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Case study (Project 3 - Resource Smoothing)
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1.0 Introduction

For the purpose of this report, resource smoothing can be defined as a project management tool used as a resource optimization technique. It is a technique that adjusts the activities of a schedule model so that all requirements for the resources do not go beyond the resource limits already pre-defined during the planning (Anon, 2018).

The aim of this report is to demonstrate how work force distribution can be optimised to avoid peaks and troughs of resource demand following initial workforce requirement planning.

Using information contained in a Gantt chart for the project, the objective is to show how the works can be completed as per the defined construction programme and required end date while spreading the available resource and rescheduling some tasks to ensure work force is always available but never over available. This will remove a certain amount of flexibility from the programme with regards to dealing with unforeseeable delays, however the report is designed to demonstrate how resource smoothing is a more efficient and cost effective with regards to resource management.

The report will also identify how other resources are affected (for example the use of cranes, earthworks plant, concreting and specific supplies of materials).

Public journals, newspaper articles and web-based documents will be used in the research and referenced in the body of text to help support points.

2.0 Background

Time Constrained Scheduling (TCS) requires that a project is completed within a pre-scheduled duration of time. The length of time is determined during schedule network analysis. In TCS, it is important that an element of respect and consideration is given to the project start and end dates. TCS also considers both the supply and demand of the resources. Time-constrained scheduling typically requires the use of resource smoothing as an optimisation technique (Dash, 2015).

Smoothing is a procedure in which the duration of the project, or group of projects, has been fixed and the requirement is to schedule the activities to give the lowest peak usage of the resources and if possible a 'smooth' or level usage (Gordon and Tulip, 1997).

The Heuristic approach to smoothing is simply the testing of various arrangements of workforce to achieve the acceptable solution. Sindhuja (2017) states that smoothing is very essential in the project where overloading and under-loading is not easy to avoid.

(Gordon and Tulip, 1997) teach that in allocation routines it is very difficult to produce a schedule which is time limited where the resource requirement does not suddenly exceed unacceptable volumes. The smoothing procedure analyses the total project and attempts to work within the time frames of the project that has been set by the project manager.

Float, also known as slack, is the amount of time an activity, network path, or project can be delayed from the early start without changing the completion date of the project. If activities that are not on the critical path have a difference between their early start date and their late start date, those activities can be delayed without affecting the project completion date. The float on those activities is called free float (Cox, 2009).

The resource smoothing technique utilises or manipulates float in different tasks. The tasks are adjusted within the period equal to their duration plus float. In other words the objective is to have a task start at any time within this period and for it to also finish within the same period. The task can be taken during the earlier, middle or later part of the duration plus float band of period providing it is finished before the float ends. Various activities can be scattered so that no high peaks or low troughs are formed in the workforce schedule (Sindhuja, 2017).

In Resource Constrained Scheduling (RCS) a project is meant to be completed with the available resources, hence the name, "resource constrained." There will be an increase in the duration of the project if resources aren't available. RCS considers both the supply (availability) and demand (requirement) of the resources. If the resource requirement exceeds the resource availability at any time during the schedule network analysis, some of the activities may be delayed until there's enough resource availability. This in turn may increase the duration of the project. Resource levelling is the resource optimizing technique used in resource constrained scheduling (Dash, 2015).

Gordon and Tulip (1997), suggest that levelling can be defined as a method used to reduce the peaks of utilisation of resource, within a predefined schedule. This can be done by re-arranging certain activities by moving to a time of lower total requirement. As a process it appears to be simple and effective, in practice it is considered to be the opposite.

Most often resource leveling requires tasks to be delayed until resources are available. Most project management software can level resources automatically based on a set of rules that determine which tasks to delay, split or adjust. The problem is that there are often too many factors affecting a schedule that software cannot properly contend with (Young, 2011). Resource scheduling algorithms are notoriously non-optimal. They are blunt instruments. It is therefore better to derive that manual leveling is often the best strategy or perhaps the use the automatic facility and to tweak the solution manually as necessary.

