

## TECHNICAL PAPER

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# COTA (Choice Of Technique Analysis) of the drainage structures component of a road construction project

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*The viability of employment-intensive (EI) techniques in road construction has been confirmed through research for a range of activities. This paper focuses on the drainage structures component of road construction, a field of application that has not been reported on to the same depth. This field holds potential for employment creation, especially with regard to the envisaged development approach to the repair of the recent flood damage. The paper consists of two elements, namely the development of a technique selection methodology based on COTA (Choice Of Technique Analysis) and a subsequent analysis to select appropriate techniques based on case study projects. The output comprises the appropriate mix of labour- and machine-based techniques along with the appropriate design type for different sets of circumstances, which can be referred to as appropriate practice, or EI practice per definition. It was concluded that under most circumstances the substitution of EI practice for current practice almost doubles the local content of expenditure without extra cost. EI practice is recommended as the norm in the execution of such projects – not only for isolated low-level bridges and maintenance on low-traffic rural roads, but also for the drainage structures component of road construction and rehabilitation projects. Whereas general guidelines are provided, it is recommended to practitioners that the selected mix of techniques for individual projects be based on a COTA analysis.*

## INTRODUCTION

Job creation has rightly been the top priority in the new South Africa. Sadly, however, the momentum of mass employment creation through public works programmes has been lost, aggravated by the current wave of job losses, particularly in the construction sector. In the rural areas, development is still hampered by the historical backlog in the provision of roads and bridges (Bosman 1997; Van der Merwe 1998), the lack of maintenance (Omar 1999) aggravated by the huge loss through the recent floods, and by investment continuing to decrease (Langenhoven 1998; Snyman & Langenhoven 1998).

Previous research and projects established the acknowledgement that employment-intensive (EI) techniques in roads construction are viable. It was shown that there is significant scope for the alleviation of unemployment, in South Africa too (IBRD 1986; Phillips 1994a; Phillips *et al* 1995; McCutcheon 1995).

As far as *drainage structures* in particular are concerned, the recent floods – although tragically – left a formidable scope for the application of EI techniques and potential for social development through the repair of particularly road drainage structures. Krige (1995) found that potential employment creation and empowerment are not being realised because of inappropriate specifications and a lack of innovation. There were promising records (Turner *et al* 1991; Thom 1992; Grobler *et al* 1995; Grobler & McCutcheon 1997) where non-standard employment-enhancing techniques replaced

conventional practice, although application was limited to isolated river-crossing projects. This journal has contained scholarly articles (Rankine *et al* 1995 and 1998; De Bruin 1996) on the technical feasibility of some of these techniques, preparing the ground for appropriate specifications.

However, academic confirmation that empowerment objectives in this section of road construction can generally be realised in South Africa in a viable way is outstanding. The aim of this paper is to investigate the potential by determining the appropriate mix of EI and conventional techniques for different circumstances, with the hypothesis that more often than not EI techniques constitute an appropriate choice. The focus will be on the drainage structures component of road construction, comprising the greatest area of application.

## STRUCTURE OF THE PAPER

A methodology for the identification and selection of the most appropriate techniques for the range of circumstances in a structured way is developed first. Second, after explaining the background of the input data, comparative analyses are carried out on a range of case study structures to determine their relative performance. The third part constitutes the core of the paper, where these performance values are applied to the drainage structures component of each of three case study road construction projects, from which generalised guidelines are derived.

# DEVELOPMENT OF A TECHNIQUE SELECTION METHODOLOGY

## Point of departure

The principles in public works programmes (hereafter shortly referred to as PWP) set by government are summarised as follows (NCCLIC 1993; ANC 1994; NEF 1994; DPW 1996b):

- Technical development and research work should be conducted.
- Decision support methodologies should be developed.
- Chosen methods must be subjected to performance appraisals and monitoring and evaluations.
- Appropriate standards and specifications should be developed.
- EI methods must be used wherever (but only where) technically and economically feasible.
- Designs that support the principles of the National Public Works Programme (NPWP) should be implemented.
- Procurement of goods and services produced in developing areas must be maximised.
- Opportunities must be provided for local emerging contractors and other entrepreneurs.
- Projects must form part of sustainable programmes.

The first three establish the concept of correct technique choice. The last six provide the direction in making that choice. It is important that barriers caused by conventional standards must be removed and that 'EI techniques must be used wherever ... feasible'. This norm means that it should be the *only norm* as opposed to the opinion still held by some that 'it has its place'.

