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Rawan Ahmed Azzam

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Proposed Model to Study Effect of Lighting Parameters on Construction Sites

Rawan A. Azzam[1,*], Tamer El-korany[2], and Adel I. Eldosouky[3]

[1]M.Sc. Student, Structural Engineering Dept., Faculty of Engineering, Tanta University, Tanta, Egypt. – email: rawan132810@f-eng.tanta.edu.eg
[2]Associate Professor, Structural Engineering Dept., Faculty of Engineering, Tanta University, Tanta, Egypt. – email: tamer.elkorany@ f-eng.tanta.edu.eg
[3]Professor, Structural Engineering Dept., Faculty of Engineering, Tanta University, Tanta, Egypt. – email: adel_eldosouky@hotmail.com

***Abstract*- Inadequate lighting plans for the operations performed at night on construction sites can affect the quality of the implemented work, labor productivity, safety, as well as the project's overall cost. Accordingly, to avoid inadequate lighting conditions, the location of the luminaries utilized to illuminate the chosen construction area and its configuration, including luminaire height and luminary angle, are crucial choices in the design of the lighting plan. Besides making sure that the chosen installation pattern is cost-effective and as much as possible meets the lighting levels needed for each point according to the nature of the implemented work and safety considerations, In this way, a maximal coverage location model using LINGO software is developed in order to investigate the best locations of luminaires, taking into account gradual and cooperative covering. The objective is to ensure that the selected allocation of luminaires minimizes the summation of the received illuminance by the points that exceed the demand and the received illuminance that is below the demand. The optimized results refer to that smaller luminary angles lead to large coverage and minimizes the objective function. Making sure that the selected luminaire height leads to the desired illuminance levels according to the inverse relationship between the height and the illuminance.**

***Keywords*- Nighttime Construction, Allocation, Gradual and Cooperative Covering, Optimization, Mixed Integer Linear Programming.**

I. INTRODUCTION

Lighting affects functionality, comfort, and productivity during nighttime construction shifts. So, it is imperative to consider the benefits of light while addressing energy issues, as lighting quality entails achieving the right balance between architectural needs, human needs, and energy efficiency [1]. Besides, Kralikova, and E. Wessely defined lighting quality as being based on how well the installation satisfies the requirements and goals of the designer, as lighting quality is linked to goals including enhancing work performance, encouraging preferred behaviour patterns, and ensuring visual comfort [2].

In lighting problems, timelines for project completion, budgets, specified procedures, and design standards that must be followed can all contribute as restrictions. In this way, and based on previous studies, Davila summarized all the advantages and disadvantages of nighttime work [3]. Most of these disadvantages relate to an unsuitable lighting plan and poor visibility. So, achieving a lighting plan that satisfies most lighting requirements is a must. As the selected luminaire height and luminary angle have a great effect on illumination distribution, this research aims to study the effect of lighting parameters (the luminaire height and the luminary angle) on the lighting coverage on construction sites.

In the following sections, authors are conducting a comprehensive literature review on mathematical models that aim to identify the best location of the luminaires, studying the effect of the different lighting configurations, implementing the mathematical optimization model, conducting field visits to understand the type of work implemented in the case study, investigating the site conditions, and solving the model with various cases of luminaire mounting height and luminary angles, analyzing the results,

"LINGO" is the software used to solve the model and make a simulation of the outdoor construction work zone illumination, as the computed optimized results are presented graphically in the shape of contour maps.

II. LITERATURE REVIEW

A. Overview of the previous optimization models.

Prior to presenting the research on lighting design optimization, Elrahman, and Perry [4] have presented a detailed approach for an analytical comparison between nighttime construction operations and daytime ones summarized in eight steps, helping decision-makers choose the most effective alternative. Steps to make a lighting plan were referred to by Anani [5], which briefly include the determination of work zone activities, the work zone area to be lit up, the selection of the type of light source, and its location. Ellis et al. [6] represented a set of activities that are commonly performed at nighttime, which have been divided into maintenance and construction activities, and also factors affecting illumination requirements, especially those that significantly affect nighttime highway activities, including human, environmental, task-related, and lighting factors.

Good lighting solutions provide the proper amount of light at the right time of day, enhancing people's sense of wellbeing, focus, motivation, and performance [2]. Kralikova, and Wessely [2] defined lighting quality as determined by the degree to which the installation fits the customer's and designer's objectives and constraints. Lighting quality is thus associated with objectives such as improving task performance, establishing specific impressions, generating desired behavior patterns, and guaranteeing visual comfort. The constraints may be established by available resources and financial budgets, project completion timelines, and predetermined practices and design methods that must be followed. Considering the Cooperative Gradual Maximal Covering Location Problem (CGMCLP) adopted by Bagherinejad, et al. [7], i.e., after defining the location of the studied nodes, their demands, and the recommended locations of the luminaires there are three cases of the nodes.