Incidentally, sometimes a distinction is made between 'resource leveling' and 'resource smoothing' – the difference being that resource smoothing is used only for tasks that are not on the critical path (i.e. non-critical tasks), whereas resource leveling has no such restriction, and usually extends the critical path of a project (Young, 2011).

Resource smoothing and resource levelling are similar in that they are both a schedule network analysis technique, are a resource optimization technique and both improve resource utilisation. However, that is where their similarities end. The differences between the two are as below:

Resource Levelling	Resource Smoothing
Aim is to adjust start and end dates of a project with resource constraints while balancing resource requirements and resource availability.	Aim is to achieve optimal resource usage by avoiding peaks and valleys in the resource usage profile. Hence the name smoothing.
Used in resource-constrained scheduling.	Used in time-constrained scheduling.
Critical path of the project will be affected, and usually the length of critical path will increase.	Critical path of the project won't change
Can be applied to resources on critical path.	Doesn't apply to resources on critical path.
Free and total float (or slack) may be used.	Free and total float (or slack) are used.
Will optimize all the resources and may change the duration of the project.	May not be able to optimize all the resources if sufficient slack (or float) isn't available, but does not change the duration of the project.
Risk: May change the critical path and hence the duration.	Risk: Loss of flexibility due to reduction in slack. Hence chances of increase in number of near-critical activities.

Figure 1: Table of differences between resource optimising techniques (Dash, 2015)

3.0 Case Study

3.1 Site Location

The case site lies North of the popular Wind Street in the SA1 postcode area of Swansea, between the Swansea Civil Justice Centre and Parc Tawe shopping centre. The site is located 1.5km to the west of The River Tawe.

3.2 Site Description

The site comprises land associated with the existing Strand building. The site currently includes existing car parking and landscaping. The site consists of some 5269m² of land, of which approx. 2000m² forms the proposed development footprint. The proposed development will consist of four blocks of differing heights, with an approximate area of 500m² for each block and are separated as follows:

- Block A – 5 Floors
- Block B – 7 Floors
- Block C – 11 Floors
- Block D – 15 Floors

Two basement levels are proposed to be installed beneath the ground level of the development. This has the potential to cause significant engineering difficulties. Deeper excavations can come with the risk of trench collapse. Much consideration has to be given to dewatering techniques to cope with the ingress of the water table, not expected to be very deep due to the close proximity to the River Tawe.

