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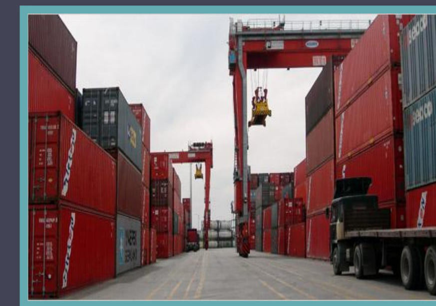
Integrated allocation of berths, quay cranes and internal trucks in container terminal

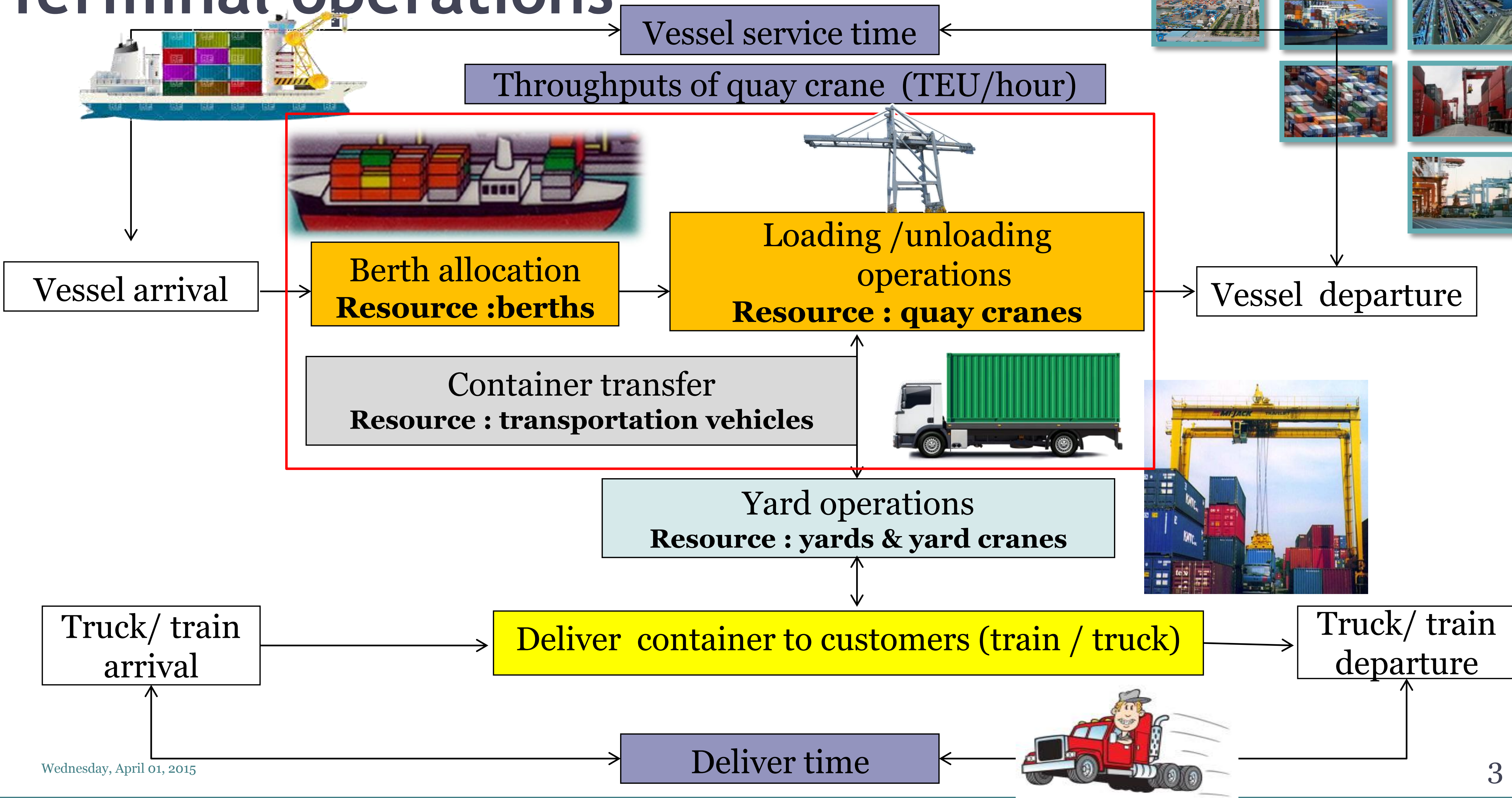

MARLOG 4
A Sustainable Development Perspective for Mega Projects

Eng/ Ahmed Karam

OUTLINES

- ❑ **Terminal operations.**
- ❑ **Berth allocation planning.**
- ❑ **Assignment of quay cranes and internal trucks.**
- ❑ **The integrated allocation of berths ,quay cranes and internal trucks .**

