PARTICLE BEE ALGORITHM FOR TOWER CRANES LAYOUT WITH MATERIALS QUANTITY SUPPLY AND DEMAND OPTIMIZATION

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ABSTRACT

Tower crane layout (TCL) is a typical construction site layout (CSL) problem, which is suitable for a wide range of work assignments and site conditions. Tower crane is one of the key facilities for vertical and horizontal transportation of materials, especially for heavy prefabrication units such as steel beams, ready mixed concrete, prefabricated elements and large panel formwork such as machinery and equipment, and a wide variety of other building materials within a construction site. However, it is a difficult combinatorial optimization problem to determine the locations of tower cranes with materials quantity supply and demand for engineers. Swarm intelligence (SI) was very popular and widely used in many complex optimization problems which was collective behaviour of social systems such as honey bees (bee algorithm, BA) and birds (particle swarm optimization, PSO). This study applied a hybrid swarm algorithm namely particle bee algorithm (PBA) based on a particular intelligent behaviour of honey bee and bird swarms by integrates theirs advantages. This study compares the performance of PBA with BA and PSO for a proposed hypothetical construction engineering of TCL with materials quantity supply and demand problem. Results show that PBA performs better performance than the mentioned algorithms on a proposed hypothetical TCL problem.

KEYWORDS

Tower cranes layout, swarm intelligence, bee algorithm, particle swarm optimization, particle bee algorithm

INTRODUCTION

Construction site layout (CSL) problems are particularly interesting because in addition to common engineering objectives such as cost and performance, facility design is especially concerned with aesthetics and usability qualities of a layout (Michalek et al., 2002). The CSL problem identifies a feasible location for a set of interrelated objects that meet all design requirements and maximizes design quality in terms of design preferences while minimizing total cost associated with interactions between these facilities. In the past, artificial intelligence (AI) based methods have been applied to solving CSL problems (Elbeitagi & Hegazy, 2001; Yeh, 2006; Li & Love, 2000; Osman et al., 2003; Hegazy & Elbeltagl, 1999; Elbeitagi et al., 2001). Tower crane layout (TCL) is a typical CSL problem, which is suitable for a wide range of work assignments and site conditions. TCL is one of the key facilities for vertical and horizontal transportation of materials, especially for heavy prefabrication units such as steel beams, ready mixed concrete, prefabricated elements and large panel formwork such as machinery and equipment, and a wide variety of other building materials within a construction site (Tam & Tong, 2003; Zhang et al., 1999; Tam et al., 2001; Huang et al. 2011).

Swarm intelligence (SI) has been of increasing interest to research scientists in recent years. SI was defined by Bonabeau et al. (1999) as any attempt to design algorithms or distributed problem-solving devices based on the collective behaviour of social insect colonies or other animals. Bonabeau et al. (1999) focused primarily on the social behaviour of ants (Dorigo, 1992), fish (Li, 2003), birds (Kennedy & Eberhart, 1995) and bees (Pham et al., 2006) etc. However, the term “swarm” can be applied more generally to refer to any restrained collection of interacting agents or individuals. Although bees swarming around a hive is the classical example of “swarm”, swarms can easily be extended to other systems with similar architectures.

A few models have been developed to model the intelligent behaviours of honeybee swarms and applied to solve combinatorial type problems (Pham et al., 2006; Yang, 2005; Karaboga & Akay, 2009; Basturk & Karaboga, 2006; Ozbakir et al., 2010). However, while BA (Pham et al., 2006) offers the potential to conduct global searches and uses a simpler mechanism in comparison with GA, it dependence on random search makes it relatively weak in local search activities and does not records past searching experiences during the optimization search process. For instance, a flock of birds may be thought of as a swarm whose individual agents are birds. Particle swarm optimization (PSO), which has become quite popular for many researchers recently (Parsopoulos & Vrahatis, 2007), models the social behaviour of birds (Pham et al., 2006). PSO potentially used in local searching, and records past searching experiences during optimization search process. However, it converges early in highly discrete problems (Korenaga et al., 2006).

Due to improve BA and PSO, Cheng and Lien (2012) proposed an hybrid swarm algorithm called particle bee algorithm (PBA) that imitates a particular intelligent behaviour of bird and honey bee swarms and integrates their advantages. The objective of this study is to formulate the design problem for a proposed hypothetical TCL case study involving locating tower cranes and associated material supply and demand points into a mixed-integer linear program to minimize the total operating cost.