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The first case is the fully covered node, the second one receives portion of its demand, these points are partially covered. "Whether this coverage received from one or more luminaires in accordance with the cooperative rule". Finally, the nodes that do not receive any signals are called uncovered nodes. Bagherinejad, et al. suggested that covering (CGMCLP) as a preferable option. As: according to the definition of cooperative-gradual covering, each node can either be totally or partially covered by one or more facilities, which helps to maximize the covered demands. On the other hand, in case the received signals by the node are not enough to satisfy the demand while adopting the cooperative coverage concept only, these received signals will be ignored.

In the same way, after dividing the working area into cells, a Mixed Integer Programming (MIP) model was created by Noor-E-Alam et al. [8] to reduce the number of cells that receive an amount of illumination that exceeds the demand and reduce the number of cells that receive illumination less than the demand. Multi-objective optimization models have many different applications in construction sites, and in role can control and optimize more than one objective function according to the studied field, as El-Rays, and Hyari [9] presented a model named CONLIGHT developed for assessing the effects of all pertinent lighting design parameters on the design criteria in nighttime work zones, which include illuminance, uniformity, and glare. to make it possible for planners to assess the effectiveness of different lighting plans and choose a feasible layout that satisfies all lighting specifications for the nighttime work zone.

Another model presented by Hammad, et al. [10] seeks to reduce the maximum amount of light pollution (the obtrusive effect of lighting), and also minimize the expenses associated with setting up lighting. while maintaining adequate illumination coverage. Hammad, and Akbarnezhad [11] show the importance of the selected constraints and the objective functions of the model as follows: while solving the model with an objective function that seeks to maximize the illumination coverage (each zone has a different required illumination level according to the implemented work) with no restriction on the used number of luminaires, all zones receive a uniform maximum illumination level, even if this maximum level exceeds the required illumination level for any zone. That leads to a high cost for installations. The model was resolved while putting a constraint on the total number of luminaires, so the luminaires were placed in a way that satisfied the demand of the areas that required high levels of illuminance, as these areas have a relative importance. Then the model was resolved by adding another objective function that seeks to minimize the installation costs. The authors found that a light pole layout that both meets demand and reduces waste from oversupply in the zones is produced by concurrently resolving the two opposing objective functions.

B. lighting parameters

The current model has been developed to take into account every parameter of lighting design that must be mentioned in the lighting scheme needed for nighttime work. The lighting setup and specifications of the lighting equipment make up the two main groups of the design parameters [9].

Table 1: Setup variables including the positioning and configuration of the lighting equipment.

Setup variables	Description
MAX_NO_OF_POLES	The total number of luminaires being used.
(X_OF_POLE, Y_OF_POLE)	X, and y coordinates of the luminaire, which specify the location of the luminaire.
Z_1	Is the luminaire's mounting height, which is equal to the vertical distance between the luminaire's center and the surface of the pavement.
SEGMA	The luminary angle, is the angle at which the fixture is tilted.
ORIENTATION_ANGLE	Refers to the orientation of the luminaires (as the rectangular shape of the studied work zone, the used orientations are 0, 90, 180, and 270).

Table 2: Required parameters related to the lighting equipment specifications.

lighting equipment variables	Description
The utilized lamps' type	Means the type of lamp enclosed in the luminaire, such as halogen, metal halide, and LED lamps.
Lumen output of the lamp	Which details the energy and light generated from the selected lamp [12].
the type of luminaire's light distribution	that shows the light distribution in various directions [13].
The depreciation of the light	That reflects the effect of the lamp's age and the accumulated dirt on the lamp on reducing the generated light from luminaires [14]. Which appears in the illuminance equation as the maintenance factor, as it is the percentage of the entire light output at the beginning of the installation's life to the light output that may finally drop to, this percentage shows how much to increase the level of light at the beginning in order to keep it above the needed level during the installation's lifetime [15].

(1) The lighting setup includes the positioning and configuration of the lighting equipment mentioned in Table 1.

(2) Specifications of the lighting equipment, mentioned in Table 2.

III. MAIN SECTIONS OF THE MODEL

The group of sets, parameters, and variables used in the model [7], [8] are shown in Table 3. The direct illuminance of the work zone is computed using the fundamental illumination science rules [9], [13]. The luminaire photometric file obtained from the luminaire manufacturer was incorporated into the LINGO model, and the pertinent data has been extracted for further computation [16], [17]. While extracting the intensity values from the photometric file, there are two interpolation techniques conducted (linear and quadratic interpolation) based on the nature of the data given in the photometric file [18], [19]. The modification in the function that calculates illuminance has been considered in the case that the luminous part is tilted by an angle [20]. The gradual and cooperative concepts were utilized in the model, as in this way more demands are satisfied [7]. More discussions of the above parameters are given in [21].

