21	08:00-12:00	11052	00:56:04	56,06
total	4800	276093	17:37:36	1057.6

According table 1 the recapitulation results for 20 working days, which are used to calculate the productivity of the three Tower Cranes. To determine the efficiency of work time, the author utilizes the following equation :

efficiency : (number of cycles total time)/(average execution time) (1)

efficiency : 1384 /4800

efficiency : 0,28

Above, the time efficiency is obtained from the cycle time of Tower Crane 1, which has a value of 0.28. To calculate the time efficiency of Tower Crane 2 and Tower Crane 3, the author uses the equation and obtains values as shown in table 4 :

Table 4. Efficiency Tower Crane

TC 1	*TC 2*	*TC 3*
0.28	0.43	0.22

After calculation effeciency Tower Cranes right in tabel 4, next calculate the productivity of three Tower Cranes, the following equation is used :

productivity : [(employment volume) / (cycle time)] x efficiency (2)

The author used data from September 6th, as shown in table 1 for Tower Crane 1, to apply the equation mentioned above. To clarify further, here the details :

$$\text{Productivity} : \frac{17115}{71{,}06} \times 0.28$$

Productivity : 240,85 x 0.28

Productivity : 67.43878 x (60 minute)

Productivity : 4046.32 kg/hour

Work by Tower Crane 1 on September 6th, the productivity value obtained was 4049.74 kg/hour. Then author used an equation to calculate the total productivity values for Tower Crane 1, Tower Crane 2, and Tower Crane 3. The result shown in table 5 :

Table 5. Productivity Tower Crane

Date	*TC* 1 (kg/hour)	*TC* 2 (kg/hour)	*TC* 3 (kg/hour)
06-sep-21	4046,327	2257.438	4178,4156
07-sep-21	2715,992	1996.2625	4003,6581
08-sep-21	3091,5709	2484.3146	5341,4483
09-sep-21	3671,7625	2919.526	3403,1647
10-sep-21	2516,372	2017.2583	3403,0581
13-sep-21	2338,0859	2320.3336	3546,4317
14-sep-21	3770,7455	2027.711	4383,9313
15-sep-21	4223,9447	2522.0948	3648,1909
16-sep-21	4649,28	1786.4991	2732,5366
17-sep-21	3680,3823	2012.9124	2725,9726
20-sep-21	3328,4666	1734.5805	3505,8341
21-sep-21	2935,8847	2385.2503	3956,5342

Date	*TC* 1 (kg/hour)	*TC* 2 (kg/hour)	*TC* 3 (kg/hour)
22-sep-21	3731,9196	2027.1429	3488,9054
23-sep-21	2752,2626	1867.1315	3375,4154
24-sep-21	2187,9013	2264.0208	1930,3741
27-sep-21	3015,6552	2721.8103	2165,0357
28-sep-21	4662,57	1994.7556	2774,6465
29-sep-21	3104,149	2269.4647	2421,6914
30-sep-21	3369,6469	1776.9979	2140,0791
01-okt-21	2734,844	2237.0792	2602,3261
		Avarage	
	3326.3881	2069.2752	3286.3825

From the summary of productivity calculations table 5, the author converted the tabular data into a line graph format for visualization. The resulting line graph shown in figure 2 :

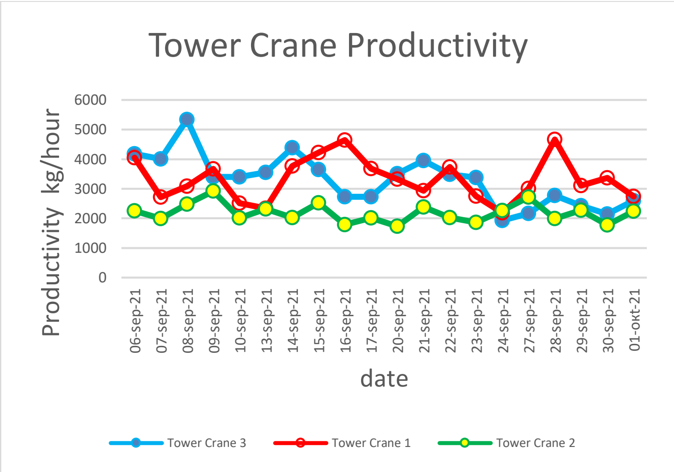

Figure 2. Productivity Each Tower Crane
Source: Author's Analysis, 2023

3.3 Optimization Analysis of Tower Crane Placement

Figure 3. Site Plan Project
Source: Project Data, 2023

The picture displays the coordinates of the Tower Crane points, supply points (red triangle), and demand points (green circle). The Tower Crane coordinate data is collected through observation and data collection. Each Tower Crane is assigned to handle specific tasks in each apartment. For further details, shown in table 6:

Table 6. Coordinate Of Tower Crane

TC 1		*TC* 2		*TC* 3	
x	y	x	y	x	y
215497	119556	238715	176793	276793	107657

To determine the distance between Tower Cranes, it is necessary to calculate the coordinates of each Tower Crane point. For example, the author describes the calculation of the distance between Tower Crane 1 and Tower Crane 2 from table 6 using the following equation:

$$L = (XTc1 - XTc2)^2 + (YTc1 - YTc2)^2 \quad (3)$$

$$L = (215497 - 238715)^2 + (119556 - 176793)^2$$

$$L = 3815149693$$

Then, the L value mentioned above is converted from coordinate units to meter units by dividing it by a value of 56694119.41

$$L = 67.29357$$

Table 7. Distances Tower Crane

Tower Crane		
TC 1 – *TC* 2	*TC* 1 – *TC 3*	*TC 2 – TC 3*
67.29357 m	68.76879 m	109.883 m

The following table 7 are the results of calculating the distance between the Tower Crane point and other Tower Crane using the equation above. And apply the calculation to Tower Crane 2 and Tower Crane 3, for calculation of distances.

Table 8. Supply Demand Point

TC 1				*TC* 2				*TC* 3			
supply		*demand*		*supply*		*demand*		*supply*		*demand*	
x	y	x	y	x	y	x	y	x	y	x	y
197437	93953	180036	126711	200297	166931	253617	189338	262817	77675	249367	69738

The following table 8 are the coordinate supply and demand point. To determine the distance between supply and demand points, it is necessary to calculate each coordinate point of the supply and demand points by using the following equation:

$$L= (Xs\text{-}Xd)^2 + (Ys\text{-}Yd)^2 \quad (4)$$

$$L=(197437-180036)^2 + (93953-126711)^2$$

$$L = 1375881365$$

Then, the L value mentioned above is converted from coordinate units to meter units by dividing it by a value of 56694119.41

$$L = 24.26850226$$

Note:
L : Distance between Supply point and demand point
Xs, Ys: Supply coordinates
Yd, Xd: Demand coordinates

The following are the results of calculating the distances between the supply and demand points for each Tower Crane using the equation mentioned above:

Table 9. Distances Supply Demand Point

TC 1	*TC* 2	*TC* 3
supply -demand	*supply -demand*	*supply-demand*
24.26850226 m	59.00252237 m	4.302006 m

The following table 9 are the results of calculating the distance supply demand point among Tower Crane point. And apply the calculation to Tower Crane 2 and Tower Crane 3.

After calculating the distance between the supply point and the demand point, then the author calculates the minimum area that must be reached by the Tower Crane jib arm using the minimum radius equation as follows:

$$Rmin= \frac{Lmax}{2} \times 1.10 \quad (5)$$

$$Rmin= \frac{24.2685}{2} \times 1.10$$

$$Rmin= \frac{24.2685}{2} \times 1.10$$

$$Rmin= 13.348 \text{ meter}$$

For Tower Crane one has a minimum radius between supply or demand with a value of 13.348 meters. The following are the results of the calculation of the minimum radius of each Tower Crane using the equation above:

Table 10. Radius Minimum

TC 1	*TC* 2	*TC* 3
R min (m)	R min (m)	R min (m)
13.348	27.582	2.3661

Based on table 10, data on the minimum radius each Tower Crane is obtained. After obtaining the minimum radius value, it is crucial that the distance between the Tower Crane and the supply or demand points is greater than the calculated minimum radius value. For further details right in table 11 :

Table 11. Distances Between Tower Crane and Supply Demand Point

Tower Crane					
TC 1		*TC* 2		*TC* 3	
supply	*demand*	*supply*	*demand*	*supply*	*demand*
17.3153	23.0831	44.2513	22.5992	19.3009	38.6289