HYBRID SWARM ALGORITHM PARTICLE BEE ALGORITHM

Particle bee algorithm (PBA) was proposed by Cheng and Lien (2012) that based on the intelligent behaviors of bird and honeybee swarms. For improved BA local search ability, PSO global search ability and to seek records past experience during optimization search process, that study reconfigures the neighbourhood dance search (Pham et al., 2006) as a PSO search (Kennedy & Eberhart, 1995). Based on cooperation between bees (BA) and birds (PSO), the PBA improves BA neighbourhood search using PSO search. Therefore, PBA employs no recruit bee searching around “elite” or “best” positions (as BA does). Instead, a PSO search is used for all elite and best bees. In other words, after PSO search, the number of “elite”, “best” and “random” bees equals the number of scout bees. In PBA, the particle bee colony contains four groups, namely (1) number of scout bees (n), (2) number of elite sites selected out of n visited sites (e), (3) number of best sites out of n visited sites (b), and (4) number of bees recruited for the other visited sites (r). The first half of the bee colony consists of elite bees, and the second half includes the best and random bees. The particle bee colony contains two parameters, i.e., number of iteration for elite bees by PSO (*Pelite*) and number of iteration for best bees by PSO (*Pbest*).

CASE STUDY OF TOWER CRANE LAYOUT PROBLEMS

Modeling of tower crane layout problem

<u>A reference tower crane layout</u>

In the past, before planning the tower crane layout (TCL), the engineers consider site condition, structure of the building, construction sequence, market conditions and climate conditions to selecting the locations of tower crane, supply, demand points and necessary equipments. In this study, the modeling for TCL was based on the minimum the operation time that referenced from previously works (Tam et al., 2001; Huang et al., 2011). In Tam and Hoang’s work, they assumed the influence only the cost of material operation flow from per crane operation time. They neglect for consideration the important factors such as rent cost, labours cost and, tower crane setup cost, etc. Therefore, this study continues their work and designs the more practical from the construction site current situation of the TCL modeling. A project is adopted and modified as a reference (Tam et al., 2001) case study to determine optimal TCL with materials quantity supply and demand through PSO, BA and PBA. The project includes 12 alternate tower crane selecting areas, the coordinates as show in Table 1. Besides, this project has 9 supply points and 9 demand points, the coordinates as respectively show in Tables 2 and 3. The completed site map of this project is shown in Figure 1.

Table 1 Coordinates of crane points

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
X	45	65	65	45	51	60	70	70	60	51	42	42
Y	36	36	57	57	33	33	41	52	58	58	52	41
Z	30	30	30	30	30	30	30	30	30	30	30	30

