STANDARD METHOD OF MEASUREMENT FOR UNDERGROUND DEVELOPMENT WORKS

M.J. Maritz, R. Du Rand***

**Department of Construction Economics, University of Pretoria*
tinus.maritz@up.ac.za Tel +27 12 420 2581
***J.S. Redpath Ltd, Ontario, Canada*
rouan.durand@jsrl.com

ABSTRACT

Purpose: Bills of quantities for underground development works (UDW) are presently prepared with no uniformity of practice, leading to troublesome misinterpretations and inconsistent pricing by contractors. This article describes the results of research to determine if there is a requirement from the underground development industry to develop a separate standard system of measurement.

Methodology: Firstly, an empirical study was conducted, with existing bills of quantities reviewed by way of methodological analysis and, secondly, market opinion was tested through purposive sampling to obtain responses from a relatively small population of experienced underground development professionals.

Findings: The results showed that UDW bills of quantities are not standardised and that there is a need to develop a bespoke standard system of measurement. UDW differs from civil works, and therefore the nature of the work, the circumstances under which it will be executed (site conditions) and the materials to be used have to be described in the bills of quantities in order to make tender comparisons easier.

Limitations: Only underground development unit operations (drilling, blasting, supporting, loading and hauling activities) were studied, with brief references to auxiliary operations. The influence of contractual strategies and contract types was excluded.

Value: Motivation is provided for developing a commonly accepted standard system of measurement (and associated model bills of quantities) to suit the needs of the UDW industry. Such a modified method of measurement should work in harmony with existing building, civil or other recognised measurement systems.

KEYWORDS

Underground development works, (UDW), standardisation, system of measurement, bills of quantities, unit operations.

INTRODUCTION

Equitable tendering processes

Contracts that are placed as a result of competitive tendering bills of quantities that are common to all bidders ensure comparability and are more economical in time and effort [1]. In addition, a project manager heading up a multi-disciplinary engineering construction project requires appropriate tools that define the scope of work in a clear, concise and manageable format.

Bills of quantities for the building and civil construction industries have been established largely to manage and control construction costs. It is prudent to review the primary functions and benefits of standard systems of measurement (on which bills of quantities are based) to establish what potential utilisations there are for UDW.

Primary functions of standard systems of measurement

The primary functions of a standard system of measurement can be described as follows [2]:

- Standardising the system of categorising construction work;
- Indicating the differentiating circumstances e.g. location or position of items to distinguish between degrees of difficulty, risk or site conditions;
- Indicating circumstances and/or parameters whether standard, special, repetitive or non-repetitive that can significantly affect the costs;
- Defining the limits of the items to leave no doubt as to what is included, deemed to be included or excluded; and
- Prescribing the method and sequence of determining dimensions, and calculating the quantities of measured items.

The building and civil engineering industries developed standard systems of measurement to control work executed by contractors. Examples of the foregoing in South Africa are the Standard System of Measuring Building Work (1999)[3] and the SABS 1200 Standardised Specifications for Civil Engineering Construction Work (1981)[4]. The study has revealed that the UDW industry does recognise the value of bills of quantities, although no commonly accepted standards appear to be available.

Benefits of standard systems of measurement

The following benefits can be suggested by standardising the method of measurement (and model bills of quantities) for UDW:

- Employers and consultants will understand what the minimum requirements are when compiling bills of quantities;
- The distribution of cost risks between employers, consultants and contractors will be better understood;
- The effectiveness of project control and contract administration can be improved;
- Potential disputes arising from the interpretation of measured items can be minimised;
- Tender documents may be comparable as all the contractors interpret the method of measurement and bills of quantities in the same manner;
- A more competitive tendering environment can be established (saving time in re-work and constant re-invention);
- Unit rates can be used as comparative measures between different projects;
- Unit rates can be used with better accuracy when applied by employers and/or consultants in feasibility studies;
- Technology development in terms of software and systems development may improve, enabling users to price tender documents more efficiently; and

- Successful standardisation in South Africa may lead to a global standardisation effort.

From a modern cost and project management perspective standard systems of measurement do not operate as stand-alone systems, but are often used in conjunction with a work breakdown structure (WBS) and code of accounts. The discussion and integration of a WBS and code of accounts are excluded from this article.

OVERVIEW OF UNIT OPERATIONS AND FACTORS INFLUENCING UDW COSTS

UDW unit and auxiliary operations

The core of UDW activities consists of drilling, blasting, support, loading and hauling. These basic steps are termed the unit operations of UDW.

Auxiliary operations consist of an array of different activities that support the unit operations, but do not have a direct impact on them. The auxiliary activities can be categorised as follows [5]:

- Gas and dust control;
- Ventilation and air conditioning;
- Disease prevention;
- Noise abatement;
- Groundwater protection;
- Subsidence control and roof control;
- Man cages, trips and cars;
- Water, compressed air, power, fuels, lubricants and pumping systems;
- Storage and delivery of supplies;
- Radio and telecommunication systems;
- Construction of roadways, haulage ways, settlers, silos or other civil structures; and
- Workshop or shop facilities.