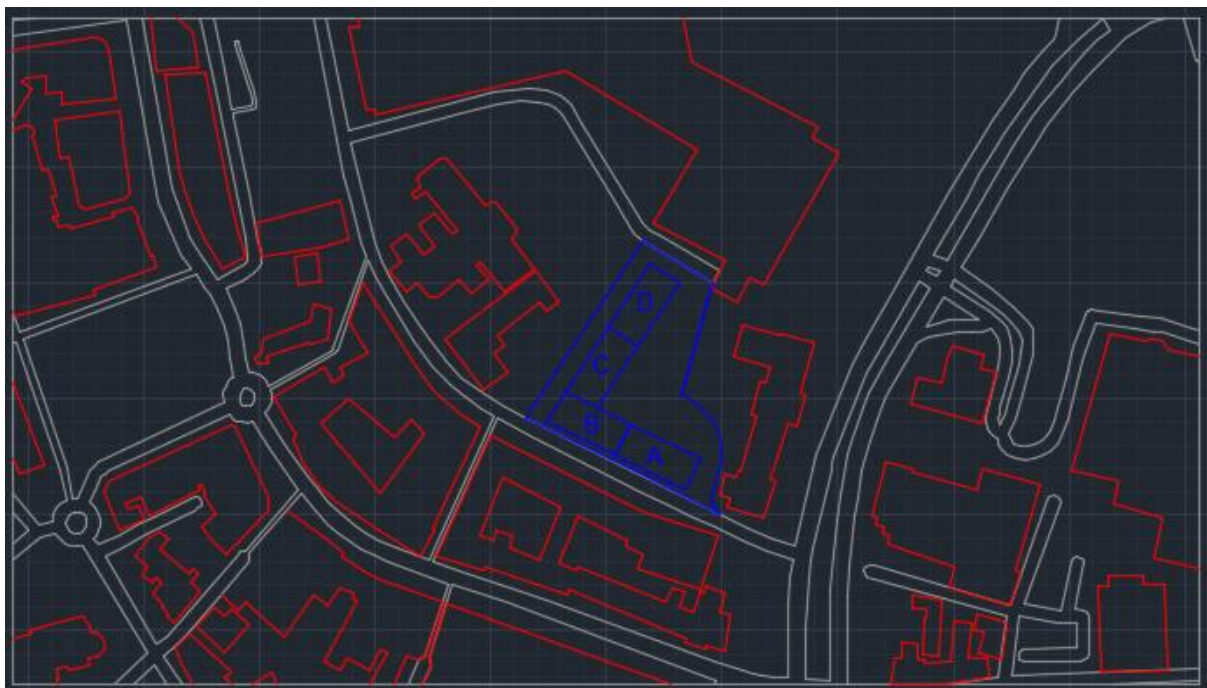


Figure 2: Proposed site footprint (Ferriz-Papi, 2018)

4.0 Solutions

This solution implemented for this report was a reconfiguration of resources to achieve optimal resource usage. Due to the large scale of the development and the requirement for a high number of operatives, each area of work has been split into gangs rather than individuals. For example, Gang 1 consists of 6 operatives (2x Excavator operators, a dumper driver, a crane operator, a skilled labourer and a banksman). As a result, although only two gangs have been specified for the site set up in November, 12 operatives will be undertaking these works, however for the purpose of this report, individuals have been condensed into gangs. An industry accepted approach to determining how many individuals are required for each gang has been taken from the SPON's book as demonstrated in Figure 3 below (AECOM, 2016).

Concrete gang			Reinforcement gang		
1 ganger or chargehand (skill rate 4)	15.28		1 foreman steel fixer (craftsman)	23.18	
2 skilled operatives (skill rate 4)	28.62		4 steel fixers (craftsman)	82.2	
4 unskilled operatives (general)	53.48		1 unskilled operative (general)	13.37	
1 plant operator (skill rate 3) – 25% of time	4.35			125.08	
	101.73 /hour			50.64 /day	
	813.84 /day		Cost = £	1081.997	
Cost = £	17388.87		2 Gangs =£	2163.994	
2 Gangs =£	34777.73				
Formwork Gang			Reinforcement on-site bending/baling gang		
1 foreman joiner (craftsman)	23.18		1 steel fixer (craftsman)	20.55	
2 joiners (craftsman)	41.1		1 unskilled operative (general)	13.37	
1 unskilled operative (general)	13.37		1 plant operator (craftsman) – 25% of time	6.33	
1 plant operator (craftsman) – 25% of time	6.33			125.08 /hour	
	83.98 /hour			1000.64 /day	
	671.84 /day		Cost = £	21380.12	
Cost = £	14354.83		2 Gangs =£	42760.24	
2 Gangs =£	28709.66				

Figure 3: Table showing the individuals in a gang and the cost of their services (Author, 2019)

To calculate total project float, the author began at the start date and added the duration of each activity in each possible path through the network diagram in the Gantt chart developed in Task one, including nonworking days from the resource calendars, to determine the earliest project end date. The longest path through the network is the critical path. The difference between the early end date and the required completion date of the project is the total project float, and the start date of each activity is the early start date. To calculate the late start dates, begin with the required project completion date and work backward, subtracting the duration of each activity through each possible pathway.

To calculate the average workforce per month, the required gangs (specialised and multifunctional professionals), for each particular task were first specified. With reference to Figure 4, Gang 1 & 2 are considered as being versatile in their capabilities. For example, Gang 1 & 2 are utilised for site setup, excavation of the guide trench, excavation of dumping to name a few. Therefore, the site will be more likely to see Gang 1 & 2 employed to undertake works of differing variety throughout the duration of the construction programme. Gang 3 & 4 on the other hand are very limited in their capabilities, or on the flip side, are specifically employed to undertake works that are of a specialised requirement, that say, an average labour is unlikely to be able to carry out (i.e. form work and steel fabrication).