Table 2 Coordinates of demand points

	D1	D2	D3	D4	D5	D6	D7	D8	D9
X	34	34	51	60	76	76	60	51	43
Y	41	51	65	65	51	41	26	25	44
Z	15	15	15	15	15	15	15	15	15

Table 3 Coordinates of supply points

	S1	S2	S3	S4	S5	S6	S7	S8	S9
X	73	83	87	73	55	35	22	36	55
Y	26	31	45	67	73	67	46	27	15
Z	2	2	1.5	1.5	1.5	0	0	1	1

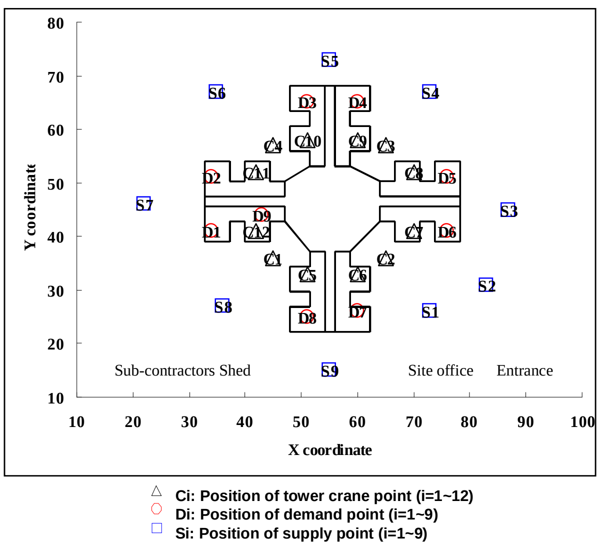

Figure 1 – A reference of tower crane layout

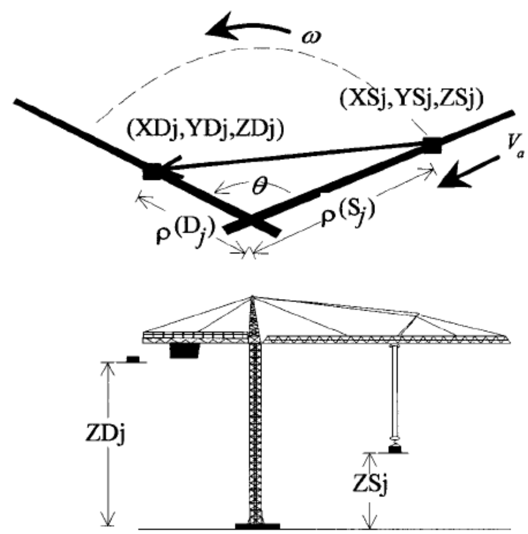

Figure 2 – Hook travel time

<u>Objective function</u>

In this study, particle bee algorithm (PBA) was used for optimizing the locations of tower crane. At the meanwhile, based on the material requirement of demand and supply points, PBA was also used for optimizing the operation distance and frequency from demand and supply points base on minimize total operating cost. The objective function of the TCL problem must satisfy two requirements: (1) It must be high for only those solutions with a high design preference; and (2) it must be high for only those solutions that satisfy the layout constraints. Therefore, this study was based on Ref. (Tam et al., 2001), giving the total objective function as follows Figure 2 and (Equation 1).

Minimize
$$TC = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{o} T_i \times Q_{jk} \times CU_i + R + S + L \quad (1)$$

$$T_i = \max(T_{hi}, T_{vi}) + \beta_i \times \min(T_{hi}, T_{vi}) \quad (2)$$

$$T_{hi} = \max(T_{ai}, T_{wi}) + \alpha_i \times \min(T_{ai}, T_{wi}) \quad (3)$$

$$T_{vi} = \left| ZS_m - ZD_o \right| / V_{hi} \quad (4)$$

$$T_{ai} = \left| \rho(D_o) - \rho(S_m) \right| / V_{ai} \quad (5)$$

$$T_{wi}=\frac{1}{V_{wi}}\times \arccos(\frac{l_p^2-\rho(D_o)^2-\rho(S_m)^2}{2\times\rho(D_o)\times\rho(S_m)}) \quad (6)$$

