CHAPTERS 1, 2 and 3 DRAFT

CHAPTER 1 - UNITS OF MEASUREMENT

1.0 Introduction

One thing sadly missing in our construction industry is clarity of expression. This means being precise in our language, as it is the pathway to a clearer understanding of the topic under discussion.

This concept is particularly applicable to the subject of earthworks. Cost estimating of earthworks is a greatly disregarded aspect of construction, even though almost every construction project features some earthworks.

2.0 Precision Lost

The most effective way to be more precise in Earthworks lies in taking care to express the units involved more exactly. To our way of thinking, the term '**m3**' should be consigned to the rubbish bin of history. It is such a vague term that causes a lot of confusion in our industry. It is the equivalent of saying 'dollar' in an international setting such as Hong Kong, and then not stating which dollar you are referring to: is it HKD, or USD, or AUD?. And it happens far too frequently!

3.0 Precision Regained

We offer what we believe are far more precise alternatives to 'm3': these are the acronyms LCM, BCM and CCM.

John learnt the importance of this concept from another person's mistakes, someone he considers to be so much smarter also. Sometimes it's good to learn from your own mistakes – it's even better (and cheaper) to learn from someone else's mistakes.

The terms we recommend all earthworks estimators ought to adopt are these:

LCM - Loose Cubic Metres

BCM - Bank Cubic Metres

CCM – Compacted Cubic Metres

LCM: The best way to visualize LCM is to picture soil in the back of a truck or, even better, in the conical stockpile at the end of a stacker conveyor. This is the idealized version of LCM. As we proceed with this discussion, you will realize that LCM may be a 'partial' condition rather than the ideal – but this small complication can be managed with densities.

BCM: This describes **undisturbed** soils, in the ground. We believe the term 'bank' is itself a bit misleading but we are stuck with it – probably thanks in part to the Caterpillar Handbook. Open-cut miners will **always** refer to soil quantities as 'bcms', but we like to think of it as 'undisturbed' cubic metres.

CCM: This describes soil after it has it is compacted. Once again the **degree of compaction** needs to be established, and this is achieved with the help of densities, and density ratios.

The above units cover a majority of situations the estimator is likely to confront when estimating earthworks. Nevertheless, there are other valid units that can play a role, particularly 'tonnes'.

4.0 Densities

As we hinted at earlier, the relationship between the units listed above is to found in densities. In other words, the soil densities in the three different situations need to be established. Some, or even all of these densities may be found in the tender documents, or via soils laboratory test reports in the general vicinity of a project, or even by having special tests taken if the earthworks component of the tender is sufficiently significant. One important rule to adhere to is to ensure the soils densities adopted (they will **usually** have to be averaged across a small site) are on a common basis: the densities are all expressed as 'dry' or 'wet'. What we are trying to establish here is a common platform for comparisons: **tonnes / lcm**, **tonnes / bcm** and **tonnes / ccm**. When these densities are established, such relationships as swell or shrinkage factors between LCM, BCM, and CCM are automatically established. Again we say…ensure the densities are **all dry** or **all wet**. We prefer using 'dry', since maximum dry density (MDD) is a figure commonly known to laboratories and is a good starting point.

For example – suppose the densities for BCM and LCM have been established, perhaps in the order of 1.85 t/bcm (dry) and 1.50 t/lcm (dry). Then:

Swell factor = 1.85/1.50 = 1.23

We will deal further with such terms as swell factor when we move onto machine production estimating.

5.0 Shades of Grey

Life would be simple - the highest form of sophistication, according to Leonardo da Vinci, if all there was to know about such matters could be covered by the three terms above. However, the reader needs to be aware that often intermediate situations arise. One example is found in the stockpiling of materials. John says…"when I was a boy engineer, I would immediately apply this new and hard-won knowledge of material densities and confidently assert the volume a stockpile would occupy. However, it didn't take long for me to discover that unless the stockpile is being formed by a stacker conveyor (or perhaps something that floats like a hovercraft) trucks or scrapers, or a bulldozer pushing up a stockpile will be running all over the stockpile as they dump their loads. Hence the actual density of materials in the stockpile will be somewhat greater than first thought."

We therefore need to apply our judgment to assessing just what the new density might be. It will be lighter than the original **t/bcm**, but will be somewhat greater than the **t/lcm** that had been established originally. Another minor example is in the re-spreading of topsoil – the effect of machinery working over the top of a layer of topsoil is to partially compact the materials as it is placed and trimmed.