The above principles comprise conflicting social and financial objectives, though. According to the generally accepted definition (McCutcheon 1993), labour-intensive (or EI) construction is indeed 'the economically efficient employment of as great a proportion of labour as is technically feasible to produce as high a standard of construction as is demanded by the specifications and allowed by the funding available'. Economic efficiency implies a trade-off between financial cost and social benefits.

Two trade-offs have been established in the NPWP (NEF 1994; DPW 1996b) and were applied also as such to Framework Agreement (NCCLIC 1993) projects. Theoretically, they could simultaneously be applicable to one project, being

- a cost premium of up to 10% if directly related to increased employment creation
- additional training cost of between 10% and 15% if necessary to enhance EI techniques and local participation

In addition to the NPWP strategy the Department of Public Works (DPW) is currently training practitioners and officials across the country to effect the Targeted Procurement (TP) Resource Specifications (DPW 1998). This new strategy is motivated by the Procurement Task Team (Watermeyer 1998) on the basis that PWPs have failed to bring about empowerment on any significant scale, whereas it is envisaged that the intervention in public sector procurement does have the potential to do that. In addition to the objectives of the NPWP, the TP specifications introduce certain empowerment objectives that do not relate to employment and development of underdeveloped rural communities. However, the following specific weights and trade-offs relevant to this paper are set:

- The successful tenderer's price can be 10% higher than the lowest acceptable tender in accordance with credits obtained for meeting empowerment objectives (in subsequent draft regulations the premium is proposed to be 20% for a project value of less than R2,0 million).
- In the determination of credits a preference factor of up to 150% is recommended for the engagement of local manufacturers, contractors and labour, with the factor being 50% to 75% for local suppliers.
- No premium is allowed for project specific training because policy provides that training is programme or area based (Ministries of Finance and Public Works 1997).

A selection methodology that takes account of these is developed below.

## Background to COTA (Choice Of Technique Analysis)

Cost-benefit analysis and other aids were shown to be useful in defining river-crossing projects in terms of justification, type, and size of structure (Turner 1991; Thom 1992; African Consulting Engineers 1993; Pienaar 1993; Jordaan & Joubert 1994). However, given such project definition, COTA is the only documented procedure that systematically addresses the set objectives in a structured way when determining the appropriate choices of technique. As such, COTA is adopted as technique selection tool for the purposes of this paper.

## Previous applications of COTA

COTA was first reported on by Phillips (1994b) shortly after his PhD thesis (1994a) on the 'Theoretical analysis of labour-intensive construction of water-bound macadam roads'. The concepts are already manifest in the thesis.

Harrison's work (1996) on a portion of the N1 in the Northern Province con-

stitutes the first practical application of COTA found in the literature. Based on successes elsewhere in the world, at the project planning stage he predicted that at no cost increase employment could be increased three- to fourfold. He hence recommended a list of work to be done on EI, which was assimilated into the contract specifications.

Based on a review of inter alia Phillips' and Harrison's work, Taylor Parkins (1997) developed COTA-P (Practical COTA) as part of his MSc studies. His work constituted a review of the input data and the improvement of the practical utilities and the form of output. As part of his PhD study he is currently developing user-friendly software to conduct COTA.

## Adaptations to the current COTA philosophy

COTA generally supports the set objectives in an exceptional way. However, the following adaptations have been introduced based on the motivations given:

- The process is adapted to take cognisance of the relation between technique choice and the range of project-specific circumstances that can occur: COTA has thus far been seen as a procedure to be applied on a specific project, the results having reference to the circumstances of the specific project alone. On the other hand, generalised results that relate specific technique choices to the range of possible typical circumstances would be of general value, diminishing the need for practitioners in all cases to conduct complicated COTA to consider project-specific circumstances. Even if user-friendly COTA suites are commercialised, it is doubtful whether a substantial number of practitioners and decision-makers will apply it on project level. This will only be realised once it is politically supported, followed by policy directives that COTA must be carried out for certain categories of projects, and if training is provided.
- The principle to apply appropriately lower standards is introduced: By not accepting this principle the COTA algorithm ignored the fact that aesthetic construction time, and other non-performance related standards were tailored on the practical 'achievability' of machine-based construction (Krige 1995). There are no basic reasons (judged against the objectives) why lower standards should not be allowed to accommodate EI techniques as long as facility performance is not affected and community needs are met.
- A step by which local entrepreneurial involvement is considered is assimilated:

Except for labour, local participation was not assimilated into the decision rule. Consideration of local participation in the form of supply and manufacturing, which can be influenced as early as the planning stage, is compulsory according to the Affirmative Procurement Policy (DPW 1997). The TP specifications allocate equal relative preference points in respect of local labour and manufacturing, with half the points for supply.