The next step involves reviewing the site plan and coordinate points to determine if the placement of the Tower Crane is truly optimal. The author then creates a distance table between the supply and demand points to facilitate the projection of distances between them. This process is aided by the following equation:

$$L= (XsTc1-XsTc2)^2+(YsTc1-YsTc2)^2 \quad (6)$$

$$L= (197437-200297)^2+(93953-208931)^2$$

$$L = 3815149693$$

Then, the L value mentioned above is converted from coordinate units to meter units by dividing it by the value of 56694119.41.

$$L = 233.324$$

The following are the results of calculating the distances between the Tower Crane points using the equation mentioned above:

Table 12. Distances Between Tower Crane and Supply Demand Point

TC 1 - *TC* 2		*TC* 1 - *TC 3*		*TC* 2 - *TC 3*	
s1-s2	*s1-d2*	*s1-s3*	*s1-d3*	*s2-s3*	*s2-d3*
233.3243	290.5043	80.0703	57.9088	372.8232	384.2119

After obtaining the calculations for the distances between the supply and demand points, the results are then input into the minimum radius formula to determine the coordinate point that serves as the optimal placement for the Tower Crane in table 12.

Table 13. Radius Minimum And Supply Demand Point

TC 1 - *TC* 2		*TC* 1 - *TC 3*		*TC* 2 - *TC 3*	
Jarak s1-s2	*Jarak s1-d2*	*Jarak s1-s3*	*Jarak s1-d3*	*Jarak s2-s3*	*Jarak s2-d3*
128.3284	159.7774	44.03869	31.84987	205.0528	211.3166

Based on table 13, the author establishes the existing conditions and conducts simulations for the placement of the Tower Crane.

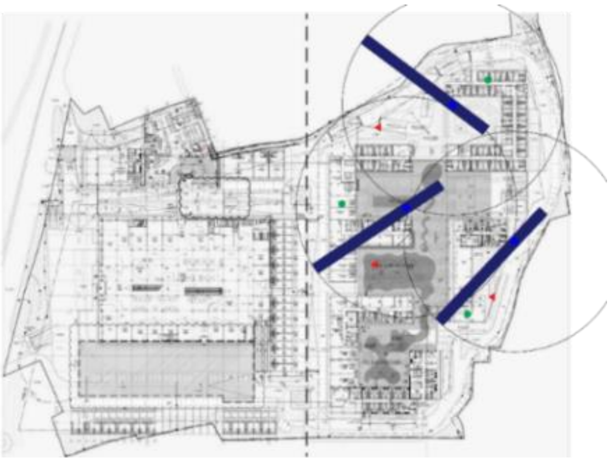

Figure 4. Existing Site Plan
Source: Author's Analysis, 2023

The illustration of figure 4, existing conditions depict the placement of the Tower Crane along with the supply and demand points, reflecting the actual setup in the Juanda-Bekasi Transpark Area Development Project. Each Tower Crane undertakes iron work at the assigned supply and demand points. Based on this simulation, it is concluded that every supply and demand requirement can be met by each Tower Crane with a maximum jib length of 70 meters. Consequently, no obstacles are anticipated in the implementation process.