Overview of the cyclic nature of UDW

A high proportion of time-related costs exist in all tunnelling operations [6]. Therefore, when advancing a single development end, a crew is bound to the cycle of operations. Activities are executed sequentially where the next operation can only be started once the preceding activity has been completed. Considering the impact that sequential activities have on the programme, it is important to understand the influence of mining equipment on unit rate pricing. The cycle of operations is generally adjusted to accommodate the type of equipment used as this can greatly affect the time taken to complete unit operations (or construction programme)[7].

Equipment and worker productivity are also not necessarily linked to physical abilities or capacities, but are restricted by the cyclic nature of the unit operations, including factors such as the proximity, accessibility and the number of available development ends. The construction duration is a critical factor in determining UDW costs [6].

General differences between the provisions of existing building standard systems of measurement and UDW requirements

Considering that UDW consists mainly of large fixed costs, with these costs driven by time elapsed and not the actual heading advance, it is important to note the major differences between UDW and aspects covered in building standard systems of measurement:

- **Method of excavation**: Underground mine owners generally have significant existing infrastructure and use a specific fleet of equipment. It is not unusual for an owner to prescribe that the contractor use specific equipment, or that equipment be free-issued by the owner. This approach sometimes restricts the choice that a contractor has in deciding on a method of excavation.
- **Conveying and hoisting**: The conveyance of personnel, materials and equipment is a critical part of most underground projects. However, by deeming that hoisting and conveying are included in the unit rates, major costs may be left outside the control of contracting parties.
- **Temporary work**: Temporary work such as compressed air equipment, mini-subs, pumps, transformers, ventilation fans, hoists/winders, etc. is generally not measured under a building contract, but deemed to be included in unit rates. UDW, however, requires significant high value construction equipment and services infrastructure and consideration should be given to the measurement of these items. Temporary services such as water, compressed air, concrete and fuel pipelines, electrical and communication cables, etc. may cover several kilometres in length and may warrant measurement to ensure equitable tender evaluations and interim payments to the contractor.
- **High value temporary building structures**: Winder houses (hoists), air compressed air plants (mobile or temporary) or other temporary structures may require significant foundations and structural steel construction. The costs of constructing these facilities are often hidden in larger lump sum values in UDW tenders. Even though temporary in nature, the measurement of these facilities is potentially warranted to ensure fair tenders and payment to contractors.
- **Operations, care and maintenance**: The building standard system of measurement focuses on the construction of new facilities or alterations to existing facilities. Items dealing with the operations, care and maintenance of newly constructed facilities are not covered in detail. There may be significant costs associated with labour, materials, equipment rentals and indirect charges when operating and maintaining a newly constructed shaft or tunnel excavation (due to the nature and large volume of excavations associated with UDW, and with projects often spanning multiple years, warranting maintenance of facilities constructed in prior years).
- **Provision for free-issued items or the categorisation of items into 'supply' and 'install':** The building standard system of measurement does not categorise responsibilities or specify unit rate prices into 'supply' and/or 'install' items. Due to the operational nature and high value of many UDW projects, employers generally have significant existing infrastructure or buying power and often opt to supply materials and major equipment free of charge to the contractor.
- **Major equipment costs:** The building standard system of measurement deems that unit rates cover the full spectrum of supply and installation e.g. the cost of hoisting and lifting items into position are deemed to be included. UDW generally has high value construction equipment and major costs may be incurred on time elapsed and not only on the development of end advances. As a result major equipment costs may vary considerably based on site duration, and may warrant separate equipment schedules, in lieu of lump sum pricing provisions.

Building measurement systems deal with detail and mostly accurate quantities, whilst UDW focuses more on bulk measurements, operational practicalities and with quantities more provisional in nature. By considering the value and/or complexity of UDW, thought must also be given to standardising the measurement of temporary work, the incorporation of method-related charges and provisions dealing with specialised or advancing technologies. It is also imperative to understand how UDW unit rates are affected by cost significant factors.

Cost significant factors affecting UDW unit rates

The following cost significant factors can potentially be identified:

- **Number of development ends (headings)**: Production capacity may not be constrained by fixed crew sizes or equipment, but by the number of available headings. The lesser the headings available, the more the operation becomes cyclic and constrained, with a higher cost per cubic metre of excavation.