6.0 Conclusion

The vagaries mentioned above should not be allowed to overwhelm anybody. It just means that sometimes judgment has to be applied in the never-ending attempt at finding the most correct answer. After all, we are 'estimating', meaning that there is no exact answer.

The key point is to recognise the importance of adopting appropriate units of measurement when working with earthworks quantities so that we can match "apples with apples".

CHAPTER 2 – PRODUCTIVITY ESTIMATING

1.0 Introduction

This topic is concerned mainly with the productivity of earthmoving machines. Please refresh your memory on ‘Densities’ discussed in the previous topic before proceeding.

In the lead-up to the discussion below, we recommend that at the very start of a tender, you should find and edit the term ‘m3’ in the Bill of Quantities. That is, when this term is applied to earthworks, roadworks or dams construction – particularly RCC dams, replace it with the more appropriate and precise terms of BCM, LCM or CCM. Even although this temporary allocation may eventually prove inaccurate, this at least starts the process of determining which situation is actually intended. We hope that one day the authors of Bills of Quantities may actually recognise the benefits and save us all a lot of confusion and heartache by adopting this convention.

2.0 Capacities

The first thing to bear in mind is that equipment manufacturers are trying to sell their products, so we’ll start by saying that at times their stated capacities (and performances) can be on the optimistic side. No doubt these capacities (and performances) have occurred somewhere, sometime, but they should not be taken as commonplace. Note: manufacturers usually select the best operators in the world to establish their productivities.

It should also be noted that the equipment capacities are usually stated in ‘m3’ and this is usually intended to mean LCM. So if the BoQ item is expressed in BCM (or even sometimes in CCM) the relationship needs to be established between that BoQ unit and LCM. That's where densities come to the rescue. Try to establish the most likely densities (preferably **all dry**) for each of the soil situations (BCM, LCM and CCM) and you are equipped to manage any of the possible relationships.

We should mention here an interesting industry exception – *Aran*, an Australian based equipment manufacturer, publishes their Continuous Mixer - otherwise known as a *Pugmill*, capacities as '**compacted cubic metres'**, thereby avoiding a very common confusion of terms, particularly with respect to RCC dams. Court battles have actually been fought over the issue of whether the stated capacity of RCC equipment is meant to be in LCM or in CCM – of course the ubiquitous (and iniquitous) term 'm3', used by both parties, lay at the heart of the problem.

For particular types of equipment, for example crushers, the output (capacity) is expressed as tonnes per hour (tph). Nevertheless, the density relationships will prove to be just as relevant.

Equipment capacities will describe different things. With scrapers, it's the bowl capacity; for trucks it's the body capacity and for excavators and loaders, the bucket capacity. In particular for scrapers and trucks, whilst we estimators are always seeking the maximum capacities, when you are not familiar with the particular equipment under consideration, it is recommended that the 'struck' capacity be used instead of the 'heaped'. This should keep you 'safe' until you become better acquainted with that particular *beast*.

Please note that even bull-dozers (dozers) have capacities: the term used is *blade capacity,* based on certain angle-of-repose assumptions. It's best to check the Handbook to better understand just what these assumptions are.

You should also note that consideration must be given to the **type** of material being excavated or hauled. Densities will give you at least indicative swell factors, but bear in mind that rock, for instance, will take longer to load and be more abrasive. And the fill factor (see later) for the equipment is going to be reduced.

Rated capacities of equipment are to be found in the manufactures' handbooks, perhaps the most famous being the **Caterpillar Handbook**. This is an essential book to have in any estimator's library, or *toolbox*. We STRONGLY suggest you obtain a copy from your nearest Caterpillar dealer. The book contains a wealth of information, apart from equipment specifications and outputs and will remain your life-long friend whenever you are estimating earthworks costs.

3.0 Cycle Times

If we are to be able to calculate equipment productivities, then we need to satisfy the following Basic Equation:

Production / hour = Capacity x Cycles/hour

Having looked at capacities earlier, we now need to consider cycle times so that we can deduce **cycles/hour**. Again we recommend that every (serious) earthworks estimator have a timing device and be ready to use it at the slightest provocation! John's grandfather used a *fobwatch*, we have used a stopwatch, but of course today a mobile phone can be used. We suggest that whenever the opportunity arises, time the machine, then make a note in a dedicated (electronic) file of its cycle times or loads per hour, also noting the particular context. By doing this exercise frequently, with a wide range of machines, you will soon build a wealth of knowledge, delivering increased confidence in your work, for yourself and others.

In the final analysis – it's got to be real!