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Table 3: presents the notation of sets, parameters, and variables

SETS' NOTATION	
POINTS_OF_CALCULATIONS	Used to define some characteristics of points on the grid.
LOCATION_OF_POLE	Used to define some characteristics of the internal luminaire.
POINT_CROSS_LUMINAIRE_1 (SEGMA_1, LOCATION_OF_POLE, POINTS_OF_CALCULATIONS)	This set is a derived set from set SEGMA_1 and the two previously defined sets to study the illuminance distribution from the internal luminaire and the points of grides.
LOCATION_OF_POLE_2	Used to define some characteristics of the side luminaire.
POINT_CROSS_LUMINAIRE_2 (SEGMA_2, LOCATION_OF_POLE_2, POINTS_OF_CALCULATIONS)	This set is a derived set from set SEGMA_2 and the two previously defined sets to study the illuminance distribution from the side luminaire and the points of grides.
PARAMETERS	
MAX_NO_OF_POLES	To limit the maximum number of poles used.
TOTAL_RECEIVED_ILLUMINANCE	Represents the illuminance received by the point from all surrounding luminaires.
DEMAND_1	To assign the value of the illuminance demand for each point according to the nature of the work implemented.
EXTRA_DEMAND	a parameter used in the objective function that should always be greater than or equal to 0.0; this parameter can be easily calculated as EXTRA_DEMAND = DEMAND_1 – TOTAL_RECEIVED_ ILLUMINANCE
EXTRA_SUPPLY	a parameter used in the objective function that should always be greater than or equal to 0.0; this parameter can be easily calculated as EXTRA_SUPPLY = TOTAL_RECEIVED_ ILLUMINANCE - DEMAND_1
VARIABLES	
YJ	is a binary variable that indicates whether the luminaire is located at this coordinate or not.

The sequence of calculating illuminance. The horizontal illuminance at each grid point can be calculated while considering all contributing luminaires, as illustrated in Fig. 1

A. Variables

The quantities that can be adjusted are known as variables. The objective of the optimization is to identify the values of a model's variables that, subject to any restricting criteria imposed on the variables, produce the optimal value for the objective function.

A.1 Binary variables

YJ is a binary variable that indicates whether the luminaire is located at a certain coordinate or not. As presented in equations (1) and (2).

For the internal luminaire, the binary variable was called $YJ\_1_{(C, G)}$.

$$YJ\_1(C, G) \in \{0, 1\} \ \forall \ (C, G) \quad (1)$$

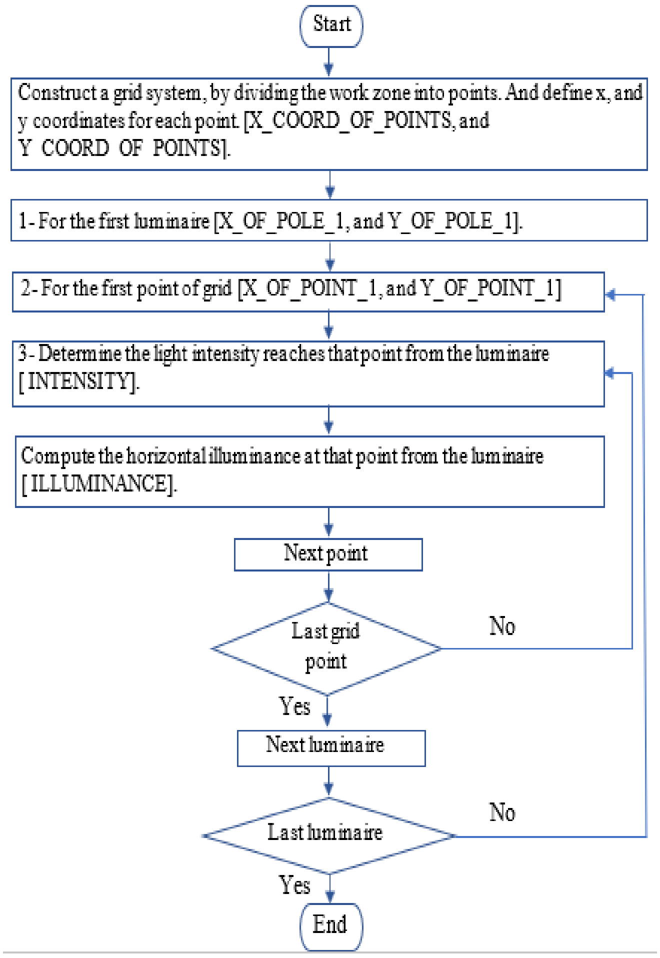

Fig. 1: The procedure of calculating illuminance at all points of the grid.

Where (C, G): is the set_index of the set LOCATION_OF_POLE mentioned in Table 3and refers to the x, and y coordinates of the internal luminaire.