### Adaptations to the application of the COTA process

The following adaptations to the way COTA has been applied previously are introduced, based on the identified shortcomings:

- In a tendering situation, the contractor should not be prescribed to regarding his production process but incentives should be offered (only design and materials (if essential) are prescribed). As a tendering aid, the COTA output could be made available. In a project management or PWP situation, the site engineer will still follow the output list of production process to be used:

Thus far, method and plant restricting specifications were drawn up based on the COTA output. Du Toit and Smith (1997) and others showed that this approach does not lead to cost-efficiency and recommended an incentive approach. Later in 1997 the Affirmative Procurement Policy assimilated this principle.

- Realistic cost data on EI alternatives and the use of local entrepreneurs are to be used as input to COTA: In previous applications labour efficiency levels achieved during the final stages of well-planned ongoing public works programmes elsewhere in the world were used. This does not take cognisance of local circumstances such as labour law and other industrial determinants. In view of the apparent shift in the government's focus from works programmes to procurement intervention, such high levels will not be achieved on these stand-alone projects until the parallel strategy of programme- or region-based training has been advanced. Although the completion report on the N1 project is pending, preliminary reported data (Taylor Parkins 1997) seems to confirm that the target levels could not be achieved. The even lower success rates of most CMIP projects (Du Toit 1997) and of many Framework Agreement projects (Watermeyer 1998) illustrate the same.

### Introducing COTA-C

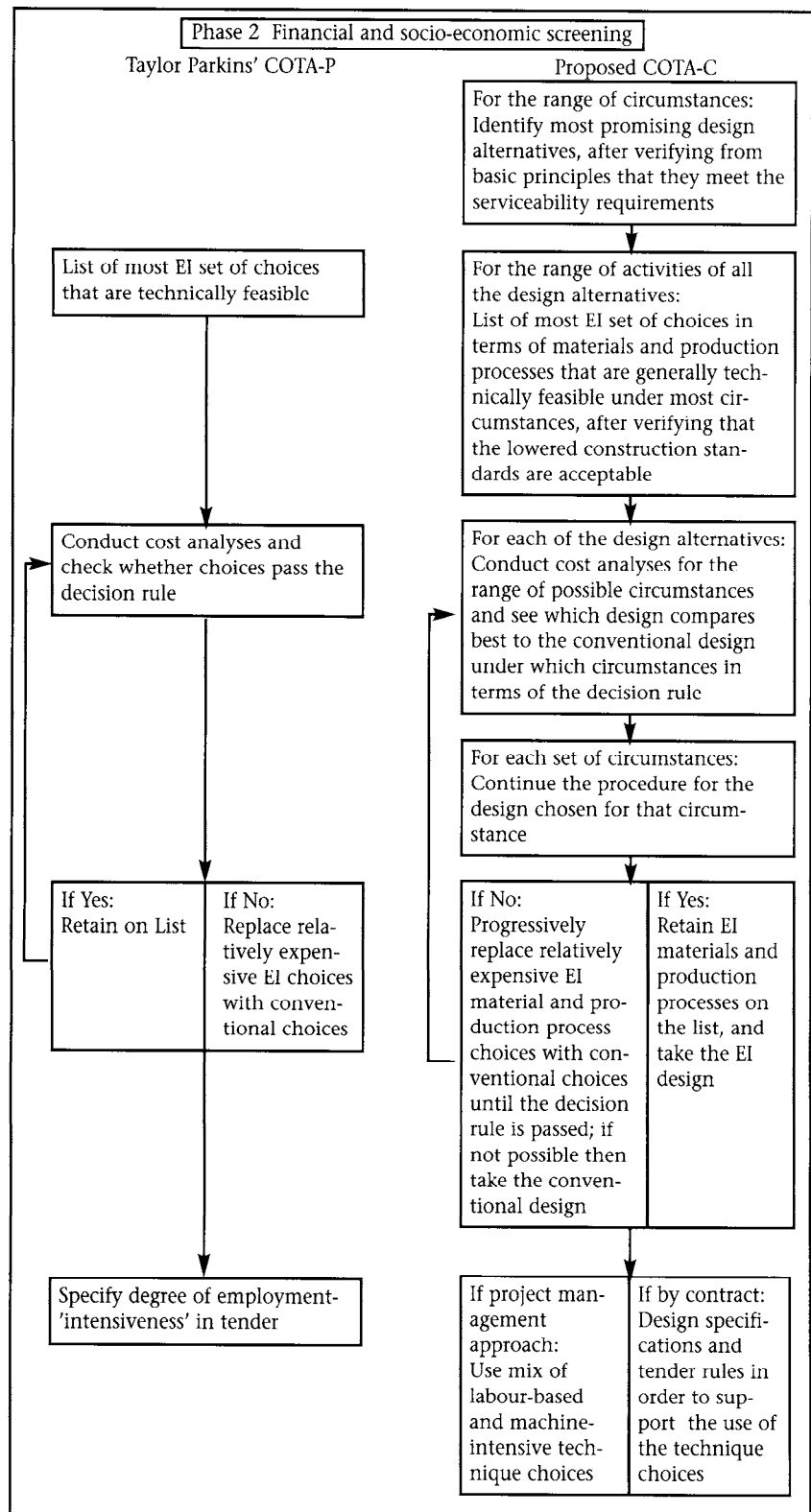
The procedure subsequently proposed is termed 'Circumstance COTA', or COTA-C,