The use of the technique of establishing the bucket capacity of a machine has allowed us in the past to evaluate machinery never encountered before and to establish reasonable productivity rates, in a little more than one hour, often to the great surprise of staff who had owned that machine for several years and had a very wide range of ideas of its productivity.

Hint: when timing equipment it is best to be a little secretive, since it might otherwise induce the operator to operate either very slowly or very fast – often because he or she does not understand the purpose of the timing exercise.

Of course, the more times you can study the cycle times of earthworks equipment, the better your knowledge of its capability will be.

With haulage trucks, the on-highway type in particular, it is worthwhile to trace out the route to be taken by the trucks and to drive that route, as if you are driving a truck. This will yield valuable data, especially if carried out at different times of the day and, perhaps, different days of the week.

4.0 Production

We now have the means to calculate productivities. But let's firstly modify the Basic Equation a little:

Max. Production / hour = Max. Capacity * Minimum Cycles / hour

In other words, if we choose the maximum capacity along with the lowest cycle time we have measured, which we translate to the most cycles/hour, we have an approximation of the best production per hour of the machine under consideration.

However, since we know this "best outcome" is unlikely to be replicated "hour-after-hour", we need to apply several production **factors** to introduce some **realism** into the exercise.

Typical production **factors** include:

- **Job** minutes / hour – typically 50 minutes = 50/60= 83% - to allow for organizational shortfalls. We often term this the "50 minute hour" factor.

- **Operator** efficiency – typically 90%, on the basis that nobody is a robot…..well, not yet, anyway! This factor accounts for workface discussions, toilet breaks and unfortunately at some sites today, mobile phone calls, and so on.
- **Swell** Factor – 25% (determined by densities)
- **Fill** Factor – say 75% (typical for rock) – this is the percentage of the nominal bucket or bowl or blade capacity that can be utilised.

Okay, let's suppose a machine, for example an excavator, has a bucket capacity of **10** LCM and a measured cycle time of **30** seconds, along with the factors given above. Then we can estimate the machine productivity as follows:

Est. prod. / hr. = 10*(60*60/30 *83%*90% /1.25 * 75% = **538** bcm/hr.

Or if we add some descriptors:

Estimated production / hr = 10*(60 mins /hr *60 secs /30 secs)*83%*90% /1.25 FF * 75% = **538** bcm/hr.

Please always express estimated production figures as rounded up numbers, WITHOUT decimal places, as it is an **estimate only** – not a fact. It is a common mistake to produce figures to one, two or even three decimal places (a habit of particular regularity in some countries such as the Philippines) and to 'pretend' that great accuracy has been achieved, even though each of the inputs is a (rough) approximation.

The application of *productivity factors* has to be carried out very carefully or you will produce an overly-optimistic or even too-easily achieved, and therefore uncompetitive, productivity result. Our approach is to aim for a productivity that is realistic and achievable – **but only just**.

5.0 Conclusion

We would like to share a *rule-of-thumb* with you: in our experience, when and IF field staff are ever asked about the productivity of any machine -and in our opinion they should be asked frequently, they will invariably give you the **best** performance they have ever seen, because that's what 'sticks' in their mind. And they will use the term **'m3', usually** without any thought on the implication of that term. But of course, you now know better!

Our rule-of-thumb is to **divide that number by 2** and you will get an idea of the **average** productivity of such a machine **-** and you probably get BCM thrown in free of charge!

On another matter, John says: "I would like to recount an experience I had in PNG, which really alerted me, perhaps for the first time, to the importance of the *Basic Equation* in our work:

Many years ago, I found myself timing a wheeled loader (a Cat 950B or thereabouts, which was loading sand out of a stockpile, on a hard and even (level) surface – ideal circumstances, I must say. I remember the bucket capacity as being about 2.3 lcm and the cycle time was something like 26 secs. To my astonishment, this 'tiny' and disregarded loader (but with a very competent operator) was capable of producing not much less than some far larger loaders would likely have produced in that same situation. It all came down to the combination of the not-insignificant bucket capacity, and a very quick cycle time."

On the basis that our work is all about economics, here was a very economical if not glamorous, solution to a typical estimator's problem!

You are now equipped to measure cycle times and determine the productivity of any earthmoving plant on your projects. Go to it, get out your TIMER and start building your own library of data. Please don't just think about it, go out and DO IT and you will reap the rewards!

CHAPTER 3 – LOADING AND HAULING

1.0 Introduction

In the previous topic we had a quick look at the productivity of a single loading tool – an excavator. In this topic we will discuss combined loading and hauling equipment such as trucks and scrapers.

