Information-based Allocation Strategy for GRID-based Transshipment Automated Container Terminal

Appendix 1 Modified SAP Model

Additional Parameters

B	Batch size;
N_s	The set of selected jobs, index *n*, $1 \le n \le B$;
N_f	The set of fixed jobs, index n_h, $1 \le n_h \le \frac{B}{2}$;
f^s	Sum of flow of fixed jobs;
w^s	Sum of containers of fixed jobs;
w_{kt}^0	Storage capacity of fixed jobs in section *k* in shift *t*;
f_{kt}^0	Flow of fixed jobs in section *k* in shift *t*;

(SAP-M) Objective:

$$\min SAP - M = \alpha_1 D + \alpha_2 U \tag{1}$$

Subject to:

Constraints (3), (7) to (9) and (19) to (21).

$$D = \left(\frac{\sum_{n \in N_s} \sum_{k=1}^{K} (l_{o_n k} + l_{d_n k})(W_{nk}^{20} + W_{nk}^{40}) + f^s}{\sum_{n \in N_s} (w_n^{20} + w_n^{40}) + w^s} \right) \tag{2}$$

$$\sum_{k=1}^{K} W_{nk}^{20} = w_n^{20}, \quad n \in N_s \tag{3}$$

$$\sum_{k=1}^{K} W_{nk}^{40} = w_{n}^{40}, \quad n \in N_s \tag{4}$$

$$w_{kt}^{0} + C_{kt} + \sum_{n \in \{n | t_n^d = t\}} \left(\frac{W_{nk}^{20}}{2} + W_{nk}^{40} \right) \le \beta \cdot c, \quad k \in K, t \in T \tag{5}$$

$$f_{kt}^{0} + \sum_{n \in \{n | t_n^d = t \vee t_n^l = t\}} \left(W_{nk}^{20} + W_{nk}^{40} \right) \le \sum_{\forall r} \sum_{j \in J_r} \delta_{stj} y_j x_j^{I_1(s,k)}, \quad s \in S, t \in T, k \in K_s \tag{6}$$

Appendix 2 Batch Sequential Allocation

Additional Parameters

N^t	Set of the jobs which arrive at shift *t*, $t = 1, 2, 3 ... T$
A	Number of shifts that the operator will know the scheme in advance; for example, if current shift is 3, then $N^3 ... N^{3+A}$ will be considered as known.

1. Calculate SI for each job and sort the job set N by SI in increasing order;
2. Move the first *B* (batch size) jobs into the set N_s; if remaining jobs are less than *B*, then move all jobs and mark this iteration as the last iteration;
3. Solve job set N_s with *SAP-M* and CPLEX; if this is the first iteration, then $f^s = 0$, $w^s = 0$, .. and $f_{kt}^0 = 0$ for all k and t; if infeasible, stop the whole process.
4. Move the first half jobs from N_s to N_f and move the rest jobs to the beginning of the set N_k; if this is the last iteration, move all jobs from N_s to N_f.

5. Update f^s and w^s using

$$f^s = \sum_{n \in N_f} \sum_{k=1}^{K} (l_{o_n k} + l_{d_n k})(W_{nk}^{20} + W_{nk}^{40})$$

$$w^s = \sum_{n \in N_f} (w_n^{20} + w_n^{40})$$

Update p_{kt} and f_{kt} using

$$w_{kt}^0 = \sum_{n \in \{n | n \in N_f, t \in \{\text{job } n \text{ staying time}\}\}} \left(\frac{W_{nk}^{20}}{2} + W_{nk}^{40} \right)$$

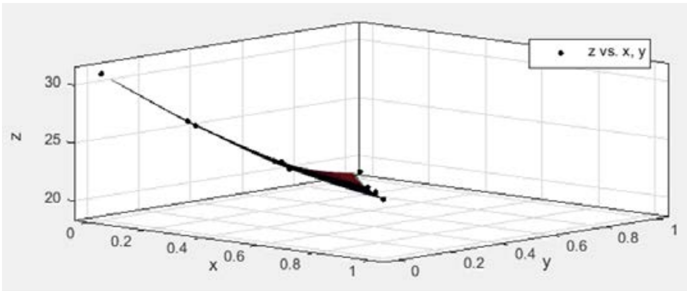
$$f_{kt}^0 = \sum_{n \in \{n | n \in N_f, t_n^d = t \vee t_n^l = t\}} \left(W_{nk}^{20} + W_{nk}^{40} \right)$$