- **Optimum number of development ends**: The number of headings can increase to a point where the optimum capacity of the crew(s) or equipment is reached. The unit cost of excavation improves (decreases) until optimum productivity is achieved.
- **Location of and access to available development ends**: Two or more headings may be available, but constraints such as ventilation, or distance between headings, insufficient compressed air or physical obstructions may prevent the optimisation of productivity.
- **Excavation size categories**: Tunnel sizes for shafts, lateral development or raise headings are not standardised and minor size changes may have significant cost implications due to different construction methods or the possible use of different equipment. Categorising sizes may seem logical, but it does not necessarily have a relationship to the cost per cubic metre of excavations or the chosen method of construction.
- **Method of excavation:** Employers do not generally prescribe the method of excavation, but due to safety requirements, mine ownership, mine layout, logistics or purchasing economies of scale, maintenance and other requirements, they may prescribe the equipment or material to be used, which may affect the unit costs, production rates or the method of excavation.
- **Time blasting**: Time blasting in an operating mine or shaft schedules (for logistical support) may have a significant impact on the cycle of operations. With time blasting all charged headings are set off at the same time (every day). Due to the cyclic nature of operations, should all preparatory work be finished before the blast time, unproductive hours may be incurred.
- **Mean averages and balanced pricing (location-based pricing)**: Providing balanced unit rates may be onerous for a contractor e.g. similar work on different mining levels may have different unit rates. Underground excavations and/or construction operations may be spread over multiple years, and where no alternatives are offered, averaged cycles may be utilised to reflect single unit rates. Averaged unit rates, however, may place a huge financial burden on a contractor, especially when the bulk of the excavations are done in the last third or quarter of a long term contract.
- **Environmental conditions and/or location restrictions**: With the cyclic nature of underground work and limited underground storage space, operations may be bound to tight logistical schedules. In addition, the layout or configuration of underground work may also restrict movement. For example, if a crew cannot develop a specific end, alternative development ends may be available on other levels within the mine, but there may be no means of readily accessing those development ends due to lack of available transportation systems. Similarly ventilation constraints and/or personnel safety requirements may prevent the development of readily accessible development ends.
- **Dealing with water**: Dealing with underground water intersections can be an arduous and unpredictable operation with the potential to significantly impact the work. When involved with pressure grouting operations, it is extremely difficult to accurately estimate the quantities of cement-based materials to be pumped (grouted), when the acceptance rate of the surrounding rock is unknown. Special provisions when dealing with water, including the pressure grouting thereof, must be considered.
- **The nature of material cannot be assumed**: The hardness and abrasiveness of the rock are critical aspects for the UDW contractor when deciding which type of equipment, materials or consumables to use. The method of excavation depends on knowing what type of rock is anticipated and assumptions should be avoided where possible.
- **Ground conditions**: Generally a single unit rate applies for the driving of similar sized development ends with the rates based on employer provided information. Should ground conditions improve and better advance rates be achieved, the contractor makes windfall profit (high value fixed costs do not increase when development ends advance rates improve). Where the contractor achieves less than the tendered advance rate, the contractor may incur losses (potentially recovered through claims).

Suggested factors influencing the measurement of unit operations

The following factors require consideration when measurements are taken for underground drilling and blasting activities:

- The expected ground conditions in general should be included or referred to in the project specifications (or assumed reference conditions should be used);
- Differentiation should be made between hand-held and mechanised drilling;
- Differentiating between the number of development ends (to be able to identify in-line or concurrent operations);
- The type of explosives, at least for tendering purposes, should be listed;
- Differentiation between conventional or smooth wall blasting techniques; and
- The acceptable limit of normal overbreak should be specified.

The following factors require consideration when measurements are taken for ground support activities:

- A detailed specification of the type of support including grout admixtures;
- Density, pattern or thickness (shotcrete) of the ground support;
- Differentiation between conventional hand-held or mechanised roof or sidewall bolt installations;
- The sequence of installation (in-line or concurrent);
- Maximum allowable distance of unsupported hanging wall or side wall; and
- Testing and/or quality control requirements.

The following factors require consideration when measurements are taken for underground rock loading (mucking) activities:

- Specific equipment to be used must be specified e.g. trackless or track-bound equipment;
- The specific density of the material to be handled;
- The location of the development end, and the average one way distance to the closest tipping point;
- The average and maximum tunnel or drift dimensions to be expected during operations;
- Special requirements regarding safety, environmental and noise control; and
- Any restrictions on the use of diesel or electrically driven equipment.

The following factors are to be considered when measurements are taken for underground rock hauling activities:

- Specific equipment to be used must be specified e.g. trackless or track-bound equipment;
- The specific density of the material to be handled;
- The final point of discharge (shaft ore pass or level ore pass) and the one way distance thereto;
- The average and maximum tunnel or drift dimensions expected during operations;
- Special requirements regarding safety, environmental and noise control;
- Any restrictions on the use of diesel or electrically driven equipment; and
- Restrictions related to the maximum capacity of the hauling system.

REVIEW OF UDW TENDER BILLS OF QUANTITIES

Review of existing UDW tender bills of quantities and associated documentation

Ten UDW tender bills of quantities and associated documentation were subjected to an assessment matrix to determine the level of standardisation (or non-standardisation) and to evaluate how effective cost significant factors were measured. Projects were also benchmarked against a 'potentially ideal bills of quantities' to measure each project's position relative to the ideal.

Overview of selection criteria

The review did not cover the tender documents in their entirety, but only focused on the methods of measurement, bills of quantities, schedules of responsibilities and relevant project specifications. The criteria used to select the tender documents were:

- Tender documents must relate specifically to UDW;
- Tender documents must have been issued between 2004 and 2006;
- Tender documents must cover small projects (less than R50-million), medium sized projects (exceeding R50-million, but not exceeding R500-million) and large scale projects (exceeding R500-million);
- Estimated project durations must range from less than 12 months to 60 months (or exceeding);
- Tender documents must be open market tenders (not negotiated) and issued to three or more contractors;
- Tender documents must be issued by different employers;
- Employers issuing tender documents must be active participants in UDW; and
- The tender documents in combination must cover the full spectrum of UDW.