For the side luminaires, the binary variables were called $YJ\_11_{(L, M)}$, $YJ\_22_{(L, M)}$, $YJ\_33_{(L, M)}$, $YJ\_44_{(L, M)}$ which also indicate whether the luminaire with a specified orientation is located at a certain coordinate or not.

$$YJ\_11(L, M), YJ\_22(L, M), YJ\_33(L, M), YJ\_44(L, M) \in \{0, 1\} \ \forall \ (L, M) \quad (2)$$

where:

$YJ\_11_{(L, M)}$: indicates whether there is a side luminaire located at this coordinate with an orientationangle of 0.0º or not, $YJ\_22_{(L, M)}$: indicates whether there is a side luminaire located at this coordinate with an orientationangle of 90º or not, $YJ\_33_{(L, M)}$: indicates whether there is a side luminaire located at this coordinate with an orientation angle of 180º or not, $YJ\_44_{(L, M)}$: indicates whether there is a side luminaire located at this coordinate with an orientationangle of 270º or not, and (L, M): is the set_index of the set LOCATION_OF_POLE_2 mentioned in Table 3 and are refers to the x, and y coordinates of the side luminaire.

For more discussion of the orientation angles, see [21]

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B. Objective function

This model seeks to reduce and minimize the number of points that receive an amount of illumination that exceeds the demand, which is called EXTRA_SUPPLY in the model, and also reduce the number of points that receive illumination less than the demand, which is called EXTRA_DEMAND**,** as demonstrated in the previous literature review [8].

In this way, the objective function aims to minimize the summation of EXTRA_DEMAND and EXTRA_SUPPLY at all points of the grid as mentioned in equation (1), EXTRA_DEMAND and EXTRA_SUPPLY can be calculated as mentioned in Table (3).

$$\text{Minimize} \sum_{A,B} \text{EXTRA\_DEMAND}_{A,B} + \text{EXTRA\_SUPPLYA, B} \quad \forall (A, B) \qquad (3)$$

where:
(A, B): is the set_index of the set POINTS_OF_ CALCULATIONS mentioned in Table 3 and refers to the x and y coordinates for each studied point while dividing the work zone into points.

C. Constraints

As there are some restrictions on the values that a model's variables can take, which are called constraints, these restrictions are represented as functions of the model's variables, such as:

C.1 Constraint that controls the total number of used luminaires

The following constraint controls the total number of used luminaires: as the sum of the values of the binary variable (**YJ**) = MAX_NO_OF_POLES. As shown in equation (4). Which means that the sum of all located luminaires in the lighting plan that have binary variable of 1 equals the specified maximum number of luminaires.

$$\sum_{C,G} \text{YJ\_1}_{C,G} + \sum_{L,M} \text{YJ\_11}_{L,M} + \text{YJ\_22L, M} + \text{YJ\_33L, M} + \text{YJ\_44L, M} = \text{MAX\_NO\_OF\_POLES} \qquad (4)$$

C2. Constraint that prevents putting two luminaires in the same point

To prevent the model from putting two luminaires at the same point or more than one luminaire at the same point but with different orientations. The thing that increases the probability of overlap in some points of the illuminated areas by the luminaires leads to an increase in the EXTRA_SUPPLY attribute and also an increase in the objective function. Equation (5) was used as the summation of the binary variables at each point must be less than or equal to 1, so the summation of this equation has only two results: (1) This equation would equal zero, which means that there are no luminaires located at this coordinate; (2) it would equal to 1 if there is a luminaire located at this coordinate.

$$\sum_{L,M} \text{YJ\_11}_{L,M} + \text{YJ\_22L, M} + \text{YJ\_33L, M} + \text{YJ\_44L, M} \leq 1 \qquad \forall\,(L, M) \qquad (5)$$

C.3 Some important data entered in the model according to the used luminaires

Firstly, the value of the maintenance factor for each luminaire.
- The value of the importance factor, as this factor is used to distinguish between the points that have importance and priority to be illuminated and the points that have less importance.
- The maximum number of used luminaires.

For discussion of the maintenance factor, importance factor, and maximum number of poles, are [21].

IV. Case Study

The proposed model was applied to a real-world project to demonstrate the applicability of the suggested model. Tahya Misr Bridge (Rod Al Farag Cable Stayed Bridge) was chosen as a case study for applications, specifically the preassembly yard at which the assembly of the steel frame of segments was implemented, as shown in Fig. 2. The values of the x-coordinates, and y-coordinates of the points of the grid were defined. These values are detected from drawings of (TYPICAL SEGMENT) adopted from the technical office of the project, 2018 **[**22**]**, and Google Earth is used to detect the coordinates.

The attribute DEMAND_1 has a varied value for each point of the grid depending on the accuracy needed for the implemented work. As the coordinates of the intersections between steel elements have a high level of illuminance defined in the attribute DEMAND_1, these coordinates are the locations where the tasks of welding and bolt installation, which require high accuracy, are implemented and where illumination levels should be checked. Other coordinates that have no tasks to be implemented on them have a general illuminance level defined in the attribute DEMAND_1.