to reflect the introduced principle that the circumstances of choice are recognised. The implications of the adaptations to the latest version of the COTA algorithm are presented in figure 1 below.

monitored by the authors, and not on some better potential scenario.

- Financial costs only – without considering the effect of shadow pricing or market distortions – are used.

Figure 1 Comparative diagrammatic presentation of COTA-C



The following specific parameters will be applied in the application of COTA-C:

- The cost of EI technique alternatives are based on the actual case study productivities and efficiencies achieved consistently during projects

Decision-makers in South Africa do not yet value such indirect, long-term or spin-off economic benefits of alternative methods. Although the necessary provision is made in current policy (such as the APP), it is generally not being practised.

- The decision criteria adopted are price, labour participation, profit by local subcontractors and suppliers (the gross order value cannot be taken as benefit), and the appropriateness of the technology in the area of application from a community-based construction and maintenance viewpoint.

- The decision rule used is as follows:

- That technique that maximally uses employment-enhancing materials, labour-based production processes and empowerment-friendly designs, that meets the adopted appropriate standards, and that does not take longer than what is acceptable to the community is to be used unless ruled out by the price criterion.
- The price criterion is that the technique chosen in this way is retained if it does not result in exceeding the base price plus allowed premium, with as basis a conventional procurement approach without any targeting requirements.
- The allowed premium is as follows:
  - \* 50% X {wage bill of the additional employment creation}
  - \* plus 50% X {amount profited by local sub-contractors}
  - \* plus 50% X {amount profited by local suppliers}
  - \* in total – and including project training cost – not to exceed 10%

The premium is well within the proposed values of the TP specifications (see above). Also deviating from that proposed in the TP specifications, the relative weights are set equal on the grounds that all three entities reflect 'money in the pocket' of the local community.

- Criterion of sustainability: If two empowerment-friendly designs perform almost equally, the one that best builds capacity in the community, that is least reliant on imported skills and technology and that has the least technology-reliant maintenance requirements is taken.

The recommended technique choices following from COTA-C are related to specific environmental, demographic and engineering circumstances, from which guidelines are compiled enabling quick first-approach choice of technique decisions by practitioners.

## ANALYSES OF TECHNIQUE ALTERNATIVES

At the time of this investigation, Taylor Parkins had not completed his user-friendly COTA suite. To facilitate the efficient selection of the appropriate technique choice, an analysis spreadsheet was developed. The spreadsheet contains

default input data that can be made project specific, can conduct global as well as item-specific sensitivity analysis, accommodates user choice of material and production process, and produces output per item, resource, and project in terms of the set performance criteria. Through an iterative process of selecting the production process and inspecting the outputs against the decision rule, the list of appropriate technique choices evolves.