$$\rho(D_o)=\sqrt{(XD_o-XCr_i)^2+(YD_o-YCr_i)^2} \quad (7)$$

$$\rho(S_m)=\sqrt{(XS_m-XCr_i)^2+(YS_m-YCr_i)^2} \quad (8)$$

$$l_p=\sqrt{(XD_o-XS_m)^2+(YD_o-YS_m)^2} \quad (9)$$

$$R=\sum_i^n M_i\times(\text{int}(DY_i/30)+1) \quad (10)$$

$$S=\sum_i^n IS_i+MS_i\times MST_i+RS_i \quad (11)$$

$$L=\sum_i^n LC_i\times LA_i\times DY_i \quad (12)$$

where *TC* is total cost; *n* is the number of crane; *m* is the number of supply points; *o* is the number of demand points; T_i is hook travel time by i_{th} crane; T_{hi} is hook horizontal travel time by i_{th} crane; Q_{jk} is quantity of material flow from S_j to D_k; CU_i is cost of material flow from S_j to D_k per unit quantity and unit time by i_{th} crane (define value is $1.92 (Tam et al., 2001)); α_i is degree of coordination of hook movement in radial and tangential directions in horizontal plane by i_{th} crane (define value is 1 (Zhang et al., 1999)); T_{vi} is hook vertical travel time by i_{th} crane; V_{hi} is hoisting velocity of hook by i_{th} crane (this study setting the value are between 35 to 60 m/min (Tam et al., 2001)); β_i is degree of coordination of hook movement in vertical and horizontal planes by i_{th} crane (define value is 0.25 (Zhang et al., 1999)); T_{ai} is time for trolley radial movement by i_{th} crane; V_{ai} is radial velocity of trolley by i_{th} crane (this study setting the value are between 33.1 to 53.3 m/min (Tam et al., 2001)); T_{wi} is time for trolley tangent movement by i_{th} crane; l_i is distance between supply and demand points; Vw_i is slewing velocity of jib (this study setting the value are between 2.8 to 7.57 rad/min (Tam et al., 2001)); $\rho(D_i)$ is horizontal distance from tower to demand point; $\rho(S_i)$ is horizontal distance from tower to supply point; $Cr_i(XCr_i, YCri, ZCr_i)$ is coordinate of tower crane; $D_i(XD_i, YD_i, ZD_i)$ is coordinate of demand point *i*; $S_i(XS_i, YS_i, ZS_i)$ is coordinate of supply point *i*; *R* is total rent cost; *S* is tower crane total setup cost; *L* is total labour cost; M_i is rent cost per month by i_{th} crane (define value is $1,000 (Cheng & Chen, 2002)]); DY_i is days of renting tower crane / labour work by i_{th} crane (define value is $80 (Cheng & Chen, 2002)]); IS_i is tower crane initial setup cost (define value is $5,000 (Cheng & Chen, 2002)); MS_i is tower crane modify setup cost by i_{th} crane (define value is $500 (Cheng & Chen, 2002)); MST_i is modify setup times by i_{th} crane (define value is 10 (Cheng & Chen, 2002)); RS_i is disassemble cost (define value is $2,000 (Cheng & Chen, 2002)); LC_i is labour cost per person by i_{th} crane (define value is $100 (Cheng & Chen, 2002)); LA_i is labour amount by i_{th} crane (define value is 5 person (Cheng & Chen, 2002)).

Subject to If actual supply capacities (i) > limit supply capacities (i) then TC=TC+40,000
If actual demand capacities (i) <> limit demand capacities (i) then *TC*=*TC*+40,000

Table 4 – Parameter values used in the experiments

PSO		BA		PBA	
n	100	*n*	100	*n*	100
w	0.9~0.7	*e*	n/2	*e*	*n*/2
v	Xmin/10~Xmax/10	*b*	n/4	*b*	*n*/4
		r	n/4	*r*	*n*/4
		n1	2	*w*	0.9~0.7
		n2	1	*v*	X_{min}/10~X_{max}/10
				Pelite	15
				Pbest	9

n=population size (colony size); *w*=inertia weight; *v*=limit of velocity; *e*=elite bee number; *b*=best bee number; *r*=random bee number; n_1= elite bee neighbourhood number; n_2=best bee neighbourhood number; *Pelite*=PSO iteration of elite bees; *Pbest*=PSO iteration of best bees.

Results and discussion for single tower crane

This study was adapted from 30 experimental runs with the values found in Table 4 through 100, 300, 500, 1000 and 5000 iterations by BA, PSO and PBA. The parameters value used for single tower crane design found in Table 5. Table 6 and Figure 3 present the evolution of the TCL problem result. As seen in Table 6, the best mean fitness and best solution for PBA are respectively 7.03E+05 and 5.41E+05, which is better than BA (8.86E+05 and 8.35E+05) and PSO (8.68E+05 and 7.50E+05). The result shows that PBA provides a better evolution result than BA and PSO.

Table 5 – Parameter values used in single tower crane

	CU	*α*	*Vh*	*β*	*Va*	*Vw*	*M*	*DY*	*IS*	*MS*	*MST*	*RS*	*LC*	*LA*
Crane #1	1.92	1	60	0.25	53.3	7.57	1,000	80	5,000	500	10	2,000	100	5

Table 6 – The result of three algorithms

	Iteration	Mean	Worst	Best	Std
PBA	100	7.62E+05	8.92E+05	7.08E+05	6.64E+04
	300	7.34E+05	8.50E+05	6.21E+05	5.31E+04
	500	7.44E+05	8.28E+05	6.19E+05	5.63E+04
	1000	7.08E+05	8.12E+05	5.83E+05	6.28E+04
	5000	**7.03E+05**	8.55E+05	**5.41E+05**	5.99E+04
BA	100	9.52E+05	9.83E+05	9.10E+05	1.46E+04
	300	9.30E+05	9.56E+05	8.83E+05	1.64E+04
	500	9.17E+05	9.46E+05	**8.35E+05**	2.14E+04
	1000	9.12E+05	9.35E+05	9.03E+05	6.39E+03
	5000	**8.86E+05**	9.08E+05	8.59E+05	1.55E+04
PSO	100	9.29E+05	1.01E+06	8.90E+05	2.88E+04
	300	9.05E+05	1.00E+06	7.87E+05	4.25E+04
	500	8.84E+05	9.40E+05	8.24E+05	2.88E+04
	1000	8.82E+05	9.73E+05	7.91E+05	3.69E+04
	5000	**8.68E+05**	9.46E+05	**7.50E+05**	3.87E+04