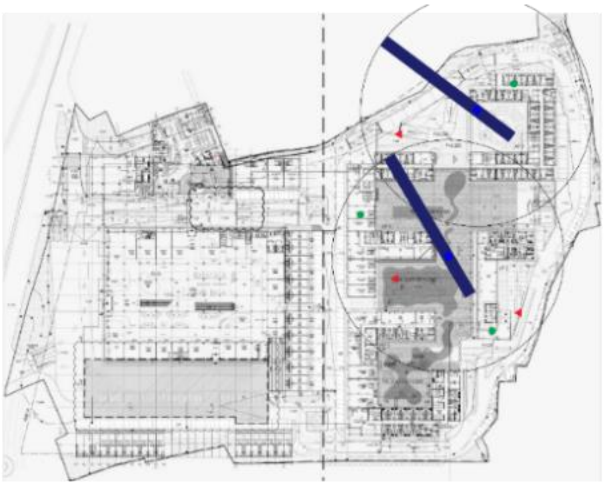

Figure 5. Simulation 1
Source: Author's Analysis, 2023

Figure 5, assumes the use of two Tower Cranes in the Juanda-Bekasi Transpark Area Development Project. With two Tower Cranes, the needs of each supply and demand point can be met within a maximum jib range of 70 meters. Using two Tower Cranes is more cost-effective compared to using three Tower Cranes. However, there are certain factors that need to be considered. By assigning additional work to Tower Crane 1 and Tower Crane 3, they will have a higher workload compared to the other Tower Crane. In the current setup, each Tower Crane is assigned to one apartment. In this simulation, Tower Crane 1 is assigned to two apartments. It is possible to implement this arrangement, but careful consideration should be given to ensure efficient operations and optimum productivity.

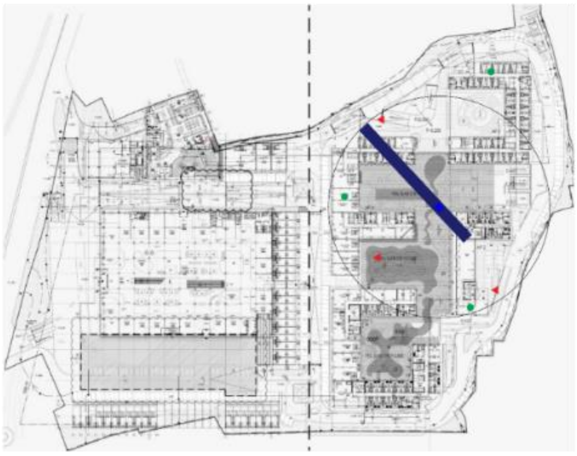

Figure 6. Simulation 2
Source: Author's Analysis, 2023

Figure 6, assumes the use of one Tower Crane for the Regional Development Project Transpark Juanda-Bekasi. It is evident that using only one Tower Crane has limitations in reaching the supply and demand points. Despite utilizing a maximum jib length of 70 meters, Tower Crane 1 is unable to reach the demand points that should be served by Tower Crane 2. Several considerations must be taken into account, such as the requirement for one Tower Crane to handle all the workload. While opting for a single Tower Crane may result in cost savings by eliminating the need for an additional crane operation, it significantly prolongs the project duration due to the increased workload. Given these assumptions, it is certain that this simulation involving only one Tower Crane cannot be implemented since it fails to meet the demand points.

From the existing conditions and simulations presented above, it can be concluded that based on this analysis, simulation one represents the optimal placement of the Tower Crane. The coordinates for Tower Crane 1 are (x: 224778, y: 107666), and for Tower Crane 2 are (x: 276793, y: 107657). This placement allows for reaching all supply and demand points effectively, utilizing the maximum 70-meter jib reach. By employing two Tower Cranes, the project requirements can be adequately met.

4. CONCLUSIONS

The Juanda-Bekasi Transpark Development Project utilizes three Tower Crane lifting equipment of the same type, namely the C7030-12T. This particular Tower Crane model has a travel range of 70 meters and a lifting capacity of 12 tons. It is equipped with a 4-fall type hook, which effectively reduces stress on steel ropes compared to two-rope models. The hoist tools included with the Tower Crane have a load capacity of 6 tons. In terms of vertical trolleying movement, this equipment can operate at speeds ranging from 10 to 40 m/min. However, in the Juanda-Bekasi Transpark Area Development Project, a constant speed of 36 m/min is utilized during the 20 working days. For slewing ability, the Tower Crane can rotate at a speed of 0 to 0.7 rad/min. In the Juanda-Bekasi Transpark Area Development Project, a constant speed of 0.6 rad/min is maintained throughout the 20 working days. The Tower Crane also possesses the ability to travel horizontally on the Tower lifting tool. Based on productivity values, Tower Crane 1 demonstrates the highest productivity with a value of 3326.3881 kg/hour, followed by Tower Crane 3 with a value of 3286.3825 kg/hour, and finally Tower Crane 2 with a value of 2069.2752 kg/hour. Simulation 1 represents the optimal placement of the Tower Crane, with the coordinates for Tower Crane 1 being (x: 224778, y: 107666), and for Tower Crane 2 being (x: 276793, y: 107657). This configuration allows for the Tower Cranes to reach all supply and demand points effectively, utilizing their maximum 70-meter jib reach.

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