Terminal operations

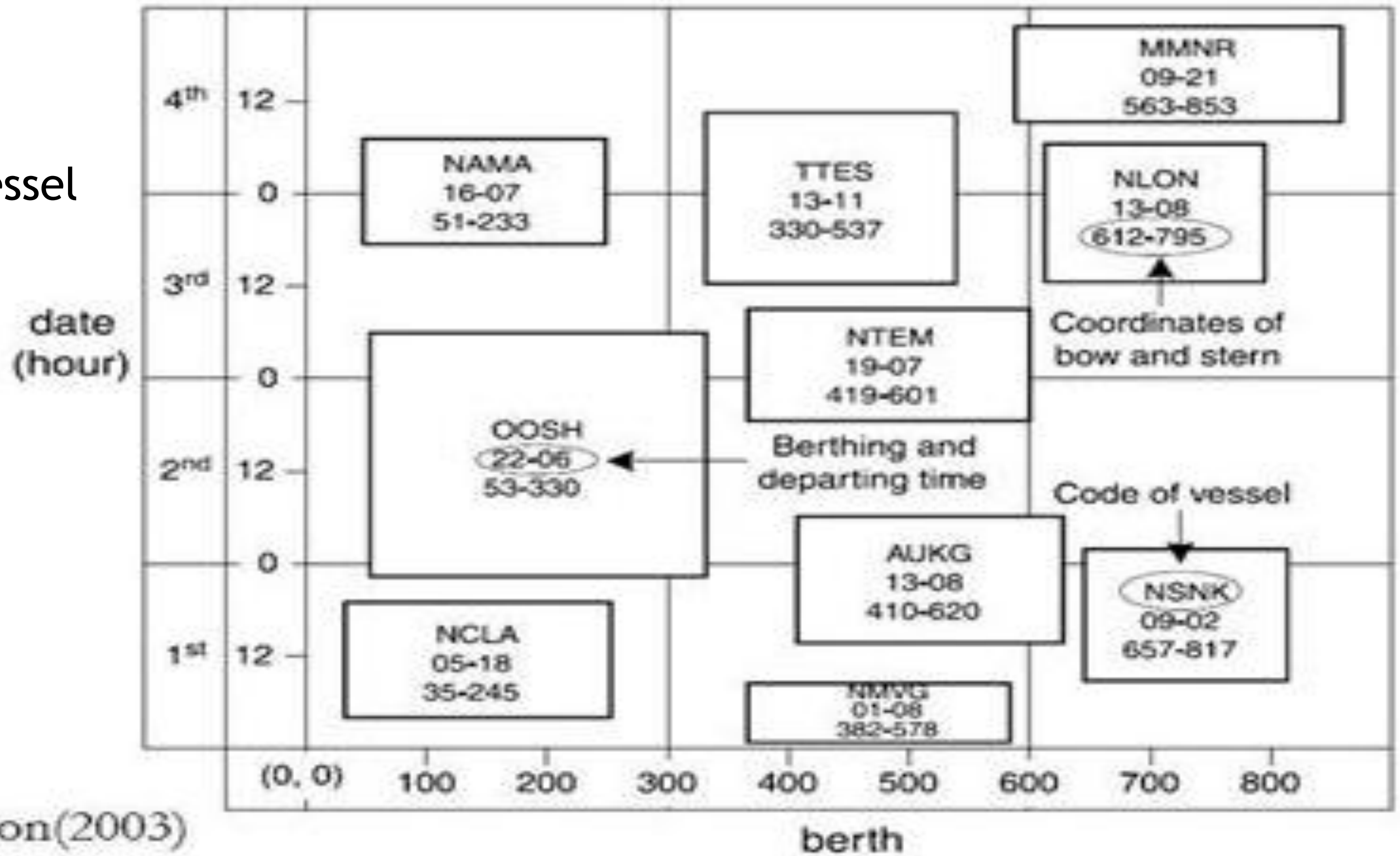


Berth allocation planning

Example of Berth plan

❑ **The berth allocation plan determines**

- The berthing time,
- Berthing position and
- Departing time of each vessel



Kim and Moon(2003)






Modeling of berth allocation







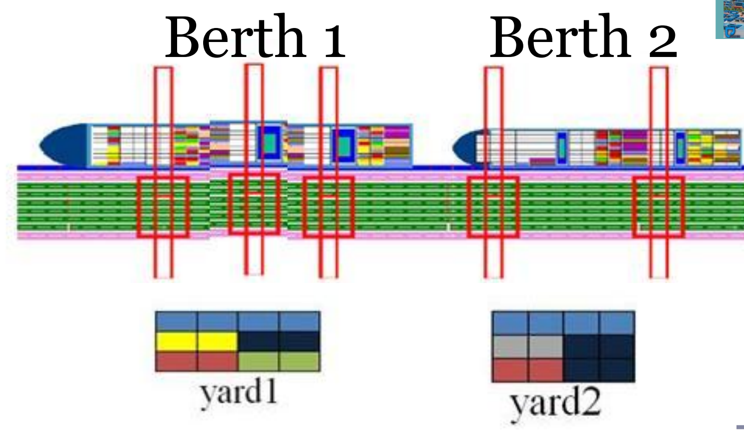
Linear programming

- Objective function
- constraints

Minimizing average service time .

Length of quay .

Integer programming model



Input parameters		
	$i\ (=1,\ldots,I) \in B$	Number of berths
	$j\ (=1,\ldots,T) \in V$	Number of vessels to be served
	S_i	Time when berth *i* is available to serve vessel
	A_j	Arrival time of vessel *j*
	C_{ij}	Handling time of vessel *j* at berth *i*

Decision variable (solution)		
	x_{ijk}	1 if vessel *j* is serviced as the K[th] vessel at berth *i* , 0 otherwise

$$x_{2A1}=1$$

Berth 2 ← 2

Vessel A ← A

Order of service ← 1

Integer programming model (cont.)