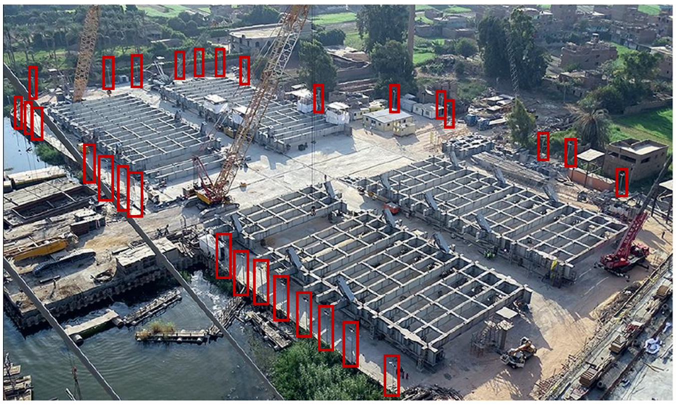

Fig. 2. Adopted from Yu and Chen [23], shows the preassembly yard, which is divided into four identical quarters, each quarter has four segments to be assembled. And also presents the allocation of the used luminaires in the preassembly yard, adopted by project administration.

V. Results

The proposed model was solved in two phases. In the first phase, the first group of results was obtained while solving the model using angle segma of the side luminaires equals 5º. The following group of results were obtained while solving the model using angle segma of the side luminaires equals 10º.

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Then the following group of results were obtained while solving the model using angle segma of the side luminaires equals 15º. And the last group of results were obtained while solving the model using angle segma of the side luminaires equals 20º. in order to study the effect of increasing the luminary angle on the value of the objective function, and the percentage of the covered demands, within the same number of the used poles. The results obtained in the first phase are shown in Table 4, Table 5, and Table 6.

The results of the second phase were obtained while varying the height of the luminaires: In the first group of the solved models, the internal luminaire height is 3m and the side luminaire height is 3m. In the second group of the solved models, the internal luminaire height is 3m and the side luminaire height is 4m. In the following group, the internal luminaire height is 3m and the side luminaire height is 5m. then the internal luminaire height is 4m and the side luminaire height is 4m.

Table 4. The results while Z_1 of the INTERNAL luminaire= 3m, and Z_1 of the SIDE luminaire= 5.

	SEGMA=5º	SEGMA=10º	SEGMA=15º	SEGMA=20º
9 poles	COVERAGE =68.59% OBJ=18208.2	Have the same light pole locations.		
		COVERAGE = 68.55% OBJ=18477.9	COVERAGE = 68.34% OBJ=18535.1	COVERAGE = 68.068% OBJ=18522.6
10 poles	COVERAGE = 73.63% OBJ=18881.3	COVERAGE = 73.23% OBJ=19214.6	COVERAGE = 72.62% OBJ=19324.5	COVERAGE = 72.286% OBJ=19269.7
11 poles	COVERAGE = 77.45% OBJ=19847.3	COVERAGE = 75.64% OBJ=20171.7	Have the same light pole locations.	
			COVERAGE = 75.11% OBJ=20196.3	COVERAGE = 74.97% OBJ=20147.1
12 poles	COVERAGE =81.3% OBJ=21012.1	Have the same light pole locations.		
		COVERAGE = 78.09% OBJ=21294.5	COVERAGE = 77.84% OBJ=21227.5	COVERAGE =77.69% OBJ=21212

Table 5. The results while Z_1 of the INTERNAL luminaire= 4m, and Z_1 of the SIDE luminaire= 4m.

	SEGMA=5º	SEGMA=10º	SEGMA=15º	SEGMA=20º
9 poles	COVERAGE =67.55% OBJ=17915.6	COVERAGE =66.46% OBJ=18342.5	Have the same light pole locations.	
			COVERAGE =66.20% OBJ=18300.1	COVERAGE =66.088% OBJ=18292.9
10 poles	COVERAGE =74.15% OBJ=18323.3	COVERAGE =71.27% OBJ=19055.1	Have the same light pole locations.	
			COVERAGE =70.69% OBJ=18964.2	COVERAGE =70.449% OBJ=18954.1
11 poles	COVERAGE =77.82% OBJ=19064.5	COVERAGE =75.1% OBJ=19935.7	Have the same light pole locations.	
			COVERAGE =73.29% OBJ=19865.4	COVERAGE =73.047% OBJ=19884.6
12 pole	COVERAGE =80.54% OBJ=20223.3	COVERAGE =77.51% OBJ=21026.3	COVERAGE =75.94% OBJ=20953.3	COVERAGE =76.133% OBJ=20996.3
13 poles	COVERAGE =81.6% OBJ=21709.5	COVERAGE =79.42% OBJ=22257.9	COVERAGE =79.295% OBJ=22117.8	COVERAGE =80.252% OBJ=22116

Table 6. The results while Z_1 of the INTERNAL luminaire= 4m, and Z_1 of the SIDE luminaire= 5m.