The collection and validation of cost and productivity data were addressed in a separate paper (Grobler & McCutcheon 1997). The paper recommended a spectrum of item costs for use as a look-up table by estimators and tenderers as a first approach in planning. The circumstance-related data ranges, following from a sensitivity analysis, covered both labour- and machine-based techniques.

## THE RELATIVE PERFORMANCE OF THE TECHNIQUE ALTERNATIVES

For each drainage structure a certain design alternative and mix of EI and machine-based production processes are optimal in achieving the objectives. Before COTA-C could be conducted on the drainage structures component of road construction projects (the core of this paper), the circumstance performance of a number of technique alternatives was determined first, for which the following methodology was followed:

- From more than 30 case study river crossings, five were selected with the view to cover a variety of topographical and hydraulic conditions, as well as designs. The structures were selected from three projects that were executed in the Northern Province (Grobler *et al* 1995; African Consulting Engineers 1995). The design types of the five bridges are a prefabricated concrete cells bridge, an ARMCO bridge, an in-situ cast concrete cells bridge, a concrete deck bridge, and a stone masonry arch bridge.
- COTA-C analyses were carried out for each of the design alternatives for each of the five river crossings. The performance – measured against the criteria of choice – of the design as was used, relative to the other four designs, was determined.
- The spreadsheet default inputs for local conditions were replaced by values as prevailed for the specific project.
- The cost of the facility was related to serviceability: hydraulically, all alternatives must accommodate the design flood; structurally, all alternatives must carry the same live load; geometrically, all alternatives must perform equally in terms of road width, etc.
- The decision rule as described earlier was applied.

The project descriptions, and analyses input and output are not included here because of lack of space. The following conclusions were drawn from the analyses:

- The more empowerment-friendly designs (concrete deck on masonry piers, and stone masonry arch) yielded project cost savings of between 5 and 23% (on average 7%) while retaining machine-based production processes. This is not a good reflection on current engineering practice of justifying the quick-design prefabricated units on the basis of cost.
- For the chosen mix of labour-based and machine-based production processes (EI practice), the additional labour expenditure and local profit of these chosen designs over that of the conventional ones using machine-based production processes (current practice) averaged 12,4 percentage points on the total cost (ie including overhead costs) of the project. This represents an increase of the local content of the expenditure by 75%, which is significant if considered that the EI practice results in the same project cost or even less.

From an analysis of the results, relations could be identified between technique choice and circumstances, yielding the general guidelines as are provided in table 1 below. It follows that, unless the mentioned special circumstances dictate otherwise, the general alternatives of choice are first, the stone masonry arch followed by the concrete deck on masonry piers. The conventional alternatives do not at all enhance the social objectives, neither do they warrant their use on the basis of cost. It is appreciated though that the specific circumstances of a particular case as well as the economy of scale of a project could yield a different comparison.

## METHODOLOGY FOR COTA-C OF THE ROAD CONSTRUCTION PROJECTS

The above findings in respect of the technical, social and financial performance of alternative techniques can be expected to apply to the structures of a road construction project as well. To confirm this, COTA-C analyses were carried out in this section for each of three case study road construction projects.

While the cost data from the tender documentation were used as input, accurate employment and local content figures were not available for all projects. Therefore, in such cases these entities had to be inferred using the estimation spreadsheet discussed above. The three case study projects were selected with the view to cover a variety of physical circumstances so that general guidelines can be derived.

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**Table 1 Guidelines on circumstance technique choice of design type**

Circumstances	Choice of design
In general	The stone masonry arch is most appropriate unless replaced due to limiting circumstances as follows:
Limited by hydraulic capacity	The stone masonry arch is disfavoured to the more lean concrete deck on masonry piers if maximisation of capacity is important because the smaller aperture of the arch renders a lower capacity relative to its height; this limitation is often applicable in a flat road environment where river courses tend to be flat and wide and the road formation at the crossing not as high.
Limited by high flow velocity:	
• Downstream erosion potential	When designing for overtopping, the stone masonry arch is disfavoured to the more lean concrete deck on masonry piers because of the larger obstruction of first-mentioned relative to its hydraulic capacity; this is particularly pertinent if the structure is high and under super-critical flow conditions – often applicable in a mountainous road environment where the problem is exacerbated by high debris loads.
• Scour of bridge elements	The masonry piers of the concrete deck design should be replaced by concrete if the quality of the cement block or stone masonry material is not adequate – pertinent under super-critical flow conditions and boulder river bed.
Limited by availability of stone for masonry	The EI alternatives become less competitive, however, they can still emerge as the alternative of choice; the stone masonry arch bridge can be replaced by a mass concrete arch or one of the other concrete alternatives; the stone masonry piers of the concrete deck bridge can be replaced by cement block masonry piers.
Limited by poor founding conditions	In the absence of rock founding conditions and if the possibility exists that liquefaction with consequent scour of the founding material under the bridge could take place the more elastically designed concrete cells alternative is favoured above all others.
Limited by socio-economic environment	The stone masonry arch alternative is ideal in remote areas where skills, supervision and imported (from town) purchased materials and equipment are scarce or costly; on the condition that pre-construction skills training is provided the in-situ cast concrete alternatives are also viable.

