AN ON-SITE MATERIAL HANDLING CALCULATION MODEL

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ABSTRACT

The efficiency of the UK construction industry is estimated to be between 40 and 60%. To improve this situation many new ideas are being investigated. This paper reports on research being conducted to improve the way that materials are delivered to and moved around construction sites. The research uses four different models taken from operational research to produce a materials handling schedule for each commodity required for the construction project. The optimum schedule is the one which best matches the project objectives which will be lowest cost, shortest time or maximising the output from the available resources. The model is being tested on two construction sites at the University of Southampton and reduced cycle times for a number of operations.

KEY WORDS

Lean construction, material handling, scheduling

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INTRODUCTION

The UK construction industry is estimated to operate at only between 40 and 60% efficiency (Egan 1998). In addition, a significant proportion of the industry's workload is focused on the redevelopment of inner city areas on very restricted construction sites. Frequently the construction site is the building footprint resulting in very limited space for the storage of materials and onerous restrictions placed on the unloading of materials from delivery vehicles.

Consequently, operatives are often prevented from working through shortage of materials. One way to improve efficiency is to provide a means for the efficient movement of construction materials using rigorous mathematical tools to replace the intuitive methods adopted at present. However, there is little consensus amongst researchers as to the best means of achieving this.

Ballard (2000) suggested that load sizes could be changed to match capacity by accelerating work flow and that capacity can be changed to match load size by reducing or increasing resources. Ballard et al (2005) referred to the fact ‘‘that variability cannot be completely eliminated’’, and proposed to ‘‘try to adjust labour flow according to the unplanned variation of work available’’ by means of resource flexibility. Thomas et al (2002) suggested that ‘‘the development of flexible capacity management practices seems to be a better application of lean thinking to the management of variability in construction than workflow management’’. Howell et al (2004) criticised the idea of flexible capacity management proposed by Thomas et al (2002), because ‘‘the relevant concept of work-flow reliability is that of work-load predictability and not uniformity of percentage complete or quantities installed’’. Thomas et al (2004) concluded that without clear and precise definitions and collaborating data, the discussion of Howell et al (2004) adds little value to the debate over lean construction in general and specifically on workflow variability. Abdelhamid (2003) argued that the effects of variability are buffered through excess inventory, flexible capacity, and/or work-ready backlogs.

The common element between these three approaches to tackle production process variability is that they are all attempts to combat the effects of variability and not to reduce or eliminate variability altogether. “Reducing or eliminating the variability that plague the production process requires the removal of the root causes of variability’’ using statistical-based methodologies such as six-sigma Abdelhamid (2003), which provides a structured framework to organise and implement strategic process improvement initiatives. Howell and Ballard (1996) argue that it is impossible to make good decisions about causes or corrections of deviations, relying only on productivity and progress data, without understanding work flow. Thomas et al (2005a) proposed that the Last Planner technique ‘‘has perhaps been the most successful use of lean production in construction’’ and that there is more to lean production. Horman and Thomas (2005) believe that ‘‘Material stockpiles help manage variable conditions of construction by cushioning activities from the variability’’, and when inventory act in this way, they act as a buffer (Horman and Thomas 2005). This necessitates site material management, which is ‘‘the allocation of delivery, storage, and handling, spaces and resources’’ (Thomas et al 2005b). Thomas et al (2005b) proposed site material management as a technique to stabilise the flow of labour, and to minimise inefficiencies caused by congestion in the working areas and excess material. Thomas et al (2003) conducted three studies in which labour was treated as one of the workflows, based on the baseline productivity method, and found that of 909 work hours charged 672 work hours were inefficiently used. The most significant cause of loss of labour efficiency relates to the labour resource specifically labour flow, i.e., insufficient work to perform and overstaffing. Thomas et al (2005a) concluded that ‘‘more research is needed in this part of lean construction to provide data’’ (Thomas et al 2005a).

This research deals with the development of a calculation model as a mean to generate schedules for workers to perform the on-site material handling activities. Two construction projects for trials of the on-site material handling calculation model at the University of Southampton have been provided. Both projects consist of a reinforced concrete structure and include laboratories, lecture theatres and offices. The first project involves the construction of a three-story building for the Institute of Sound and Vibration Research and the second project involves the construction of a four-storey building for the School of Electronics.