	A	B	C	D	E	F	G	H	I	J	K
1	Task	Total Cost	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19
2											
3	site setup		Gang 18 & 2								
4	setting out		Gang 17								
5	excavate guide trench			Gang 18 & 2							
6	Construct Guide beam			Gang 9 & 10	Gang 9 & 10						
7	Excavate & Construct basement wall				Gang 18 & 2	Gang 18 & 2					
8	Excavate Dumping						Gang 18 & 2	Gang 18 & 2			
9	Place formwork for B2							Gang 3 & 4			
10	Prep floor and place steel reinforcing							Gang 5,6,7,8			
11	Cast B2 floor							Gang 5,6,7,8	Gang 5,6,7,8		
12	Prep & Cast Columns								Gang 9,10,11,12		
13	Place formwork for basement floor 1								Gang 3 & 4		
14	Place steel reinforcing								Gang 3 & 4		
15	Cast B1 floor									Gang 9,10,11,12	
16	Waterproofing									Gang 18	
17	Prep & Cast Columns									Gang 9,10,11,12	
18	Place formwork for ground floor									Gang 3 & 4	Gang 3 & 4
19	Lay service ducts in/out of building										Gang 18 & 2

Figure 4: Extract of excel sheet derived from the Gantt chart with workforce assigned to specific monthly tasks (Author, 2019)

The number of gangs per calendar month when combined together calculated the total workforce required for that month. For example, November required three gangs, December required four gangs, and January required four gangs etc. Figure 4 only highlights the workforce required between the months of November 18 – June 19 and the works that are involved during those months, followed the critical path with no room for float or slack. However, Figure 5 is an extract from the schedule that shows tasks with the ability to rearrange the workforce requirements due to float (float is shown as a Green bar).

1	Task	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20
2													
3	site setup												
4	setting out												
5	excavate guide trench												
6	Construct Guide beam												
7	Excavate & Construct basement wall												
8	Excavate Dumping												
9	Place formwork for B2												
10	Prep floor and place steel reinforcing												
11	Cast B2 floor	Gang 5,6,7,8											
12	Prep & Cast Columns	Gang 9,10,11,12											
13	Place formwork for basement floor 1	Gang 3 & 4											
14	Place steel reinforcing	Gang 3 & 4											
15	Cast B1 floor		Gang 9,10,11,12										
16	Waterproofing		Gang 18										
17	Prep & Cast Columns		Gang 9,10,11,12										
18	Place formwork for ground floor		Gang 3 & 4	Gang 3 & 4									
19	Lay service ducts in/out of building			Gang 18 & 2									
20	Erect Steel Frame building A			Gang 5,6,7,8									
21	Erect Steel Frame building			Gang 5,6,7,8	Gang 5,6,7,8								
22	Erect Steel Frame building			Gang 5,6,7,8	Gang 5,6,7,8								
23	Roof edge protection and safety nets Building A			Gang 15 & 16									
24	Fit composite roof panels to Building A			Gang 13 & 14	Gang 13 & 14								
25	Roof edge protection and safety nets Building C			Gang 15 & 16									
26	Fit composite roof panels to Building C			Gang 13 & 14									
27	Roof edge protection and safety nets Building B			Gang 15 & 16									
28	Fit composite roof panels to Building B			Gang 13 & 14									
29	Kinross TEK Cladding												

Figure 5: Extract of excel sheet derived from the Gantt chart with free float periods included (Author, 2019)

Figure 6 includes a row at the bottom that gives the total gangs per month.