This immediately brings to mind the prime importance of constructing and maintaining very good haul roads. Money spent in this area will usually be rewarded many times over with the increased productivity of hauling vehicles.

And this is an opportune time to point out what should seem obvious: we are modeling on our computers the types of decisions that will need to be taken during actual construction. If it is economical to do a particular activity during construction, then it is equally valid to do it in the estimate **-** and vice versa. Therefore, in both situations don't skimp on haul road construction! Then we can reflect the high quality of our haul roads in higher travel speeds of our *running* equipment.

Now let's take things to a higher level in our quest for excellence in Earthworks Estimating with some new concepts.

2.0 Running Resistance

There are two main types of resistance to be taken into account – rolling resistance, and grade resistance (or assistance).

Rolling resistance is a function of the softness of a haul road surface. Obviously the softer the surface, the greater the rolling resistance, resulting in slower travel speeds for the equipment. The *Cat Handbook* contains tables that give the equivalent grade resistance for various haul road conditions.

Actual **grade resistance** (or assistance) is the result of an undulating haul road. Obviously, the design of a haul road needs to minimize steep sections as far as possible, to facilitate the smooth travel or movement of equipment.

For any given segment of a haul road, the Rolling Resistance (**RR**) is added to the Grade Resistance (**GR**) to determine the Total Resistance.

$$TR (\%) = RR (\%) + GR (\%)$$

Bear in mind that GR can be a negative percentage when considering downhill sections and that is then referred to as **Grade Assistance (GA).**

For example:

Rolling Resistance (RR) = 10% (loose sand)

Grade Resistance (GR) = 5%. Note: if travel is uphill, the factor is a **+ %.** If travel is downhill it is a **- %**.

Therefore **Total Resistance (TR)** = 10% + 5% = **15%**

This percentage is then applied to a **performance chart -** again, refer to the *Cat Handbook* or equivalent reference for the particular equipment being utilised, to determine the *gear-box ratio* the equipment would be expected to operate in in order to “combat” such a Total Resistance. When using a Performance Chart the **loaded** or **empty** condition of the equipment must be taken into account. This is fully explained in the *Cat Handbook*.

Furthermore, it is worth noting the speed that is determined from a Performance Chart for any TR, is the **average** speed the machine can travel at, for that **TR**. You also need to take account of the site conditions or circumstances of the section of road prior to entering that section of the haul road. For instance, if the previous section of the haul road is a downhill run, then the average speed may be a little bit **greater** than that indicated on the charts, due to the advantage of the ‘run-on’ speed, whereas if it is an uphill section, then the average may a bit **less** than indicated on the chart.

Of course, anyone using simulation programs will not have to worry about such things. But then again, they may not have as much fun, or be in a position to properly understand the relevant issues quite as well as we ‘manual drivers’.

Before proceeding to the next section we recommend you go back and re-read this section. It is very important you have a firm grasp on the concepts we have covered, before moving on. Remove any mental ‘resistance’ here team, we have much to do and we need you to be ‘on-board’ the *Estimator Train* as we attack more exciting **Earthworks Estimating Fundamentals**!

3.0 Haul Roads

As discussed above, consideration needs to be given to the design of haul roads at tender time, leading on to the cost of their **construction**.

Although there is rarely enough time in a tender period to carry out a proper design of haul roads, some consideration needs to be given to road geometry, including such issues as sight distance – both vertical and horizontal, and particularly the width of the haul road. For any haul road, the minimum width, by a Rule-of-thumb, is **2.5 times the width of the vehicle**. We must also make allowance for haul road drainage and possibly even temporary bridges or pontoons where applicable. Again, don’t skimp on these very important elements of the haul road ‘infrastructure’, because money not invested will usually be money lost.

Now, having allowed for the cost of **construction**, there we must allocate funds for haul road **maintenance**. This will typically involve the periodic or even continual application of road graders and water trucks and occasionally some dozers and rollers. You will also find you require a nominal quantity of gravel or **FCR** – fine crushed rock, to resurface or repair the haul roads.

4.0 Optimising the Fleet

Okay, now that we have a 'perfect' running surface to operate our haul fleet on, perhaps this is an opportune time to discuss the optimization of such a *loading and hauling* fleet. This applies to 'master and servant' fleets such as loader and trucks, or even to 'pusher-dozer' and 'open-bowl' scrapers.