BACKGROUND TO THE MODEL

The lean principles applied in construction are originally the lean production principles developed by the Toyota Company over the past five decades. Thomas et al (2005 a) suggest the improvement of workforce management strategies as a solution for ‘‘achieving real gains in industry performance’’ inspired by the ‘‘DNA of Toyota’’ (Spear and Bowen 1999). Spear and Bowen (1999) studied the reason that made the decoding of the Toyota Production System so difficult, and ‘‘believe that observers confuse the tools and practices they see on their plant visits with the system itself’’. Companies that have tried to adopt the Toyota Production System were unable to perceive that ‘‘activities, connections, and production flows in a Toyota factory are rigidly scripted’’ (Spear and Bowen 1999), yet at the same time recognised that the operations are extremely flexible and adaptable. To understand Toyota’s success, it is important to recognize that ‘‘the rigid specification is the very thing that makes the flexibility and creativity possible’’ (Spear and Bowen 1999).

The specific objective for the on-site material handling calculation model is the determination of a minimum-cost plan for transporting a single commodity from a number of material storage locations, buffers, to a number of destinations within the construction site. This objective puts the lean supply principles into practice as a result of having to reduce the batch size of the supplied material for each load, increasing the frequency of material supply and reducing the required cycle time. This requires that the batch size for each load of material is optimized individually in respect to the available resources. Koskela (1992) recognised that ‘‘the temporal and spatial flows of construction teams on site are often closely associated with the material processes’’. Lamming and Cox (1995) termed the formation of collaborative business supplier partnerships as lean supply. Lean supply is very demanding and in some cases it could lead to economic inequality among partners in a business partnership. London and Kenley (2001) consider the dualist theory as a negative factor responsible for the economic inequality in business partnerships. Lamming (1993) recognised the importance of transparency in the exchange of information between suppliers and believes that the planning of capacity and the operational communication must be undertaken jointly for lean supply to be effective.

DESCRIPTION OF THE MODEL

The material flows and associated work processes in construction could be balanced by making use of the transportation model. This model is constrained in balancing supply to demand. Taha (2003) proposed that the model deals with the determination of a minimum-cost plan for transporting a single commodity from a number of sources (e.g., factories) to a number of destinations (e.g., warehouses). The model can be extended in a direct manner to cover practical situations in areas such as inventory control, employment scheduling, personnel assignment, cash flow and scheduling dam reservoir levels. The model can also be modified to account for multiple commodities.

As part of the planning cycle, the buffer locations and the locations of demand within the construction site must be identified in collaboration with the construction workers involved. The capacities of the buffer locations and the material demand of each location must also be identified in collaboration with the construction workers.

The cycle time between every buffer (buffer1, buffer2 and buffer3, etc) and each location (A, B, C, etc) must be measured and plotted into the transportation timetable. Time must be measured for each worker transporting the required material between the buffers and the locations of demand, then averaged into cycle time.

After the identification of the buffer locations and the material demand at each location (A, B, C, etc) in association with the measured cycle times, the on-site material handling calculation model is made ready for implementation and the plans can be prepared in respect to the logic of the following methods:

- North West Corner Method.
- Least Cost Method.
- Vogel's Approximation Method.
- Ad Hoc Method based on the longest required transportation cycle time.

Once the schedules are generated, the given results of the plans can be altered through simulating different scenarios by changing the given variable parameters (working days/ working week, working hours/ working day, number of units X per load, payment/worker/ hour and the required number of workers).

Based on the simulation outputs, the best method and its generated schedules are selected.

Once the plan is ready for implementation, the selected schedules are handed out to the workers, so that the workers can start to supply the predefined demand of materials to the identified locations (A, B, C, etc) from the identified buffer locations (buffer1, buffer 2 and buffer 3, etc). The actual amount of transported material by all workers must be monitored on a weekly basis and a balancing item, between the targeted amount and the actual transported amount of Material Must Be Documented And Altered In Further Plan Preparations.

APPLICATION

The on-site material handling calculation model was introduced to the HBG technical services project manager, who is responsible for the construction activities at the construction site of the new School of Electronics at the University of Southampton. From the layout of the construction site it was concluded that the construction site is constraint to two cranes only used for carrying out the material handling activities. Furthermore, the construction site has only two storage and drop off areas, which function as buffer locations, buffer 1 and buffer 2. The capacities of the buffer locations and the material demand at each location of demand were identified in collaboration with the site manager given in Table.1.