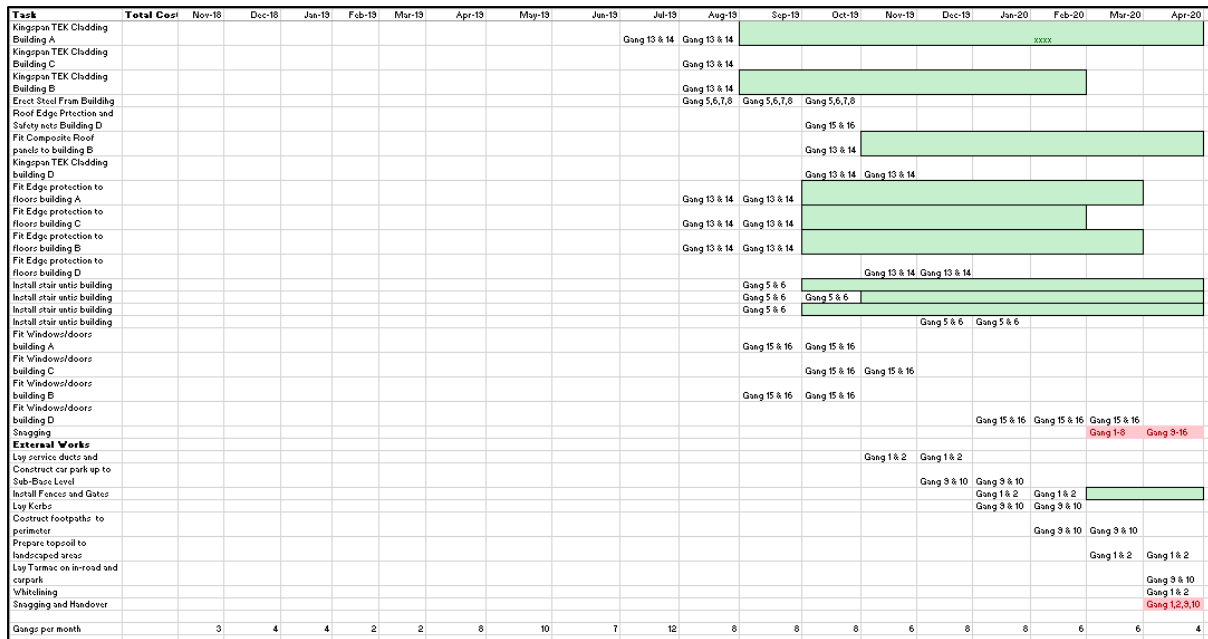


Figure 6: Extract of excel sheet derived from the Gantt chart with workforce assigned to specific monthly task (Author, 2019)

As previously stated, there is no float available between the months of Nov 18 – June 19 as they follow the critical path, therefore resource smoothing is not possible, however as is evident in Figure 6 there is availability for smoothing between the months of Jul 19 – Apr 20 (end date).

A total of twelve gangs are being utilised during the month of Jul 19, this is considered a 'peak' of workforce within the schedule, whereas in the month of Apr 20 only four gangs are being utilised, this would be considered a 'trough' in comparison to the other months that tend to average at around 6-8 gangs (per month). Therefore, by using the resource smoothing technique, it is possible to delay task 23 (Roof edge protection and safety nets Building A) and the use of Gangs 15 & 16, which were due to start Jul 19, until April 20, without delaying the overall construction schedule. By doing this, only ten gangs will be on site in the month of Jul 19, which reduces the 'peak' and in turn increases amount of gangs on site in Apr 20 to six, thus bringing the 'trough' up to meet the average.

Furthermore, it is possible to bring the workforce in Jul 19 down to meet the average by delaying Task 29 (Kingspan TEK Cladding Building A) and moving Gang 13 & 14 to complete these works in the month of Feb 20. This brings the total workforce in Jul 19 down to eight and takes the total workforce in Feb 20 up to eight and therefore smooths out the resources over the ten month period of construction as shown in Figures 7 & 8.