The basic equation in this case is:

$$\textbf{No. of Trucks} = \frac{\text{Total Truck C.T. including loading time}}{\text{Loading Time}}$$

Note: the term C.T. is an abbreviation for *Cycle Time*

It goes without saying – well, we are saying it anyway, that only whole numbers of hauling vehicles can be employed. Have you ever seen 'half' of a truck? If the answer is, say, **4.2 or less,** it is very likely that the optimum solution (lowest practical cost / bcm) will be **4.0**, with a calculable reduction in output, since theoretically, the excavator will **not** now be operating at its full potential. Whether or not the optimum solution is **4.0** or **5.0** (continuing our example from above) will depend on the relative costs / hour between the loading machine and the transporting machines.

As the costs / hour converge - perhaps because of an economical excavator and expensive hauling units, the higher will be the calculated number of trucks that may need to be 'rounded down' rather than 'rounded up'. In other words, even a calculated solution such as **4.4** might need to be 'rounded down' to **4.0**, as the least cost solution, depending on the relative costs of the plant equipment utilised in the work operation.

It is vital that each case be considered on its merits.

In the case of a dozer loading open-bowl scrapers, the same equation applies, with the loading cycle time consisting of **push**, **boost** and **return** to the original starting point. Note: on the odd occasion where the dozer does not need to return to its original starting point, then the loading time is reduced to only **push** and **boost** plus **maneuver** time, in order to ‘catch up” with a scraper. This is a rare occurrence, since the objective is always to take advantage of downhill loading, whenever possible.

Is this clear? Again, study this concept before proceeding. In real, on the job situations, it is the successful combination of plant that delivers optimal performance. The combination of a MOUSE loader with ELEPHANT trucks will only lead to ….tears. And it also goes without saying, stand back and take a PRACTICAL look at any solution you derive from your numbers. There is rarely a substitute for common sense, even though we often find that (ideal) approach is not common.

5.0 System Optimisation

In order to really optimize our earthworks estimates, we need to understand that when multiple machines /activities are involved we are really dealing with a fleet **system**.

John says: “My introduction to this concept was came when I would drive past a road construction project each day, witness the spreading and compacting equipment working one day, and then see it standing idle the next time I went past and so on. On checking the reasons for this situation, I found we had saved a small amount of money **per ccm** on purchase of the crushed rock, but the supplier had limited resources for delivering the crushed rock. It occurred to me then that we might have saved say $1.00 /ccm in supply and delivery of the crushed rock, but then cost ourselves perhaps $4.00 / ccm for the inefficiencies of our spreading and compaction operations. Talk about FALSE ECONOMIES!”

Thus was born the very obvious ‘**total system concept’**. We really need to select equipment based on an **overall** evaluation of the least cost. As an example, the load and haul operation might require dozer assistance with ripping and dozing up of materials into a stockpile. The productivity of that dozer must match closely the load and haul production envisaged. The spread and compact operation needs water to be supplied by a water truck (I will use the term *watercart* from this point on*)* of sufficient capacity to match the delivery rate and the expected delivered moisture content, as compared to the optimum moisture content of that material. Also, the compaction equipment *capacity* must match as closely as possible, the expected delivery rate of the crushed rock, or any other material.

We can use a spreadsheet to great advantage for this purpose. Many different scenarios can be estimated based on a broad range of different **total** fleets. It will soon become apparent that the **overall optimum solution** is very often not simply represented by the cheapest *load and haul* equipment and cost.

6.0 Conclusion

Okay, we have covered some concepts here that will lead you to look differently at your earthworks estimates. In future chapters we will look at some techniques and take this process further.

Remember, we are striving to achieve the most accurate but at the same time, realistic cost estimate we can. We must always be on the lookout and recognise site conditions that may impact on cycle times and aim to select the best **system** we can.

And once again, frequent references have been made in this section to the *Cat Handbook*, or its equivalent. A thorough study of the Handbook will inevitably prove very rewarding and will shed a lot more light on many of the topics briefly touched on above.

Note: at this point you have reached the end of **Chapter 3** of our DRAFT e-book. Please tell us how you are finding the information we have covered so far, both in terms of

CONTENT and PRESENTATION. Are we making sense? Is the information relevant or even useful? We want to know what YOU think, so we look forward to receiving your email soon.

Just in case you are wondering WHEN we will get to some charts, a few worked examples or even some diagrams……don't worry, we WILL get to those soon. It's important in our opinion to work through the FUNDAMENTLE concepts first, so that you have important tools in your ESTIMATOR TOOLBOX.

THANK you for getting to this point and we look forward to moving on to the next few chapters with YOU on board the EARTHWORKS ESTIMATOR TRAIN!