	SEGMA=5º	SEGMA=10º	SEGMA=15º	SEGMA=20º
9 poles	Have the same light pole locations.			
	COVERAGE = 68.67% OBJ=18461.6	COVERAGE =68.55% OBJ=18744.3	COVERAGE = 68.35% OBJ=18850.7	COVERAGE = 68.16% OBJ=18918.1
10 poles	Have the same light pole locations.			COVERAGE = 71.92% OBJ=20149.3
	COVERAGE = 73.375% OBJ=19128.9	COVERAGE = 73.202% OBJ=19740.1	COVERAGE = 72.824% OBJ=20004.7	
11 poles	Have the same light pole locations.			COVERAGE = 76.24% OBJ=21392.2
	COVERAGE = 77.43% OBJ=20285.1	COVERAGE = 77.18% OBJ=20990.4	COVERAGE = 76.68% OBJ=21257.9	
12 poles	Have the same light pole locations.			
	COVERAGE = 81.653% OBJ=21697.4	COVERAGE = 81.27% OBJ=22522	COVERAGE = 80.64% OBJ=22794	COVERAGE = 78.925% OBJ=22922.3

In the final group, the internal luminaire height is 4m and the side luminaire height is 5m. To explore the effect of the increase in the luminaire height on the value of the objective function, the percentage of the covered demands, and the locations of the luminaires within the same number of the used poles and the same luminary angle (segma). The results obtained in the second phase are shown in Table 7, and Table 8.

VI. Discussion

While comparing the results of all studied cases in phase 1, in most cases, the highest coverage percentage and the minimum values of the objective functions were with small values of luminary angle (segma) as shown in Table 4 highlighted in gray and blue, Table 5 highlighted in yellow, and Table 6 highlighted in yellow. At the beginning, while increasing the number of luminaires from 9 to 10, there is a satisfying increase in the coverage percentage and also a moderate increase in the objective function as shown in Table 4 highlighted in gray. On the other hand, while increasing the number of luminaires from 12 to 13, as shown in Table 4 highlighted in blue, there is a slight increase in the coverage percentage compared to the increase in the objective function. Which reflects that there is too much wasted lighting. While comparing the results of the group that uses an internal luminaire of 4m height, and a side luminaire of 4m height with the results of the group that uses an internal luminaire of 4m height and a side luminaire of 5m height shown in Table 5, and Table 6 highlighted in yellow:

- While using the number of luminaires of 9, there is a slight difference in the coverage percentage and a decrease in the objective function, which means that increasing the height in that case leads to a better use of luminaires.
- That also happens while comparing the results of 10 poles, 11 poles, and 12 poles. AT SEGMA= 5º, 10º, 15º, AND 20º

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Table 7. The results while segma=5°, the highest coverage value, and the associated objective function highlighted in blue.

The Internal luminaire height	3m	3m	3m	4m	4m
The side luminaire height	3m	4m	5m	4m	5m
9 poles	Have the same light pole locations. COVERAGE =66.98% OBJ=18685.8	COVERAGE =67.03% OBJ=18264.5	COVERAGE = 67.55% OBJ=17915.6	COVERAGE =68.67% OBJ=18461.7	COVERAGE =68.59% OBJ=18208.2
10 poles	Have the same light pole locations. COVERAGE =72.22% OBJ=19692.9	COVERAGE =72.3% OBJ=18849	COVERAGE =74.15% OBJ=18323.3	COVERAGE =73.375% OBJ=19128.9	COVERAGE =73.63% OBJ=18881.3
11poles	COVERAGE =75.73% OBJ=21026.2	COVERAGE =77.77% OBJ=19835	COVERAGE =77.82% OBJ=19064.5	COVERAGE =77.43% OBJ=20285.1	COVERAGE =77.45% OBJ=19847.3
12poes	COVERAGE =79.42% OBJ=22483.7	COVERAGE =82.52% OBJ=21047.6	COVERAGE =80.54% OBJ=20223.3	COVERAGE =81.65% OBJ=21697.4	COVERAGE =81.3% OBJ=21012.1
13poles	COVERAGE =83.97% OBJ=24237.8	COVERAGE =83.97% OBJ=22566.4	COVERAGE =81.6% OBJ=21709.5	Have the same light pole locations. COVERAGE =81.3% OBJ=23769.1	COVERAGE =81.3% OBJ=22562.2

Table 8. The results while segma=10° the highest coverage value, and the associated objective function highlighted in blue.