	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20
	12	8	8	8	6	8	8	6	6	4

Figure 7: Total gangs per month (Jul 19 – Apr 20) prior to resource smoothing (Author, 2019)

	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20
	8	8	8	8	6	8	8	8	6	6

Figure 8: Total gangs per month (Jul 19 – Apr 20) following resource smoothing (Author, 2019)

5.0 Discussion

Based on the resource smoothing that was carried out on the schedule it is easy to see that by delaying tasks until a later date within the free float period provides uniformity among the workforce resource per month. However, problems can occur when delaying tasks. A prime example of this can be seen in Figure 9. The yellow highlighted cells indicate tasks where the use of cranes is a requirement to undertake the task. Prior to resource smoothing there was only requirement for a crane within the months of Jul 19 and Aug 19. By delaying/moving back task 23 to Feb 20, it would mean that there is a requirement for a crane to be on site to assist that month also. Should the crane be procured on a hire bases, it would either mean having to hire the plant for the duration (Jul 19 – Feb 20) which would incur additional costs, or alternatively it would mean having to co-ordinate having a crane return to site at the later date. This would not only affect cost but would mean that the site layout would also need to be consulted to ensure that there is an area on site for the crane to manoeuvre and that it does not conflict with other works at that time. This could be problematic if the site has progressed considerably since the original start date.

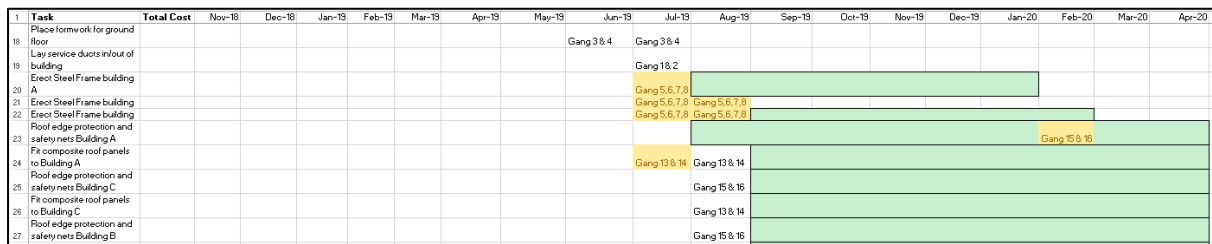


Figure 9: Extract of the schedule highlighting tasks where a crane is needed (Author, 2019)

Similarly with the crane issue, other elements could be affected. For example the delivery of plant and materials. By moving the resource, the tools, plant or material required to undertake the works will also require amending. Should a labouring gang be re-scheduled within the float, the programme manager would be expected to arrange for alternative delivery dates for the concrete mixing machine (if not kept on site), delivery of sand, cement and coarse aggregates to correspond with when the labourers are ready to carry out the works. The site may not have the capacity to store earthwork plant such as dumper trucks and heavy duty excavator vehicles, therefore consideration regarding the redelivery of such plant is required when smoothing the resources.

Resource optimising not only provides the benefit of delaying tasks as a means of creating a distributed workforce, it also allows tasks to be delayed within the free float period so that overall project cost can be reduced. For example, Figure 10 shows that Aug 19 is the most expensive month within the construction programme with a cash flow figure of £1,434,853.78 with the total interest repayable overall as £334,680.52.

	Cash in	Cash out	Cumulative	Cash flow			
Nov-18		£30,364	£30,364	-£30,364	Compound		
Dec-18	£31,153.46	£9,618	£61,517	-£6,828.38			
Jan-19	£9,867.90	£219,314	£228,142	-£218,274.22	Max borrowed		£1,434,853.78
Feb-19	£225,015.91	£633,064	£443,290	-£626,322.06	Interest rate		15.00%
Mar-19	£649,523.41	£9,179	£635,501	£14,022.56	Term (years)		1.5
Apr-19	£9,417.43	£223,349	-£4,605	-£199,909.12	Compounding periods per Year		12
May-19	£229,156.19	£375,056	£574,965	-£345,808.84			
Jun-19	£384,807.36	£266,437	£730,616	-£227,438.78	Future Value		£1,769,534.30
Jul-19	£273,364.67	£1,297,961	£1,525,400	-£1,252,034.96			
Aug-19	£1,331,707.83	£1,514,527	£2,583,743	-£1,434,853.78			
Sep-19	£1,553,904.34	£914,477	£2,349,331	-£795,426.68			
Oct-19	£938,253.66	£692,416	£1,733,680	-£549,588.78			
Nov-19	£710,418.56	£704,930	£1,254,519	-£544,100.70			
Dec-19	£723,258.67	£41,403	£1,267,359	£137,754.98			
Jan-20	£42,479.47	£84,719	-£53,036	£95,515.55			
Feb-20	£86,921.60	£193,512	-£8,594	-£110,74.87			
Mar-20	£198,543.33	£307,826	£318,901	-£120,357.99			
Apr-20	£315,829.94	£596,852	£436,188	-£401,380.35			
May-20	£1,050,580.68	0	£401,380	£649,200.33			
	£8,764,204.42	£8,115,004	Profit	£649,200.33			
					Total Interest		£334,680.52