6. Repeat step 2 – 5 until the job set is empty.

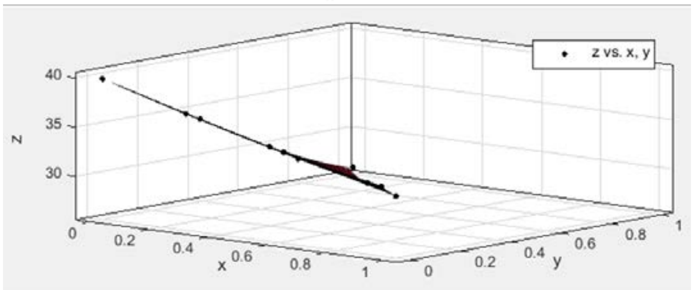
Appendix 3 Simulation of the GRID Module with Three Sections

In this study, we use the layout with three sections as shown in Figure 3 in the main context. According to Section 4.3, for each *m*, we divide the domain space into 9 regions with 10 data points, as shown in Figure 5 (1) in the main context. Since the maximum number of TUs is 13 so eventually we have 117 regions.

To obtain the data points, we run the simulation with 10 cases of the distribution of the container activities, including $(1,0,0)$, $(0,1,0)$, $(0,0,1)$, $\left(0,\frac{1}{3},\frac{2}{3}\right)$, $\left(\frac{1}{3},0,\frac{2}{3}\right)$, $\left(\frac{1}{3},\frac{2}{3},0\right)$, $\left(\frac{2}{3},\frac{1}{3},0\right)$, $\left(\frac{2}{3},0,\frac{1}{3}\right)$, $\left(0,\frac{2}{3},\frac{1}{3}\right)$ and $\left(\frac{1}{3},\frac{1}{3},\frac{1}{3}\right)$, and the number of TUs varies from 1 to 13, and then we have totally 130 data points. Figure 13 in the main context shows the simulation result of the TU handling capacity function (per hour per I/O point) with respect to the container assignment plan when TU number is 4 and 6. It should be noted that since the data in the figure is using per hour per I/O point, the value using in the constraints should multiply by 16 (8 hour-shift and 2 I/O points)



GRID in 3*Depth layout, TU = 4



GRID in 3*Depth layout, TU = 6

Figure 1 TU handling capacity function in terms of the distribution of the container activities

Appendix 4 COI, DoS and PRD

1) COI: the COI of a job is defined as the ratio of the job's total required space to the number of trips required to satisfy its demand per period. In the GRID system, a 20-foot container only occupy half unit of the storage capacity and one TU can only pick up one container regardless of its type. Therefore, for each job, the SI is defined as

$$SI = \frac{w_n \times \Gamma_n}{\left(\frac{w_n}{DoS_n}\right)} = DoS_n \times \Gamma_n$$

where w_n is the job volume, which either equals to w_n^{20} or w_n^{40} since each job only have one type of container; DoS_n is defined as $DoS_n = t_n^l - t_n^d$ if n is normal job or $DoS_n = T - t_n^l + t_n^d$ if n is wrap-around job; Γ_n is defined as job type and $\Gamma_n = 1$ is for 20-foot containers and $\Gamma_n = 2$ is for 40-foot containers.

2) DoS: the duration-of-stay of a job is defined as the dwell time between job's arrival and departure. Typically, shorter DoS jobs are preferred to place closer to the exit to achieve a higher turnover rate. Therefore, for each job, the SI is defined as

$$SI = DoS_n$$

It should be noted that $DoS_n = t_n^l - t_n^d$ if n is normal job and $DoS_n = T - t_n^l + t_n^d$ if n is wrap-around job.

3) PRD: in purely random strategy, jobs are randomly sorted and then assigned to the available space. Therefore, for each job, the SI is defined as

$$SI = random\ value.$$

Appendix 5 Framework of Operational Level Problem

Additional Parameters

N^t	Set of the jobs which arrive at shift t, $t = 1, 2, 3...T$
A	Number of shifts that the operator will know the scheme in advance; for example, if current shift is 3, then $N^3 ... N^{3+A}$ will be considered as known.

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1. Pre-process of input data – the job set N;
   a) Solve the relax model;
   b) Fix the allocation of the wrap-around jobs and remove those jobs from

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corresponding job set N^t;

c) Initial the yard storage state in each shift based on fixed jobs;

2. Job allocation in shift t;

a) Set $N = \left\{N^t, \ldots N^{t+A}\right\}$;

b) Apply GSA or BSA to the set N;

c) Fix the allocation of the jobs that belongs to N^t;

d) Update the yard storage state in each shift based on fixed jobs;

e) Set $t = t + 1$;

3. Repeat Step 2 until the end of planning horizon.