## DESCRIPTION OF THE CASE STUDY ROAD CONSTRUCTION PROJECTS

In all three of the projects in the Northern Province, a huge supply of unemployed local labour in desperate need was available. Other project specifics are as follows:

### *The Witvlag road: moderate rainfall mountainous area (source information from Barry 1997)*

In 1995, tenders were asked for the Witvlag road near Thohoyandou. Hillary Construction offered an alternative to the specified prefabricated concrete culverts, comprising in-situ cast concrete decks on stone masonry piers. This was not accepted.

This project nevertheless provides an opportunity to compare the performance of a conventional technique and an EI

alternative, the project information of both being available. The details of the project are as follows:

- Upgrading of 17 km gravel road to tar standard.
- Lowest tender R14 127 802.
- Project involved only medium- to small-sized culverts.
- Culverts component 11% of the scheduled work.
- Rainfall over the length of the project varies between 400 and 750 mm per annum.
- The road runs through a mountainous area along a valley with fast-flowing streams crossing the road.
- Stone is abundant in the area.

### *The Modjadji road: high rainfall rolling area (source information from Turner 1998)*

In 1997, tenders were asked for this road, located north-east of Tzancen. The tender documentation specified prefabricated

concrete units for small culverts and in-situ cast concrete units for river crossings. For these, the lowest tenderer offered an ARMCO alternative that was accepted.

The performance of these conventional designs along with conventional machine-based production processes can be compared to that of empowerment-friendly designs using labour-based production processes, as were applied on one of the case study projects adjacent to the Modjadji road. The details of the road project are as follows:

- Upgrading of 14 km gravel road to tar standard.
- Lowest tender R20 795 500.
- Some medium- to large-sized culverts with very high fills.
- Culverts component 26% of the scheduled work, of which one third are smaller culverts and two thirds are larger river crossings.
- Rainfall 750 mm per annum.
- The road runs through rolling terrain at the foot of a mountain with fast-flowing streams with fairly large catchment areas crossing the road.
- Stone is plentiful in the area.

### *The Gakgabudi-Mokgalakwena road: low rainfall flat area (source information from Joubert 1998)*

In 1994, tenders were asked for this road north-west of Potgietersrus. The tender documentation provided an excellent opportunity to compare conventional and empowerment-friendly design alternatives because the specifications constituted a combination of both. The details of the project are as follows:

- Upgrading of 45 km gravel road to tar standard.
- Lowest tender R19 740 558.
- Medium- to small-sized culverts as well as a low-level causeway over a large river.
- Culverts component 12,4% of the scheduled work.
- Rainfall ranges from 600 to 500 mm per annum from south to north.
- The road runs through very flat area with a few slow-flowing rivers crossing the road.
- Stone is available at intermittent locations along the road.

## Analysis of the Witvlag road

### *Alternatives analysed*

The following were specified in the contract documentation:

- No specifications, penalties or bonuses as to the production processes or employment to be created; the tenderer, however, had to indicate the amount of employment that would be created, but without a known tender

adjudication rule.

- Prefabricated concrete cells for the larger river crossings.
- Prefabricated concrete pipes for the smaller culverts
- Stone masonry inlet and outlet structures.

The following alternative technique choices were considered:

- The COTA-selected mix of labour-based and machine-based production processes.
- The in-situ cast concrete deck on stone masonry piers that was offered as alternative to the specified prefabricated concrete cells.
- The stone masonry arch culvert as the optimal alternative to the prefabricated concrete pipe culverts specified.