Objective function : minimizes total waiting and handling times for all vessels

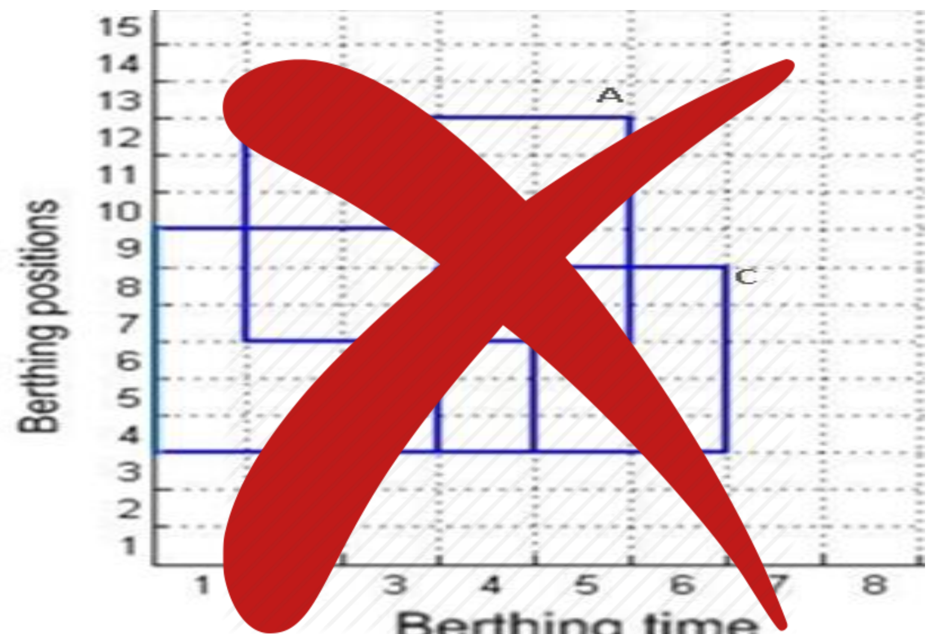
$$[\text{PS}] \qquad \text{Minimize} \quad \sum_{i\in B}\sum_{j\in V}\sum_{k\in O}\{(T-k+1)C_{ij}+S_i-A_j\}x_{ijk}$$

Integer programming model (cont.)

Example of Constraints

$$\sum_{j \in V} x_{ijk} \leqslant 1 \quad \forall i \in B, \;\; k \in O, \qquad (3)$$

Enforces that every berth services up to one vessel at any time.



Integer programming model (cont.)

[PS] Minimize $\sum_{i\in B}\sum_{j\in V}\sum_{k\in O}\{(T-k+1)C_{ij}+S_i-A_j\}x_{ijk}$

Objective

Subject to

Constraints

$$\sum_{i\in B}\sum_{k\in O}x_{ijk}=1 \quad \forall j\in V, \qquad (2)$$

Ensures that every ship must be serviced.

$$\sum_{j\in V}x_{ijk}\leqslant 1 \quad \forall i\in B,\ k\in O, \qquad (3)$$

Ensures that every berth services up to one vessel at any time.

$$x_{ijk}\in\{0,1\} \quad \forall i\in B,\ j\in V,\ k\in O, \qquad (4)$$

Binary constraint

Numerical example

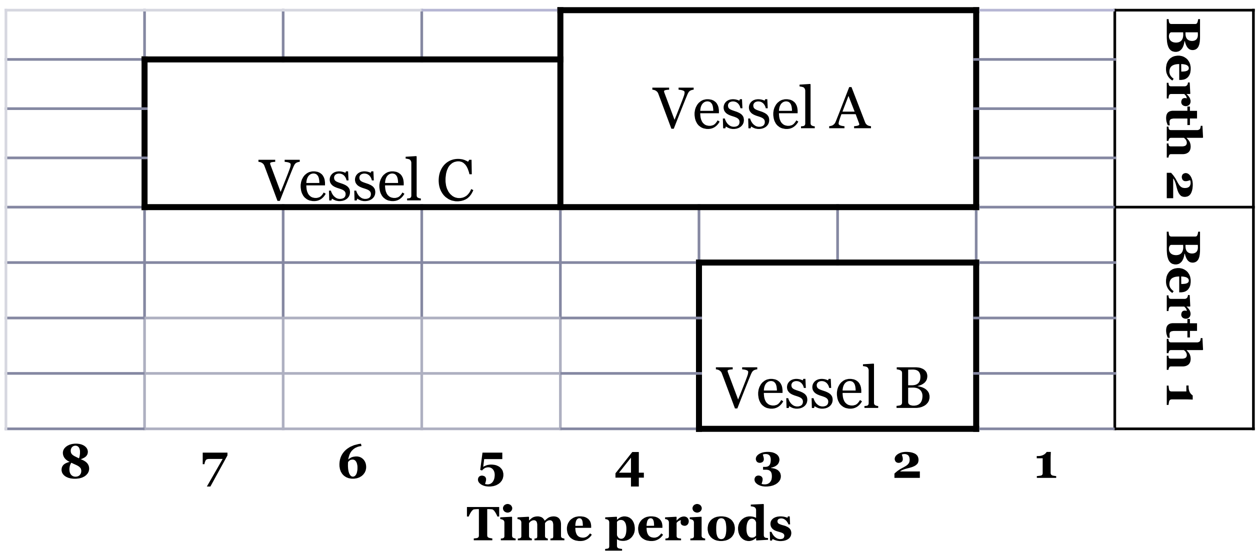
Data of vessels

Vessel	Expected handling time		Expected arrival time
	At berth1	At berth2	
A	3	3	2
B	2	3	2
C	3	3	5