Table 1: Capacity/ Demand Table

Locations of Demand	Material Demand
A	100
B	150
C	200
D	300
E	100
Buffer Locations	Buffer Capacities
Buffer 1	300
Buffer 2	550

The cycle time between every buffer (buffer 1, buffer 2) and each location (A, B, C, D and E) were identified in collaboration with the site manager given in Table 2. Finally the on-site material handling calculation model was used.

Table 2: On-site Material Handling Cycle Time per Load (minutes)

From \ To	A	B	C	D	E
Buffer 1	6	5	3	7	7
Buffer 2	8	7	4	12	6

The on-site material handling calculation model uses 7 steps:

Step 1. Allocate the material demand and storing capacity, once the values from Table 1 are entered into the respective cells, they will automatically appear in the succeeding tables.

Step 2. Allocate the cycle times in minutes, once the values from Table 2 are entered into the respective cells, they will automatically appear in the succeeding tables.

Step 3. Feed the locations of demand in respect to the Least Cost method as shown in Figure 1.

Step 4. Feed the locations of demand in respect to the North West Corner method.

Step 5. Feed the locations of demand in respect to the Vogel's Approximation method.

Step 6. Feed the locations of demand in respect to the Ad Hoc method based on the longest required cycle time.

Step 7. Enter the values for the variable parameters from Table 3 and change them until the conditions are satisfied.

Once the schedules are generated, the given results of the plans can be altered and optimised through simulating different scenarios by changing the given variable parameters (working days/ working week, working hours/ working day, number of units X per load, payment/ worker/ hour and the required number of workers) and the optimum values for this case study are shown in Table 3.

Table 3: Variable and Fixed Parameters

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
Number of Workers	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Based on the simulation output the best method and its generated on-site material handling schedule Figure 2 were selected.

DISCUSSION

Two supply chains were identified, an internal supply chain in the form of the on-site flows and an external supply chain in the form of the external supplies of material to the construction site. In order to place the pull principle of lean thinking into practice it is important to distinguish the internal supply chain from the external supply chain and to understand that the external supply chain is determined by the internal supply chain. Since each location (A, B, C, D and E) has a different demand for material, the on-site material handling calculation model calculated a different number of loads of material to be transported to the locations of demand. The batch size for each load was constraint to a maximum of 25 units per load and each location of demand had a customized batch size of material per load. This expresses the flexibility of the model and its ability to synchronize resources to meet the different levels of demand at the various locations within the construction site, creating a steady workflow. According to Thomas and Horman (2006) ‘‘flow improvement also encompass equipment availability and labour utilization’’. The model enabled the identification of the required number of working crews needed to carry out the scheduled work, Thomas and Horman (2006) proposed that ‘‘efficient material handling and timely deliveries are important for good productivity, especially on labour- intensive operations’’.