Figure 10 & 11: Extract of the cost data sheets showing cash flow values and total interest values (Author, 2019)

However, by using the float, delaying Task 24 (Fit composite roof panels to Building A) and therefore, moving Gang 13 & 14 from Aug 19 to Jan 20 (January being a month that the cash flow is in positive equity) you also move £277,272.45 worth of expenses from Aug 19 – Jan 20. What you should expect to see from this is that the cash flow for Aug 19 will decrease by the amount moved and the total interest for the overall project will also decrease, meaning you will pay back less, as can be seen in Figure 13.

Jul-19	£273,364.67	£1,297,961	£1,525,400	-£1,252,034.96
Aug-19	£1,331,707.83	£1,237,254	£2,583,743	-£1,157,581.33
Sep-19	£1,269,422.81	£914,477	£2,072,059	-£802,635.77
Oct-19	£938,253.66	£692,416	£1,733,680	-£549,588.78

Compound			
Max borrowed			£1,252,034.96
Interest rate			15.00%
Term (years)			1.5
Compounding periods per Year			12
Future Value			£1,544,075.26
Total Interest			£292,040.30

Figure 12 & 13: Extract of the cost data sheets showing cash flow values and total interest values following a resource smooth (Author, 2019)

As is evident, by smoothing the resource, the cash flow value for Aug 19 has dropped below the value for Jul 19, meaning Jul 19 becomes the most expensive month. The max borrowed will then become the same value as the cash flow for Jul 19. When factoring the interest rate and the borrowing durations, the total interest of the overall project reduces. In this example, the total interest amount repayable reduces by £42,640.22 for the overall project.

6.0 Conclusion

Resource optimisation proves to be a successful method of controlling peaks and troughs in workforce, within the programme schedule. By manipulating and delaying the tasks within the free float period, the resources could be smoothed and therefore the gangs per month, did not exceed the optimum workforce required, nor did it fall below the average. The projected end date of the construction programme could still be met, meaning that no overruns occurred.

If utilised effectively, the resource smoothing technique can reduce the overall cost of a project by reducing the total interest on borrowed money. If the cost of works within a particular month is higher than a month later on in the schedule that is in positive equity, providing the free float is available on a task, delaying works will mean that the interest costs will decrease overall.

If utilised ineffectively, resource smoothing can present significant problems. Delaying tasks also requires that the project manager anticipates that materials and plan will also need to be rescheduled or delivered to site. Should a task be moved to the end of the free float period, and the project manager has failed to recognise that new delivery dates and plant hire dates required changing also, there is no flexibility to put dates back further. Thus causing overruns and the potential to delay the whole project.

Further steps could be taken to fully optimise resource and cost. Rather than smoothing the resources to ensure that there are no peaks and troughs, or smoothing the resources to save as much money as possible, it is in the writer's opinion that a combination of workforce smoothing and cost smoothing is the best solution. Although this may mean that there are peaks or troughs at certain points in the schedule it will mean that the peaks and troughs aren't as severe as they could be if reducing the costs was the main focus. If reducing cost was the main focus it could also mean that the site is on stop for certain months due to no workforce. Similarly, if resource smoothing was the main focus alone, the potential to reduce cost could be overlooked. If the project manager produces a schedule with both resource and cost in mind, the smoothing technique can be effectively utilised.

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8.0 Appendixes

Appendix A – Project Gantt chart