TENDER DOCUMENT REVIEW CONCLUSIONS:

Review of General Structure (Questions A1 – A10 in Assessment Matrix)

Figure 1 provides a visual overview of the respective project ratings related to the General Structure, questions A1 to A10, as well as how each reviewed project compares to the benchmark.

All tender documents reviewed recognised the need for a method of measurement, yet all 10 tender documents used different methods of measurement. The bills of quantities relied heavily on project specifications and schedules of responsibilities to clarify the scope of work and responsibilities (design, approve, supply, install and remove).

The potential standardisation of a method of measurement (and model bills of quantities) may yield benefits in clarifying risk distribution, standardisation of pricing practises and making equivocal comparisons from project to project possible.

Review of Preliminary and General Items (Questions B1 – B10 in Assessment Matrix)

Figure 2 provides a visual overview of the respective project ratings related to the Preliminary and General items (P&G), questions B1 to B10, as well as how each reviewed project compares to the benchmark.

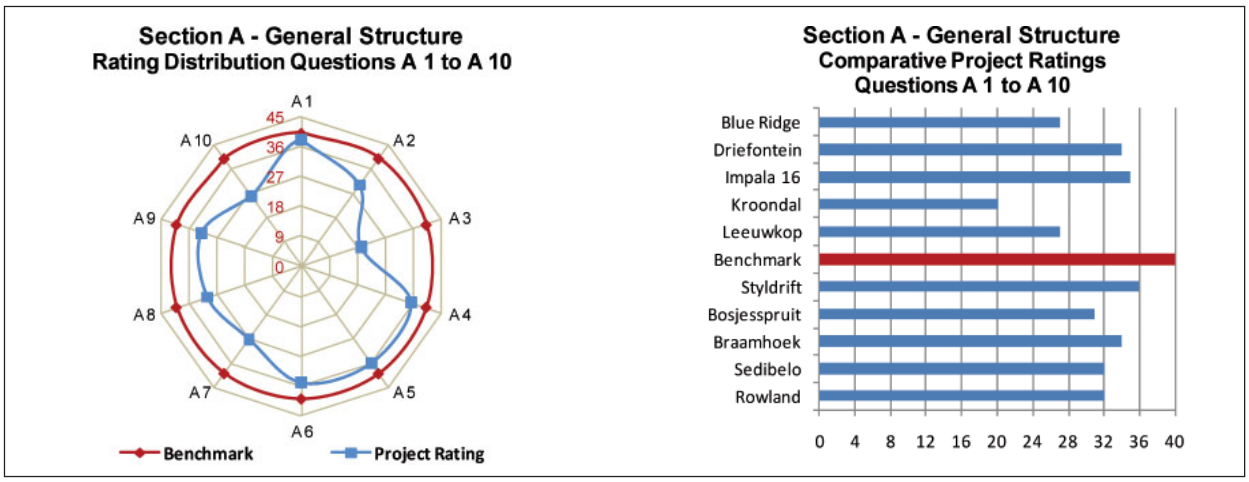

Figure 1: General Structure rating distribution and benchmark comparison of 10 selected tender bills of quantities.

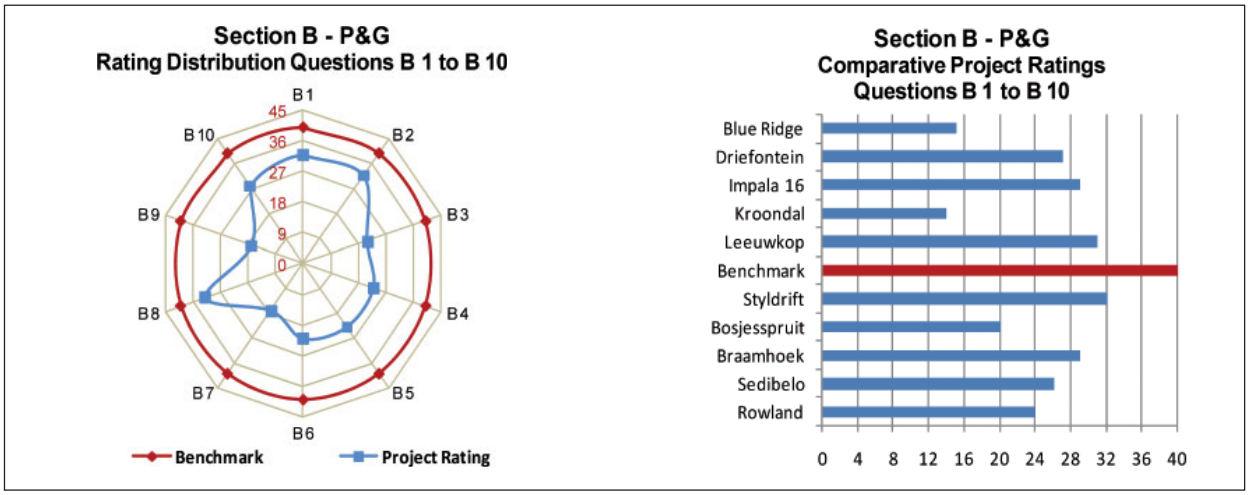

Figure 2: P&G rating distribution and benchmark comparison of 10 selected tender documents.