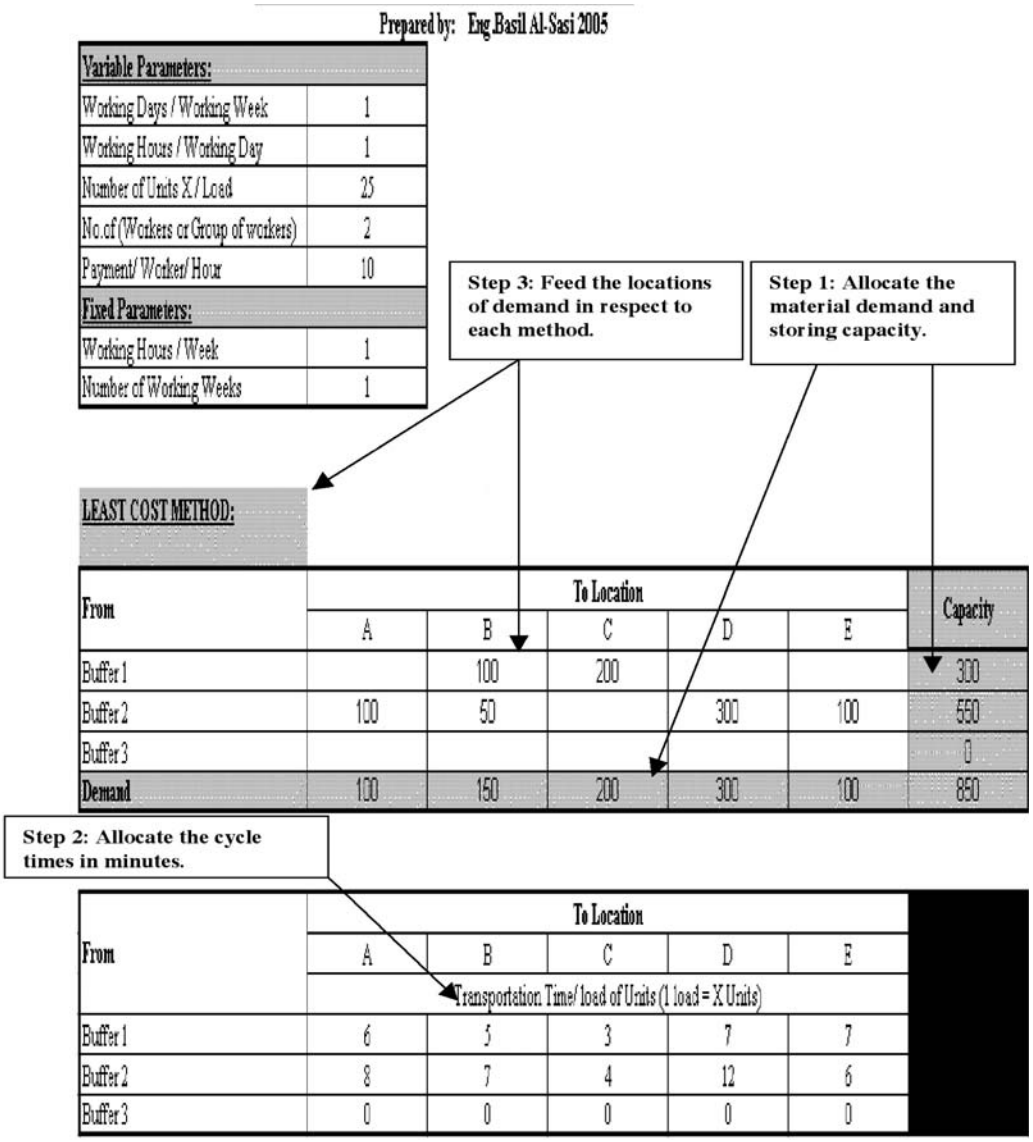
This principle if placed into practice would lead to the elimination of negative factors such as over staffing.

CONCLUSIONS

This model requires the pre-identification of the storage locations and their storage capacities, the identification of the locations of demand and their demand for material, and the calculation of the cycle times between each buffer and each location of demand. These requirements provide the flexibility for the on-site material handling calculation model to manage multiple activities carried out by construction workers.

This on-site material handling calculation model is meant to serve as a lean tool towards the ‘‘workforce management strategies’’ suggested by Thomas et al (2005 a).

The on-site material handling calculation model is available at the University of Southampton’s Construction Management Research Group, copies of the model are made available to interested researches when requested, and more research is needed to evaluate the usefulness of this model.



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Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Step 3: Feed the locations of demand in respect to each method.

Step 1: Allocate the material demand and storing capacity.