Berth availability

Berth 1	1
Berth 2	1

Solution example



$x_{2A1}=1$

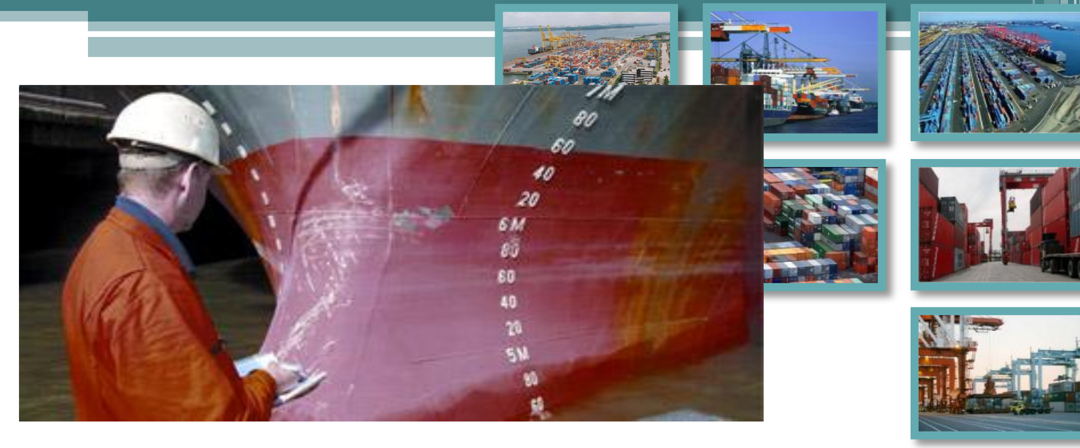
$x_{2C2}=1$

$x_{1B1}=1$

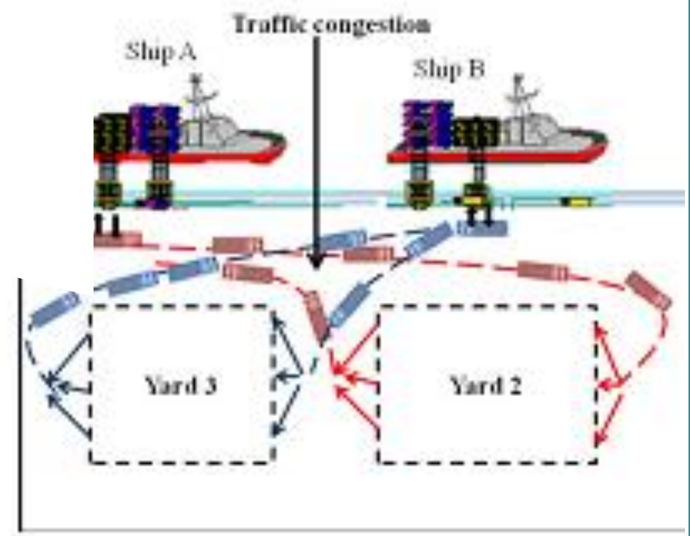
Practical considerations

Mother vessel

Feeder vessel



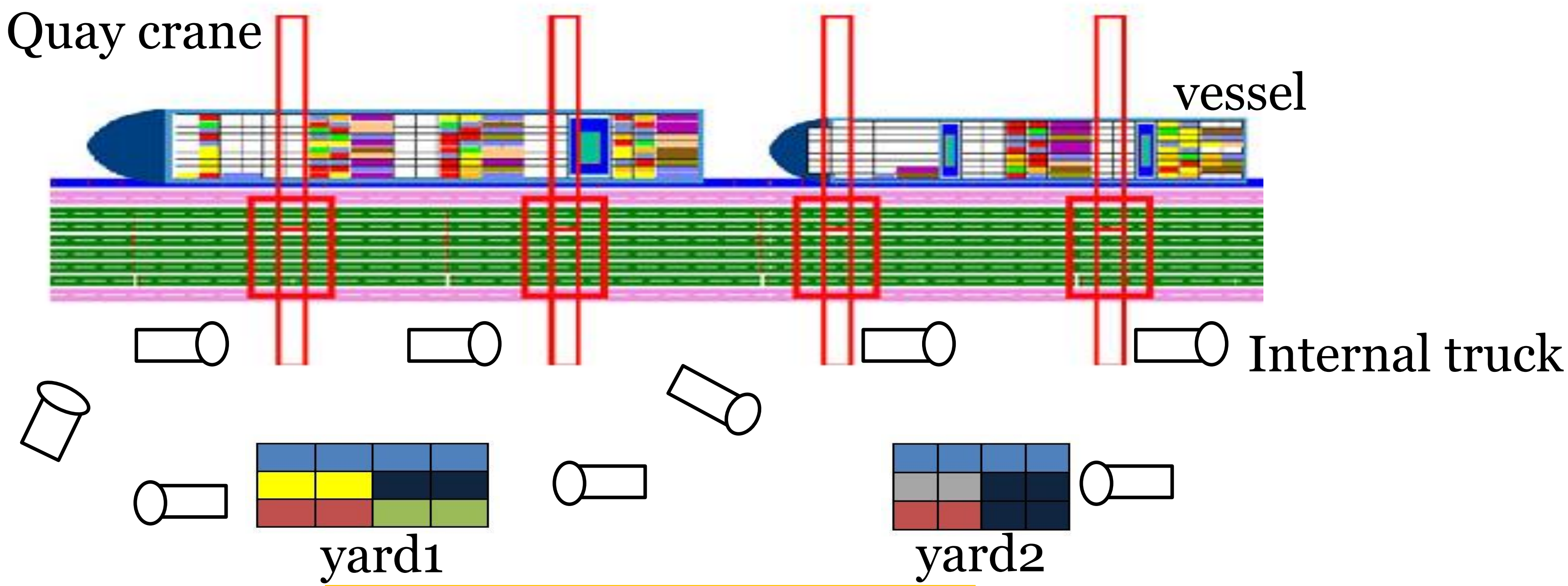
Practical considerations



Assignments of quay cranes and internal trucks

Handling time estimation

- In the berth allocation model, the handling time of each vessel is assumed to be known advance.