P&G items in general, followed the same structure as detailed in the civil standard system of measurement[8] (SABS 1200 A: General, 1986). Sections detailing fixed, value and time related costs were included and contractors were able to specify and price additional items. Figure 2, however, indicates large inconsistencies between each project and the benchmark, as well as between different projects. There was a general tendency to keep P&G items to a minimum, with additional details requested through addendums.

Review of Measured Work (Questions C1 – C20 in Assessment Matrix)

Figure 3 provides a visual overview of the respective project ratings related to Measured Work, questions C1 to C20, as well as how each reviewed project compares to the benchmark.

Work related to civil, mechanical or electrical construction generally followed the guidelines and structure of the SABS 1200. Where the SABS 1200 was deemed not applicable, employers provided project or company specific project specifications. Measured items for UDW were largely supported by separate methods of measurement. Figure 3 provides an overview of the rating distribution of questions dealing with specific measurement aspects. The bar chart in Figure 3, however, shows large inconsistencies between each project and the benchmark, as well as between the different projects.

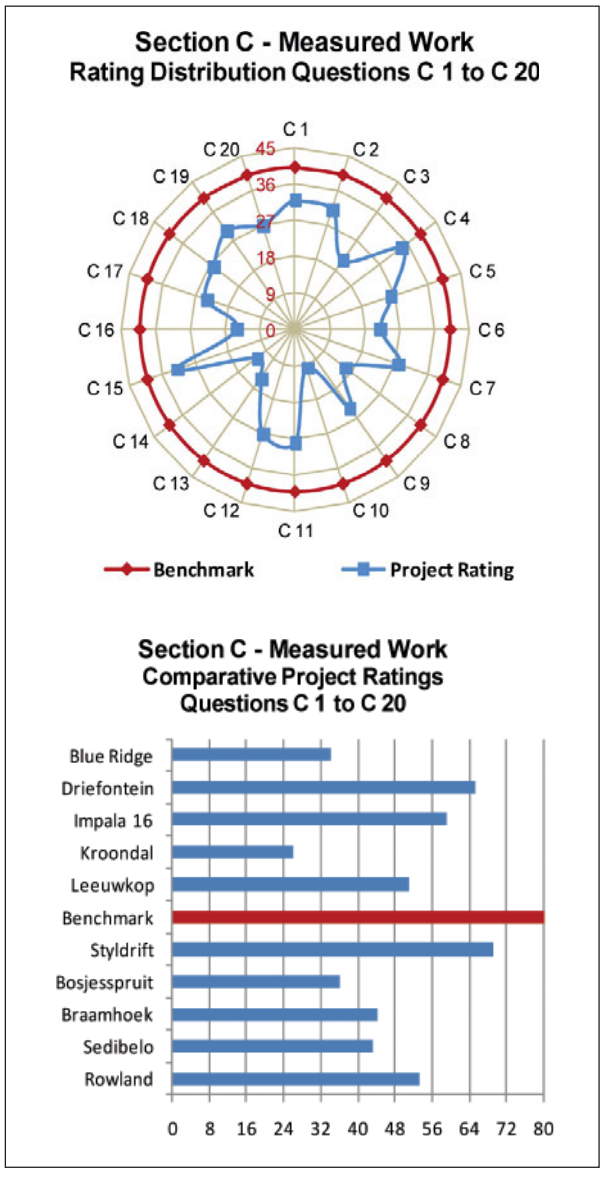

Figure 3: Measured Work rating distribution and benchmark comparison of 10 selected tender documents.

The following general trends can be summarised:

- Development end sizes were measured separately;
- The contractor was generally provided with sufficient information regarding the location and complexity of the works, as well as the anticipated ground conditions;
- Measured work was generally broken down into primary and secondary classifications;
- Permanent services and infrastructure were measured separately; and
- Items dealing with unavoidable overbreak, water and gas were included as measurable activities.

Tender documents overall

Figure 4 provides a visual overview of each project's combined ratings related to the benchmark and each project's position relative to other evaluated documents.