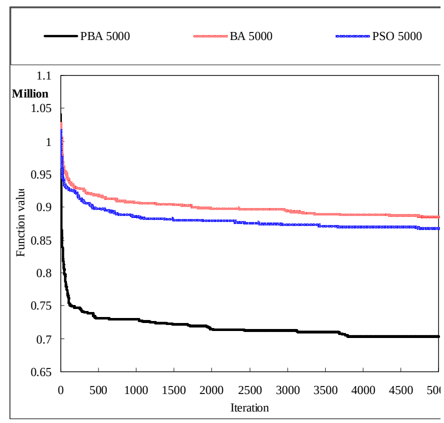

Figure 3 – Evolution of mean best values for single TCL problem

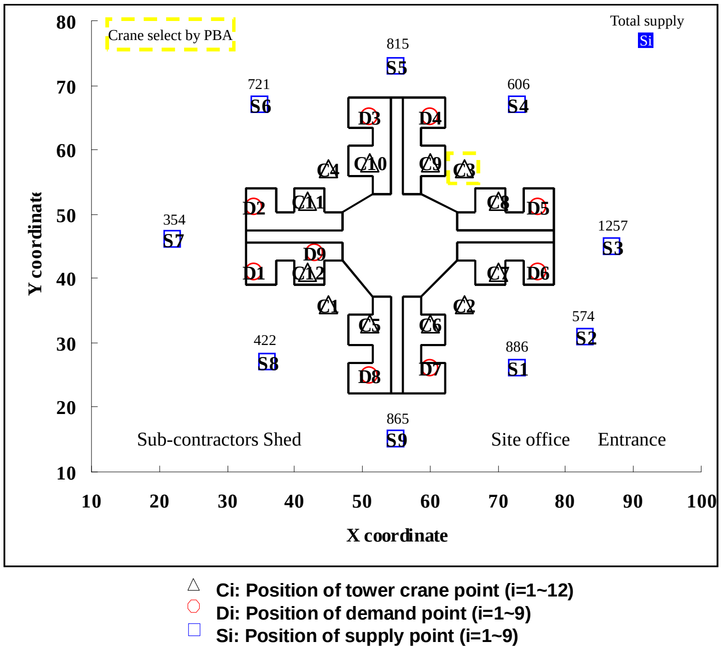

Figure 4 – PBA best single tower crane layout design

The optimal location of single tower crane alternative is shown in Figure 4. In Figure 4, the best tower crane location is selecting on location "C3". Table 7 is the best capacity of demand and supply points optimization design. As seen in Figure 4 and Table 4, supply points S1 to S6 that closely to location "C3" are having higher supply degrees of completion than S7 to S9. The result shows the PBA not only optimize the tower crane location but also satisfies minimize operating cost for the demand and supply points capacity.

Table 7 – PBA best capacity of demand and supply points design

		D1	D2	D3	D4	D5	D6	D7	D8	D9	Actual supply	Limit supply	Supply degree
C3	S1	237	0	0	208	0	231	96	0	114	886	1500	59%
	S2	154	0	111	0	0	0	82	227	0	574	1000	57%
	S3	97	151	0	179	264	0	0	314	252	1257	1500	84%
	S4	136	0	315	0	0	102	0	0	53	606	1000	61%
	S5	58	252	140	0	0	0	0	0	365	815	1500	54%
	S6	0	218	0	50	0	0	361	0	92	721	1000	72%
	S7	0	71	77	45	0	161	0	0	0	354	1500	24%
	S8	0	0	0	69	120	106	83	44	0	422	1000	42%
	S9	218	108	57	49	116	0	78	215	24	865	1500	58%
	Total										6500	11500	57%
	Actual demand	900	800	700	600	500	600	700	800	900	6500		
	Limit demand	900	800	700	600	500	600	700	800	900	6500		

CONCLUSION

In the previous section, the performance of the particle bee algorithm (PBA) was compared with particle swarm optimization (PSO), and bee algorithm (BA) on a proposed hypothetical tower crane layout (TCL) problem. Results show that PBA performs better performance than the mentioned algorithms on this proposed hypothetical TCL problem. In single tower crane design section, the result shows the PBA not only optimize the tower crane location but also satisfies minimize operating cost for the demand and supply points capacity.

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