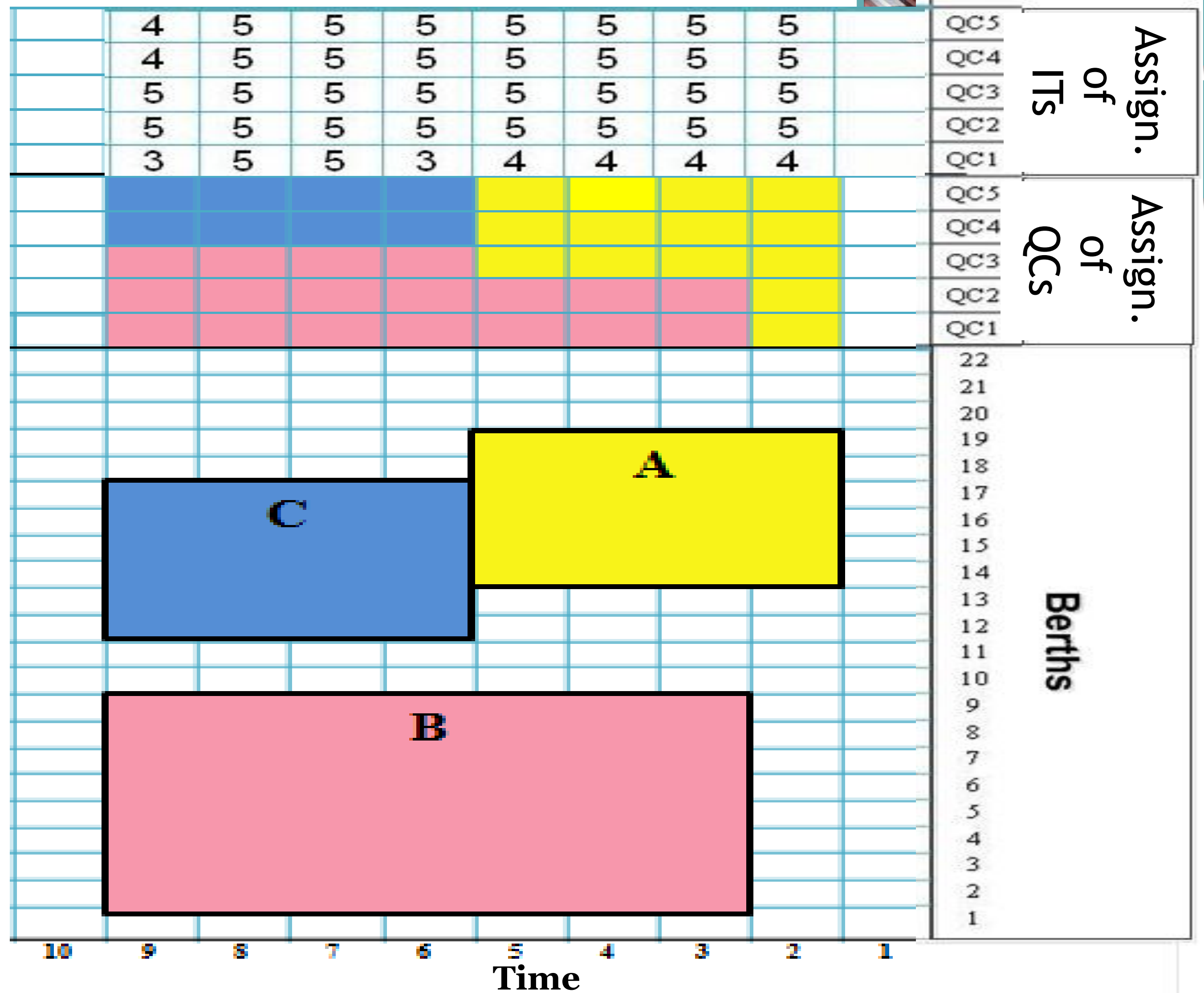


Handling time of ship

- Number of loading and unloading containers
- Number of quay cranes
- Handling rate of quay crane
- Number of internal trucks

Example of quay cranes and internal trucks assignments

- ❑ **Non crossing constraint of quay cranes is respected**
- ❑ **The assignment of internal trucks depends on**
  - The work load assigned to each QC.
  - The deviation between the berth and yard.



Quay crane and internal truck assignment model

❑ Inputs :

- No. of available quay cranes and internal trucks.
- Handling rate of the quay crane (TEU/ hour).
- Characteristics of each vessel in the berth plan
  (berthing position, berthing time, completion time, length of vessel).

❑ Decision variables (solution)

q_{vt} Number of quay cranes assigned to vessel v in time period t.

qt_{vt} Number of internal trucks assigned to quay crane of vessel v at time t.

f_{vt} The change in the number of quay cranes assigned to vessel v at time t.

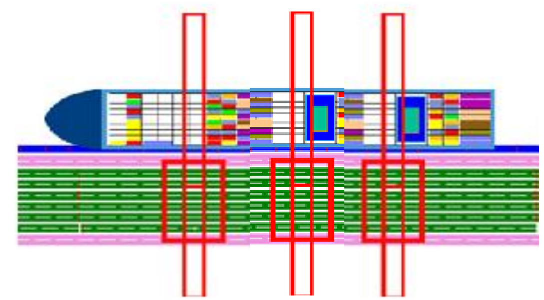
Quay crane and internal truck assignment model (cont.)

❑**Objective function :** Two objectives

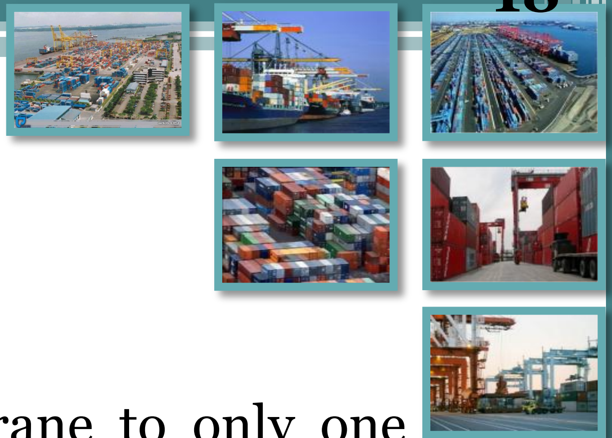
$$Minimize \quad \frac{1}{n}\left(\sum_{v\in V} z_v + \sum_{t\in T}\sum_{v\in V} |f_{vt}|\right)$$

Total handling time of the vessels.