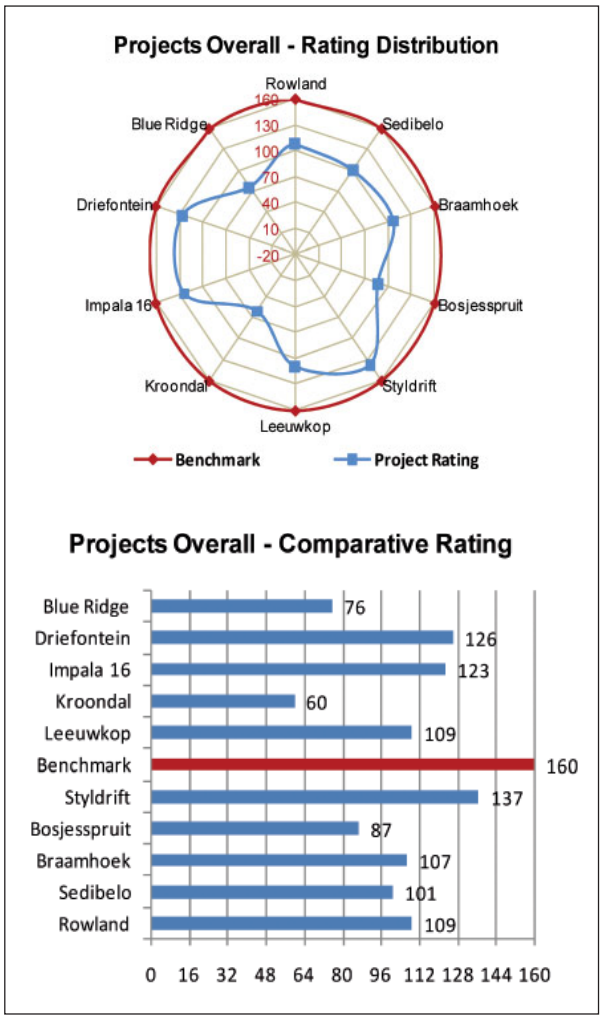

Figure 4: Overall project rating distribution and benchmark comparison of 10 selected tender bills of quantities.

With reference to the spider diagram in Figure 4, the following conclusions can be made:

- A rating distribution variance of 48% exists between the bills of quantities with the highest level of perceived standardisation and those of the lowest;
- If an arbitrary rating of above 75% of the possible benchmark score was used to accept or reject a document as being sufficiently standardised, then seven of the 10 projects would be deemed not suitable for open market tendering purposes;
- The size, complexity or value of a project does not improve the level of detail, level of standardisation or quality of the bills of quantities;

- The method of measurement strongly influenced the overall suitability and quality of the bills of quantities;
- The method of measurement and bills of quantities are dependent on the schedule of responsibilities and project specifications; and
- It is evident that the existing methods of measurement and bills of quantities in the samples reviewed are not standardised.

RESEARCH METHODOLOGY, RESULTS AND INTERPRETATION

Research purpose and design

The research design is an empirical study based on the analysis of existing or secondary data by reviewing 10 tender bills of quantities issued for pricing to UDW contractors (*supra*), and the collection of primary field data in the format of a questionnaire to understanding the views and opinions of professionals working in the UDW industry regarding procurement in order to derive meaningful conclusions.

A questionnaire was chosen as the most appropriate type of measuring instrument to evaluate the opinions of project managers, engineers, quantity surveyors, estimators and other professionals with regard to the usefulness of bills of quantities, and whether current measurement principles required modifications. The research method used was therefore quantitative and the methodology applied in analysing and interpretation of data was based on descriptive survey research.

The primary purpose of the market survey was to establish whether industry requires a standardised method of measurement for UDW and, secondly, to establish if existing bills of quantities can be modified to a commonly accepted standard.

Research population and sampling method

The research population consisted of employers and/or consultants and major contractors. The two groups were each represented by the following key occupation classifications:

- **Employers and/or consultants**: Project managers, engineers, project controllers and quantity surveyors; and
- **Contractors**: Operational site managers, engineers, quantity surveyors, estimators and other departmental managers (financial and commercial).

Although UDW tender values tend to be significant, it is not indicative of the number of professionals and contractors actively engaged in the industry. Purposive sampling was therefore used due to the relative small number of respondents and was restricted to respondents having had a minimum of three years direct or indirect exposure to UDW in South Africa.

The distribution of respondents was six responses received from employers and/or consultants and 12 responses received from contractors. The reason for having a higher percentage response from contractors can be ascribed to the fact that contractors receive documentation from a wide array of employers and/or consultants and as such are better positioned to comment on non-standardised documents issued for tender.

Data collection procedure

The questionnaire was divided into the following six sections:

- **Section A, Bills of quantities**: Established whether there was general acceptance of bills of quantities as a useful tendering and contract administration tool.
- **Section B, Standardisation of documentation**: Established if industry requires standardisation of UDW bills of quantities and related documentation.
- **Section C, Contractor's plant (equipment)**: Established whether current methods of obtaining tender prices are suitable or whether other alternatives should be investigated.
- **Section D, Contractor's general engineering supplies and/or materials**: Established if current methods of obtaining prices are suitable or if other alternatives must be investigated.
- **Section E, P&G**: Obtained each respondent's views and/or opinions regarding major and/or critical aspects of the P&G.
- **Section F, Unit operations and/or measured works**: Obtained each respondent's views and/or opinions regarding cost significant factors affecting unit rates and/or prices.

Sections A to F made used of a five point Likert rating scale and responses were grouped per category and a percentage calculated based on the resultant selections. The percentage classifications were as follows:

- **Employer average rating**: An average was calculated from the responses received from employers/consultants.
- **Contractor average rating**: An average was calculated from the responses received from contractors.
- **Combined average rating**: A combined average was calculated from all the responses received from employers/consultants and contractors.