The Internal luminaire height	3m	3m height	3m height	4m height	4m height
The side luminaire height	3m	4m height	5m height	4m height	5m height
9 poles	Have the same light pole locations. COVERAGE =66.92% OBJ=18975.3	COVERAGE =66.82% OBJ=18548	COVERAGE =66.46% OBJ=18342.5	Have the same light pole locations. COVERAGE =68.551% OBJ=18744.3	COVERAGE =68.56% OBJ=18477.9
10 poles	Have the same light pole locations. COVERAGE =72.11% OBJ=20300.7	COVERAGE =71.96% OBJ=19461.2	COVERAGE =71.27% OBJ=19055.1	Have the same light pole locations. COVERAGE =73.2% OBJ=19740	COVERAGE =73.24% OBJ=19214.6
11poles	COVERAGE =75.81% OBJ=21758	Have the same light pole locations. COVERAGE =75.86% OBJ=20570.8	COVERAGE =75.1% OBJ=19935.7	COVERAGE =77.18% OBJ=20990.4	COVERAGE =75.64% OBJ=20171.7
12poes	COVERAGE =79.41% OBJ=23308.5	COVERAGE =79.82% OBJ=21976.9	COVERAGE =77.51% OBJ=21026.3	COVERAGE =81.28% OBJ=22522	COVERAGE =78.093% OBJ=21294.5

Table 9. The variations in locations of the internal and side luminaires at the smallest value of segma [segma=5] while increasing the height from 3m to 4m for the internal and side luminaires:

	3m internal luminaire height, 3m side luminaire height	4m internal luminaire height, 4m side luminaire height
9 poles	The optimization results indicate using the same number of internal and side luminaires.	
10 poles	The optimization results indicate using the same number of internal and side luminaires.	
11 poles	The optimization results indicate using the same number of internal and side luminaires.	
12 poles	The optimization results tend to increase the number of side luminaires while increasing the height.	
13 poles	The optimization results tend to increase the number of side luminaires while increasing the height.	

While comparing the results of the group that uses an internal luminaire of 3m height and a side luminaire of 3m height with the results of the group that uses an internal luminaire of 4m height and a side luminaire of 4m height presented in phase 2 (the case that the internal and the side luminaires have the same height), there are two notes:
The first note about the allocation of luminaires is shown in tables 9, 10, and 11.

At segma= 20:

In all trials, the optimization results tend to increase the number of side luminaires while increasing the height.
The second note about the coverage and the value of the objective function is:

In trials that use 9 luminaires as the MAX_NO_OF_POLES.

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Table 10. The variations in locations of the internal and side luminaires value of segma= 10 while increasing the height from 3m to 4m for the internal and side luminaires:

	3m internal luminaire height, 3m side luminaire height	4m internal luminaire height, 4m side luminaire height
9 poles	The optimization results indicate using the same number of internal and side luminaires.	
10 poles	The optimization results indicate using the same number of internal and side luminaires.	
11 poles	The optimization results tend to increase the number of side luminaires while increasing the height.	
12 poles	The optimization results tend to increase the number of side luminaires while increasing the height.	

Table 11. The variations in locations of the internal and side luminaires value of segma= 15 while increasing the height from 3m to 4m for the internal and side luminaires:

	3m internal luminaire height, 3m side luminaire height	4m internal luminaire height, 4m side luminaire height
9 poles	The optimization results indicate using the same number of internal and side luminaires.	
10 poles	The optimization results tend to increase the number of side luminaires while increasing the height.	
11 poles	The optimization results tend to increase the number of side luminaires while increasing the height.	
12 poles	The optimization results tend to increase the number of side luminaires while increasing the height.	

The results show that the increase in height leads to an increase in the coverage percentage and a decrease in the objective function, as shown in Table 7 and Table 8 highlighted in green which reflects a better use of luminaires. That also happens while comparing the results of 10 poles, 11 poles, and 12 poles.

In the case that the internal and the side luminaires have the same height while increasing the angle segma, the height of the luminaires, and the number of luminaires, the model tends to increase the number of side luminaires, and in most cases, there is an increase in the coverage percentage and a reduction in the value of the objective function, as shown in Tables 9, 10, and 11.

While comparing the results of the case that uses an internal luminaire of 3m height, and a side luminaire of 4m height with the results of the case that uses an internal luminaire of 3m height and a side luminaire of 5m height:

At segma=5:

- While using 9 poles as the MAX_NO_OF_POLES, the results show that the increase in height leads to an increase in the coverage percentage and a decrease in the objective function, as shown in Table 7 highlighted in orange. That is because of the cooperative-gradual covering concept. as the decrease in the percentage of fully covered points has been compensated by the increase in partially covered points.

- That also happens while comparing the results of 10 poles and 11 poles.

- While using 12 poles, the results show that the increase in height leads to a decrease in the coverage percentage and a decrease in the objective function as shown in Table 7 highlighted in yellow. As while increasing the height. As the number of internal and side luminaires still the same, so this reduction is because of the inverse relation between the height and the illuminance.

At segma= 10, 15, and 20:

In all trials, the results show a decrease in the coverage percentage and a decrease in the objective function because of the inverse relation between the height and the illuminance.