Total number of shifting quay cranes from a vessel to another



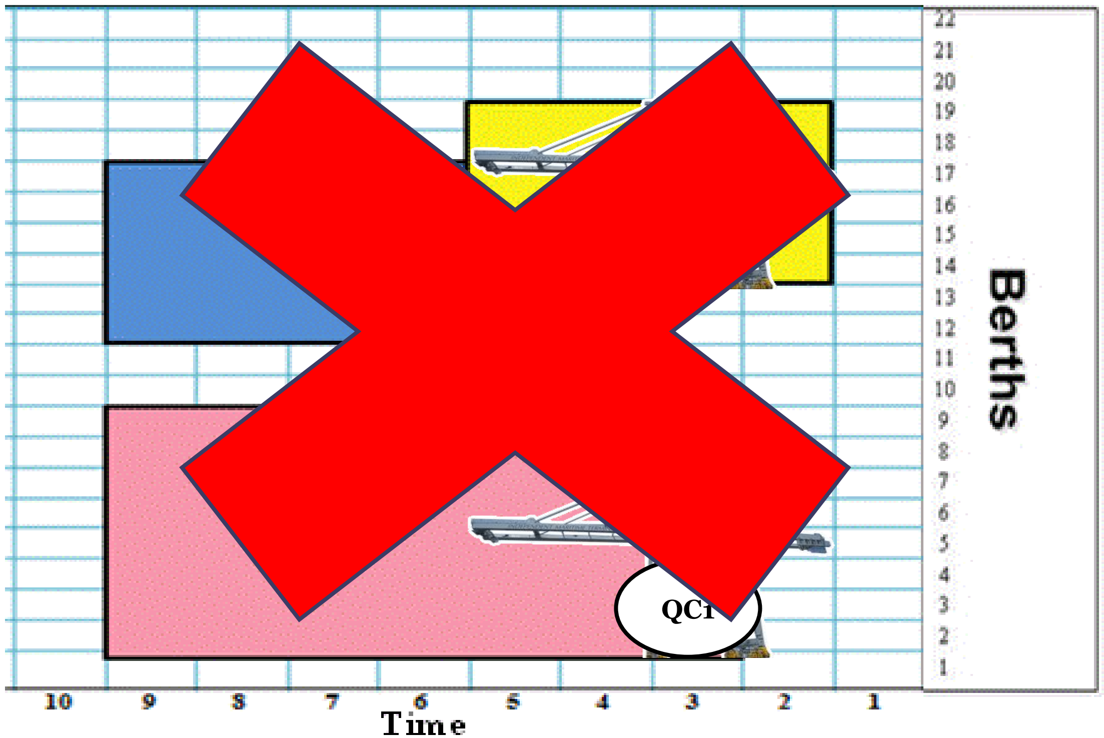
Quay crane and internal truck assignment model (cont.)



Example of constraints

$$\sum_{v \in V} q_{vt}^{k} \leq 1 \qquad \forall k \in K, t \in T \qquad (5)$$

Constraint(5) :
Assign each quay crane to only one vessel at each time period



Quay crane and internal truck assignment model (Cont.)



Subject to

$$x_{vt} \geq x_{v(t+1)} \qquad \forall v \in V, t = ST_v, \ldots, CT_v \qquad (1)$$

Constraint(1): Flow conservation

$$Sr \sum_{k \in K} \sum_{t=STv}^{CT_v} qt_{vt}^{k} \geq NC_v \qquad \forall v \in V \qquad (2)$$

Constraint (2):
Ensures that the containers on each vessel must be completely handled within its berthing stay.

$$\sum_{k \in K} \sum_{t=1}^{STv-1} qt_{it}^{k} = 0 \qquad \forall v \in V \qquad (3)$$

$$\sum_{k \in K} \sum_{t=CT_v+1}^{N} qt_{vt}^{k} = 0 \qquad \forall v \in V \qquad (4)$$

Constraints (3)-(4): Operational constraints:
ensures that no internal trucks or quay cranes are used in handling containers on any vessel outside its time window.

$$\sum_{v \in V} q_{vt}^{k} \leq 1 \qquad \forall k \in K, t \in T \qquad (5)$$

Constraint(5) :
Assign each quay crane to only one vessel at each time period

Quay crane and internal truck assignment model (cont.)






$$\sum_{k \in K} q_{vt}^{k} \leq q_{\max}^{v} . x_{vt} \qquad \forall v \in V, t = ST_v, \ldots, CT_v \qquad (6)$$

$$\sum_{k \in K} q_{vt}^{k} \geq q_{\min}^{v} . x_{vt} \qquad \forall v \in V, t = ST_v, \ldots, CT_v \qquad (7)$$

Constraints (6)-(7) : quay crane allocation

➡ Quay cranes allocated to each vessel must be between the minimum and maximum numbers

$$qt_{vt}^{k} \leq \mathrm{qt}_{\max} \cdot q_{vt}^{k} \qquad \forall v \in V, t \in T, k \in K \qquad (8)$$

$$qt_{vt}^{k} \geq qt_{\min} \cdot q_{vt}^{k} \qquad \forall v \in V, t \in T, k \in K \qquad (9)$$

Constraints (8)-(9) : Internal truck allocation

➡ internal trucks allocated to each quay crane must be between the minimum and maximum numbers

$$\sum_{k \in K} \sum_{v \in V} q_{vt}^{k} \leq Q \qquad \forall t \in T \qquad (10)$$

➡ **Constrain(10):**
Quay crane capacity constraint.

$$\sum_{k \in K} \sum_{v \in V} qt_{vt}^{k} \leq QT \qquad \forall t \in T \qquad (11)$$

➡ **Constrain(11):**
internal truck capacity constraint.