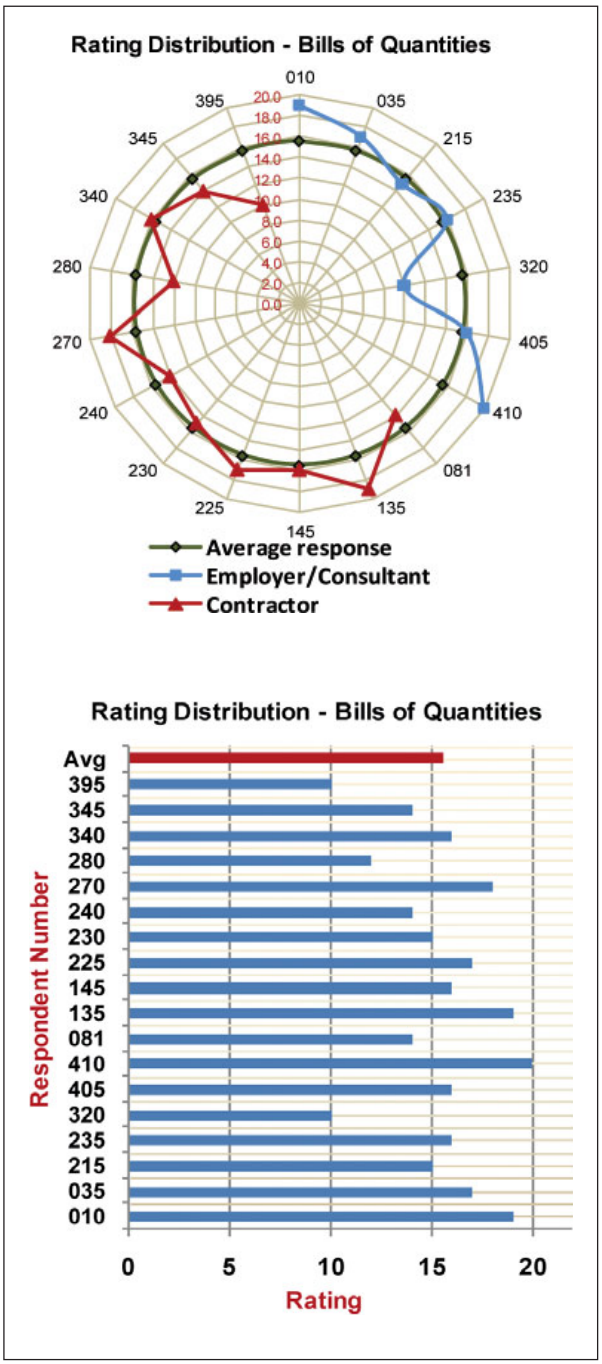

Figure 5: Bills of Quantities rating distribution.

Summary of market survey results

Figure 5 provides a summary of the perceptions of employers/consultants and contractors regarding the usefulness of bills of quantities as a procurement tool. The views of employers/consultants and contractors are similar and the following conclusions can be summarised:

- 89% of respondents agreed that bills of quantities were useful in obtaining tender prices and for contract administration; and
- No conclusive agreement could be reached as to the extent that bills of quantities should reflect pricing or contractual risks.

Figure 6 provides a summary of the perceptions of employers/consultants and contractors regarding the non-standardisation of bills of quantities, as well as the potential benefits of standardisation. The views of employers/consultants and contractors are similar and the following conclusions can be summarised:

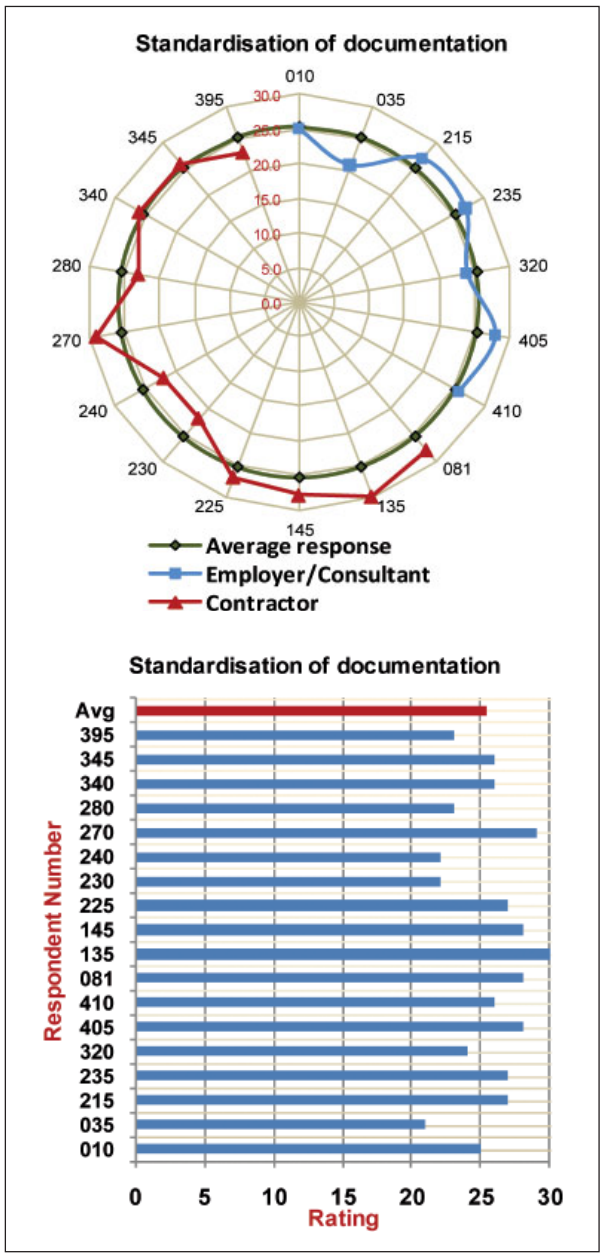

Figure 6: Standardisation of documentation rating distribution.