VII. COMPARING THE OBTAINED RESULTS WITH THE ALLOCATIONS OF THE LUMINAIRES USED ACTUALLY DURING THE IMPLEMENTATION

As shown in Fig. 2, the used luminaires in the preassembly yard were allocated only in the outer parameter of the preassembly yard, taking into consideration the tracks of the cranes shown in Fig. 2. This allocation leads to some inside areas having no lighting, which impedes performing the work due to inadequate lighting. As a result of decreased visibility in the work zone during night operations, productivity is hindered and accident hazards are increased. While there is an ability to put some luminaires in the spaces between segments to increase the area that has adequate illuminance to perform the work or close to it, as performed in the optimization model.

Fig. 3-a shows the optimized number, location and orientation of the side luminaires with segma= 10º in which The percentage of the covered demands is 88.36%. Fig. 3-b presents the illuminance coverage in the shape of a contour map.

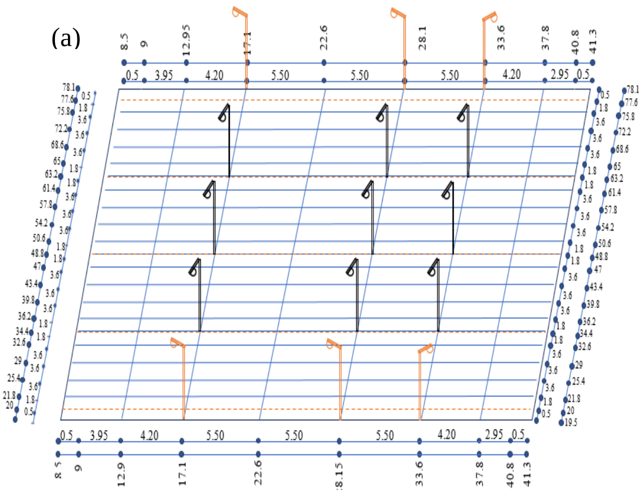

Fig. 3-a .The locations of the used luminaires.

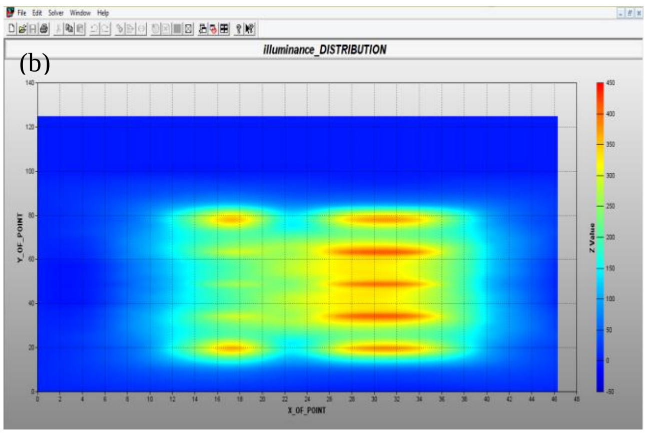

Fig. 3-b. The illuminance coverage in the shape of contour map.

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VIII. CONCLUSION

A mixed integer linear programming model was presented to investigate the effect of luminaire height and luminary angle on the illumination coverage of the work zone. The objective function used seeks to minimize the number of points that receive an amount of illumination that exceeds the demand and also reduce the number of points that receive illumination that is less than the demand. According to the previously mentioned discussion and the results:

- Keeping the angle segma as small as possible leads to large coverage and minimizes the objective function.
- Increasing the luminaire height leads to large coverage, but with a limit due to the inverse relationship between the height and the illuminance.
- In case that the internal and the side luminaires have the same height while increasing the angle segma, the height of the luminaires, and the number of poles, the model tends to increase the number of side luminaires, and in most cases, there is an increase in the coverage percentage and a reduction in the value of the objective function.

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List of Symbols

The use symbols in this paper are:

Z_1: The vertical distance measured from the luminaire's centre to the pavement's surface.

SEGMA: that represents the angle in degrees between the vertical and the luminaire's centre of beam spread (tilt).

ORIENTATION_ANGLE: represents the luminaire's rotation about a vertical axis.

MAX_NO_OF_POLES: The maximum total number of luminaires being used.

X_OF_POLE, Y_OF_POLE: refer to the x and y coordinates of the internal luminaire.

X_OF_POLE_2, Y_OF_POLE_2: represent the x and y coordinates of the side luminaire.

X_OF_POINT, Y_OF_POINT: refer to the x and y coordinates of the grid points.

TOTAL_RECEIVED_ILLUMINANCE: the cumulative illuminance received by the grid point from all surrounding luminaires.

DEMAND_1: denotes the illuminance value needed by the point to satisfy visual requirements according to the nature of the implemented work.

EXTRA_SUPPLY: is the value of the received illuminance by the grid point that exceeds the demand.

EXTRA_DEMAND: is the value of the complimentary illuminance that the grid point needs to fulfill its demand.

YJ: is a binary variable that denotes whether or not the luminaire is situated at a particular coordinate.

The use subscripts in this paper are:

(A, B): refer to the x and y coordinates for each studied grid point.

(C, G): represent the x and y coordinates of the internal luminaire.

(L, M): refer to the x and y coordinates of the side luminaire.

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