Quay crane and internal truck assignment model (cont.)






$$t \cdot x_{vt} - ST_v \le z_v \qquad \forall v \in V, t = ST_v, \ldots, CT_v \qquad (12)$$

Constraints (12): Define handling time of the vessel

$$\sum_{k \in K} q^k_{v(t+1)} - \sum_{k \in K} q^k_{vt} \le f_{vt} \qquad \forall v \in V, t = ST_v, \ldots, CT_v - 1 \qquad (13)$$

Constraints (13): Define shifts of quay cranes

$$f_{it}, qt^k_{vt} \ Integer \quad and \quad x_{vt}, q^k_{vt} \in \{0,1\} \qquad (14)$$

Constraints (14): Integer and binary constraints

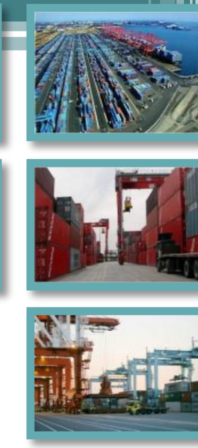
Integrated allocation of berths, quay cranes and internal trucks

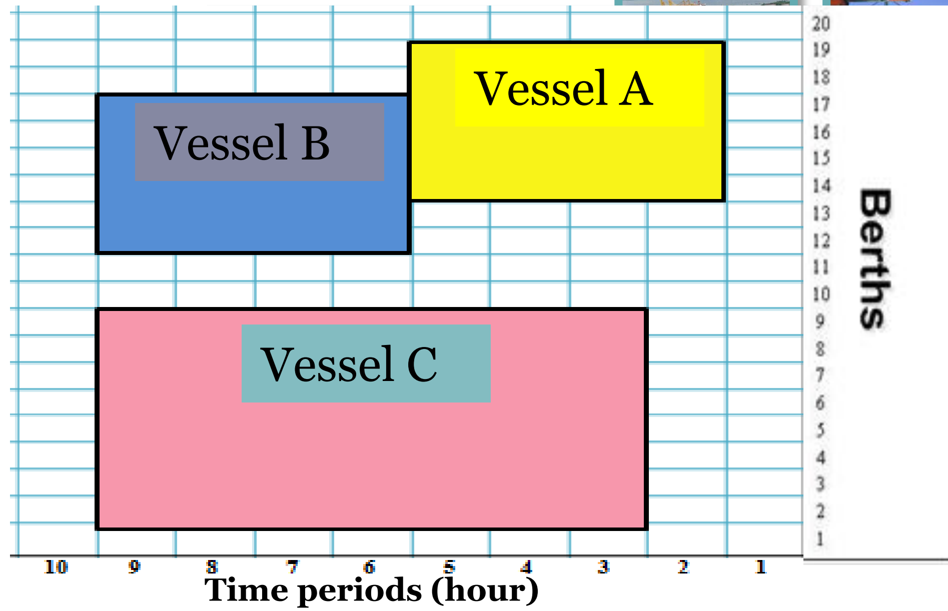
- Now, we have two models
  - Berth allocation model
  - QC and IT assignment model

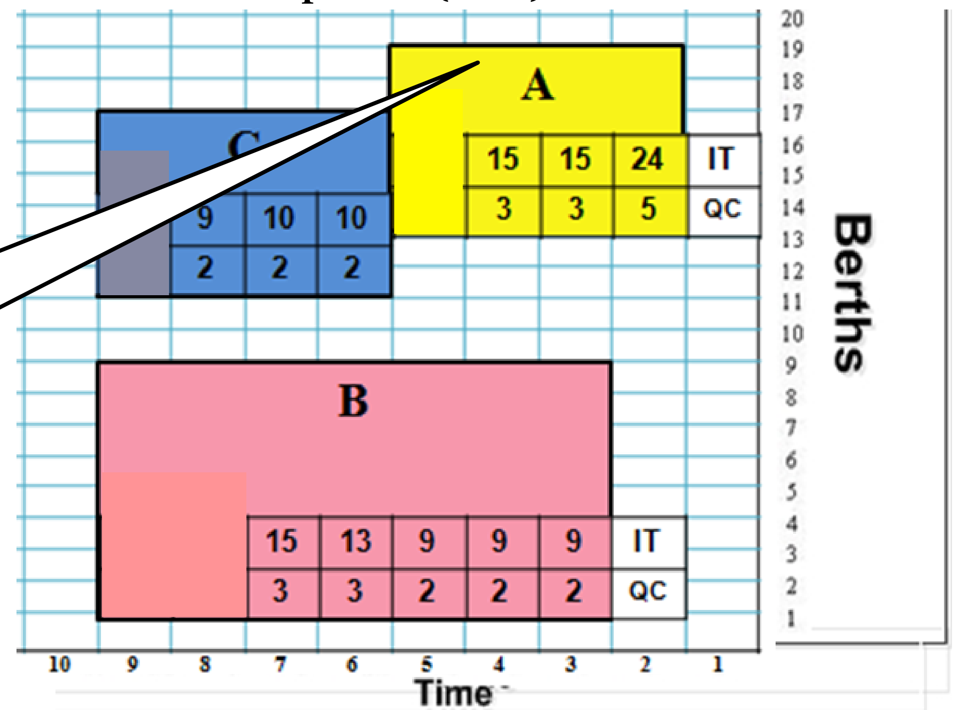
How to solve them?

Traditional method

- Handling times of ships are assumed to solve the berth allocation model.
- The assignments of quay cranes and internal trucks are determined sequentially.
- Resources are wasted if handling times are assumed large.