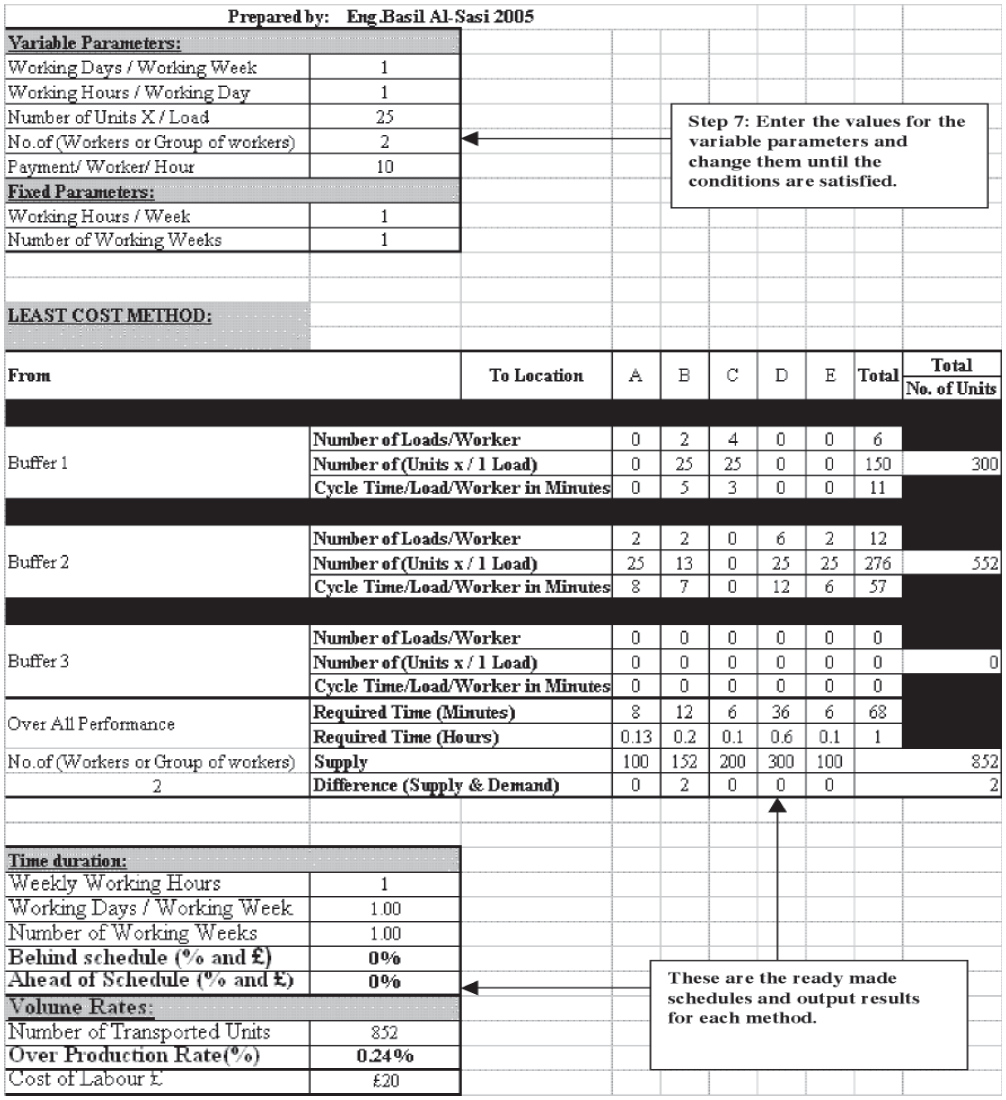
LEAST COST METHOD:

From	**To Location**					**Capacity**
	A	B	C	D	E	
Buffer 1		100	200			300
Buffer 2	100	50		300	100	550
Buffer 3						0
Demand	100	150	200	300	100	850

Step 2: Allocate the cycle times in minutes.

From	**To Location**				
	A	B	C	D	E
	Transportation Time/ load of Units (1 load = X Units)				
Buffer 1	6	5	3	7	7
Buffer 2	8	7	4	12	6
Buffer 3	0	0	0	0	0

Figure 1: Data Input Sheet Least Cost Method



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Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Step 7: Enter the values for the variable parameters and change them until the conditions are satisfied.

LEAST COST METHOD:

From	**To Location**	A	B	C	D	E	**Total**	**Total** **No. of Units**
Buffer 1	**Number of Loads/Worker**	0	2	4	0	0	6	
	Number of (Units x / 1 Load)	0	25	25	0	0	150	300
	Cycle Time/Load/Worker in Minutes	0	5	3	0	0	11	
Buffer 2	**Number of Loads/Worker**	2	2	0	6	2	12	
	Number of (Units x / 1 Load)	25	13	0	25	25	276	552
	Cycle Time/Load/Worker in Minutes	8	7	0	12	6	57	
Buffer 3	**Number of Loads/Worker**	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance	**Required Time (Minutes)**	8	12	6	36	6	68	
	Required Time (Hours)	0.13	0.2	0.1	0.6	0.1	1	
No.of (Workers or Group of workers)	**Supply**	100	152	200	300	100		852
2	**Difference (Supply & Demand)**	0	2	0	0	0		2

Time duration:	
Weekly Working Hours	1
Working Days / Working Week	1.00
Number of Working Weeks	1.00
Behind schedule (% and £)	**0%**
Ahead of Schedule (% and £)	**0%**
Volume Rates:	
Number of Transported Units	852
Over Production Rate(%)	**0.24%**
Cost of Labour £	£20

These are the ready made schedules and output results for each method.

Figure 2: Hourly Execution Plan Least Cost Method

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