- 83% of respondents agreed that bills of quantities are non-standardised; and
- It appears that employers/consultants and contractors share the same level of confidence in that bills of quantities can be standardised.

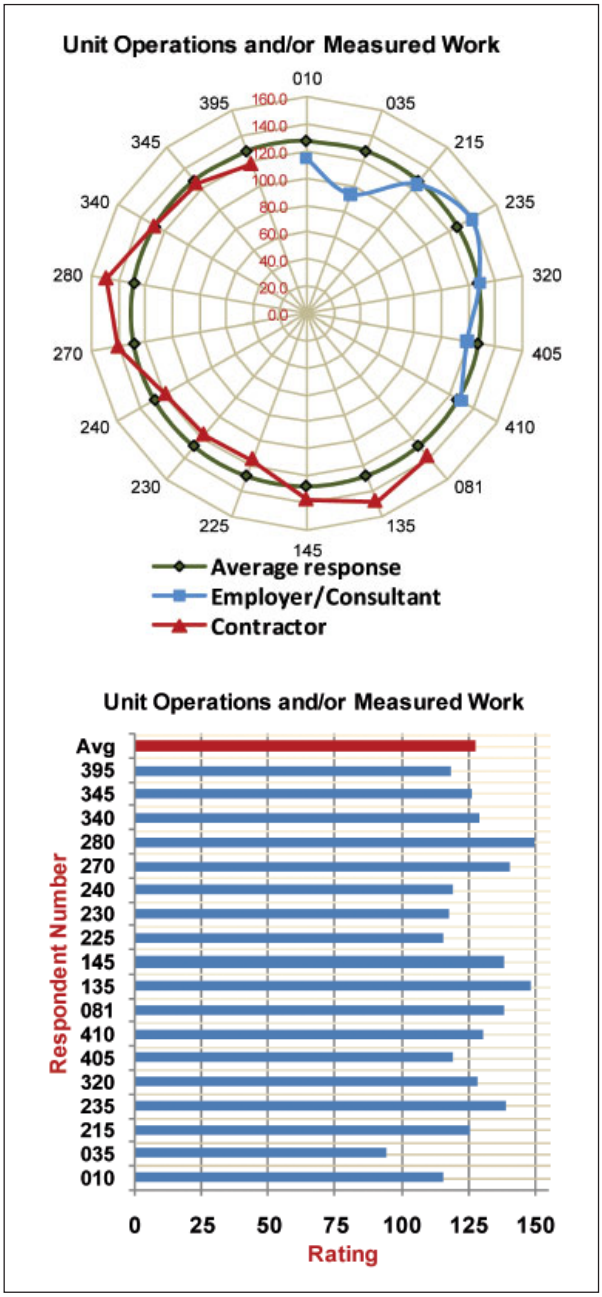

Figure 7: Unit operations and/or measured work rating distribution.

Figure 7 provides a summary of the perceptions of employers/consultants and contractors regarding the acceptability of current UDW unit rate measurement principles. The views of employers/consultants and contractors are similar and the following conclusions can be summarised:

- Differentiation must be made between supply and installation;
- Drill, blast, load and haul operations per heading must be measured per heading size as one item, with ground support installation, cover drilling and concrete linings measured separately;
- Specific preferences such as smooth wall blasting and the type of explosives to be used must be included in bills of quantities (or schedule of responsibilities);
- Underground tolerances must be stated and normal overbreak measured separately;
- Billed items must differentiate between varying locations, different underground levels or other similar cost significant factors that can affect unit rate pricing;

- Billed quantities per number of development ends must be provided by the employer/consultant prior to the issue of the tender to ensure comparative market pricing;
- The method of excavation (construction) and equipment selection are to remain the contractor's decision, unless specifically prescribed; and
- Billed items must differentiate between hand-held and mechanised operations.

CONCLUSION AND RECOMMENDATIONS

The study confirms that existing UDW bills of quantities (and associated methods of measurement) cater for most cost significant factors. Conformance to recognised standards becomes, however, critical to provide an effective means of differentiating in a competitive marketplace. Modifications are, therefore, required to establish a commonly accepted standard system of measurement (and associated model bills of quantities), integrated with a master schedule of responsibilities, to suit the needs of the UDW industry. Such a modified method of measurement should not be developed as a stand-alone system, but should work in harmony with existing building, civil or other recognised measurement systems.

An alternative method of measurement for contractor's plant (equipment) should be investigated. No conclusive evidence exists to establish a new method of measurement for contractors' general engineering supplies, although temporary work should be measured (provisionally) to ensure that comparative market pricing is obtained. The P&G should be broken down into the major project phases and must include items for ongoing care and maintenance activities. Further research is, however, required regarding the inclusion of a method-related section for capturing the costs of temporary work/installations that are linked to the method of excavation or mining.

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