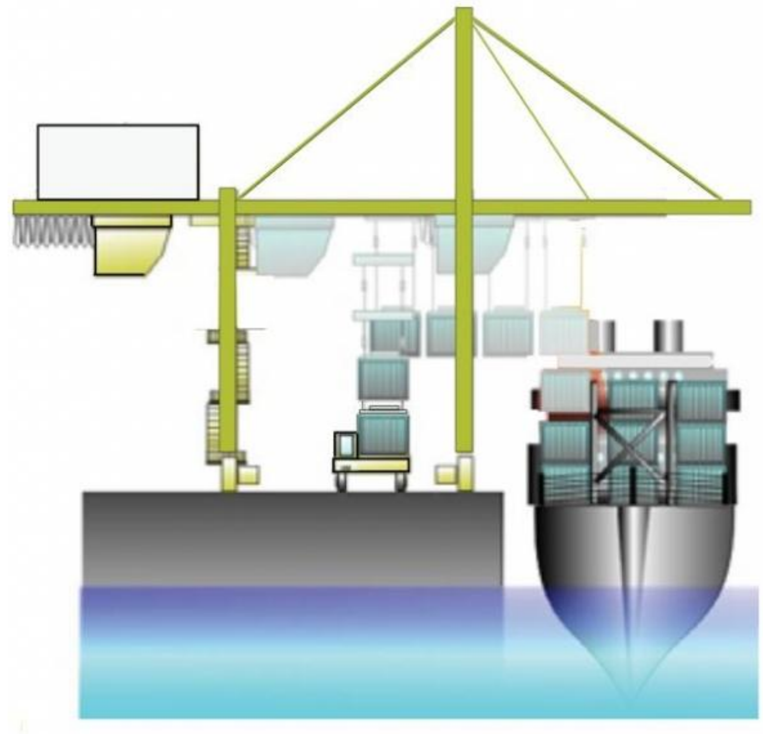


- Overestimated handling time.
- Wasting resources

Simultaneous solution approach

Berth allocation → **One model**

Assignments of QCs & ITs → **One model**



Advantage : the best solution quality

Disadvantage :very complex

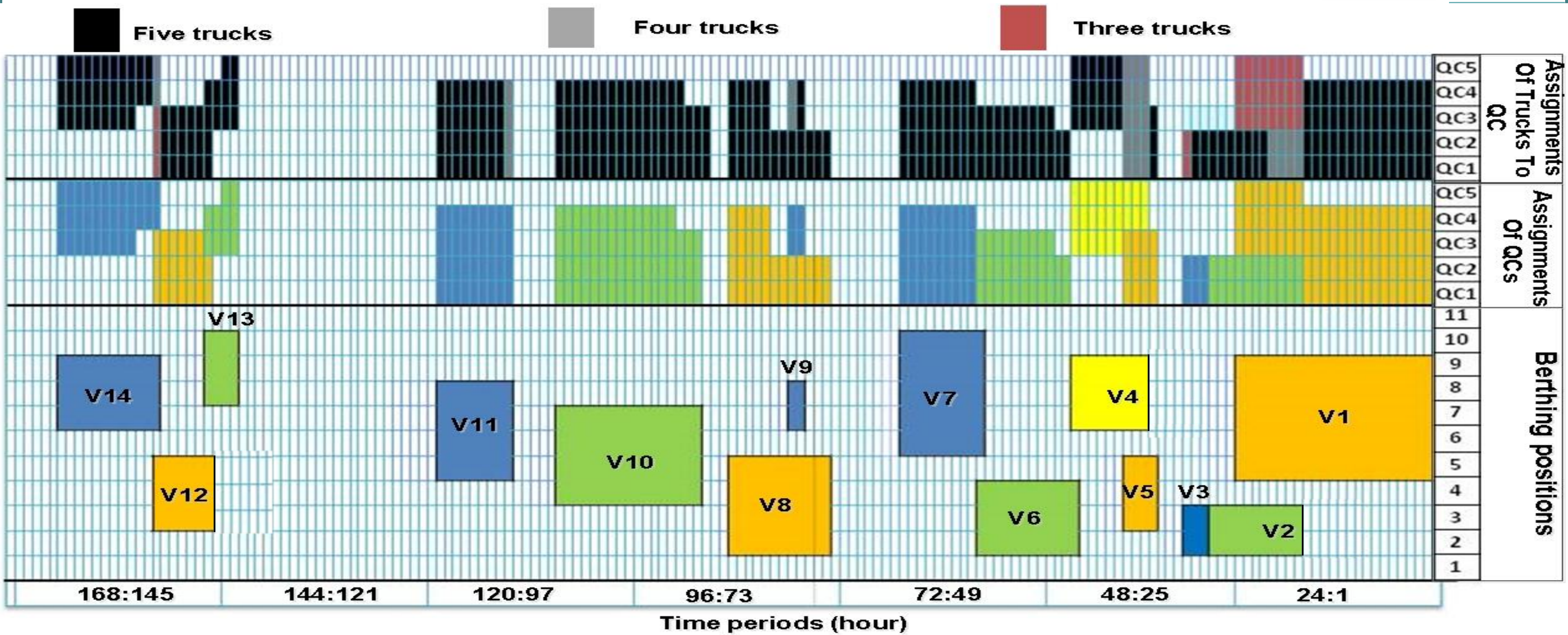
Case study based on Alexandria port data






Vessel name	*Length* (m)	*Arrival time*	*Expected completion time*	*Containers* (TEUs)	*Max. no. of quay cranes*	*Min. no. of quay cranes*
V1	247	1	27	2345	5	3
V2	96	11	27	607	2	2
V3	97	28	31	150	2	2
V4	145	30	42	683	3	2
V5	145	33	38	301	3	2
V6	147	42	53	907	3	2
V7	246	53	64	1074	5	3
V8	197	74	85	967	4	2
V9	95	77	80	104	2	2
V10	198	88	107	1921	4	2
V11	146	112	125	1053	3	2
V12	149	140	152	593	3	2
V13	149	143	148	291	3	2
V14	146	152	163	917	3	2

Simultaneous solution



Conclusions

❑The berth allocation model can be used to

- Maximize utilization of the berth.
- Reduce service time of vessels.
- Increase customer satisfaction.

❑The quay crane and internal truck assignment model can be used to

- Provide more reliable estimate for the handling times
- Increase utilization of quay cranes and internal trucks
- Reduce operation costs .

❑The simultaneous solution approach can improve the quality of the handling plan compared to the traditional method.






Thank you