### Analysis based on project information

The tendered schedule amount for the specified prefabricated concrete cells and pipes, including inlet and outlet structures, floors and backfill, was R1 108 231. The stone masonry alternative offered at tender stage having reference only to the rectangular culverts of 1 200 mm or higher would have had the following effect:

- Cost saving of R188 600 (2%) on all scheduled work.
- Cost saving of 17% on the drainage structures component.
- Amount of employment on this section to increase from 2 060 to 4 135 person days.

### Expansion of results and analyses of additional technique choices

Extrapolating this effect to include the smaller rectangular culverts would result in another cost saving of R20 000 and employment of 224 person days.

Considering that the road is in a mountainous environment with high fills at low points it is generally feasible to replace the specified pipe culverts with masonry arch culverts with their thicker crowns. From the analyses conducted on the design alternatives, the additional labour and local profit that would be realised in doing so is 11% at a cost saving of 21%. Applying this to the case study would result in an additional cost saving of R45 000 and employment of 2 431 person days.

The additional employment creation yielded by the specified stone masonry inlet and outlet structures as compared to the conventional in-situ cast design should also be considered. The cost of this item was R45 628, being roughly equal for the two alternatives considering the larger volume required by the masonry alternative. The additional labour and local profit that would be realised by this substitution is 18%. Applying this to the

case study would result in an additional employment of 376 person days without costing more.

### Conclusion

In total, therefore, the substitution of appropriate EI practice for conventional practice would not only increase local employment creation by 5 106 person days, but would yield a saving on direct construction cost of R254 000.

It is further significant to note that while the empowerment-friendly drainage structure alternatives as were proposed by the tenderer would yield a cost saving of 2% on the project cost, the expenditure on employment for the project as a whole was guaranteed by the tenderer to go up by 11% on what it would have been.

In accordance with the decision rule, the introduction of more labour-based techniques to replace some remaining machine-based techniques (such as for fills at culverts) up to a certain cost premium following a COTA process is allowed. This process was gone through but allowing no cost premium, thus merely cradating the 2% cost saving. With 40% to 50% of the cost of the substituted work going to labour, the increase in the expenditure on local employment is then 25% on that of the specified conventionally designed project.

### Analysis of Modjadji road

#### Alternatives analysed

The following techniques were specified in the contract documentation:

- No specifications, or penalties or bonuses as to the production processes.
- In-situ cast concrete cells for larger river crossings – that will be used as the ‘empowerment-friendly design’ in this analysis.
- Prefabricated concrete box and pipe culverts for road drainage culverts – used as ‘conventional design’ in this analysis.

The following additional technique choices were considered:

- The COTA-selected mix of labour- and machine-based production processes.
- The ARMCO design that was offered as alternative to the specified in-situ cast concrete cells at tender stage – regarded in the analysis as the ‘conventional design’.
- Stone masonry arch culverts as theoretical alternative to the prefabricated concrete box and pipe culverts specified.

Constructing mass masonry walls for inlet and outlet structures for the bridges that would be stable against the high fills would not be economical compared to the specified in-situ cast reinforced con-

crete walls with footings. This alternative is thus not a technically feasible alternative.

### Further input data to the analyses

The tendered schedule amounts for the drainage structure component as specified is constituted as follows:

• Pre-fabricated concrete rectangular and pipe culverts	R1 037 176
• Inlet and outlet structures for the prefabricated culverts	R259 294
• In-situ cast concrete cells bridges, including inlet and outlet structures	R3 623 768
• Total for drainage structures component	R4 920 239
• The accepted ARMCO alternative to the in-situ cast concrete bridges yielded a cost saving of	R700 657

The figures include clearing and grubbing, floors, backfill, etc, but exclude the pro rata indirect construction cost and overhead cost. For this project the indirect construction cost amounts to 24%, while the overhead costs were taken to be 18%. Because no rates were tendered for stone masonry and no project data is available for the employment creation and local content of the various alternatives, the analysis spreadsheet was used to compare these performance parameters of the alternatives.

### Results

It was found that for the large structures the in-situ cast concrete cells increase the local content of this component by 16,4% but at a cost increase of 24% on this component. In terms of the decision rule, and provided that funds allow, this premium is accepted in the context of the total project cost. For the small rectangular and pipe culverts, the stone masonry arches reduce the cost by 21% and still increase the local content of this component by 13%. At no cost difference, the local content of the in-situ cast inlet and outlet structures component is increased by 9% if done with masonry.

### Conclusion

The combined effect of the above is that at a cost premium on the total project cost of 2,3%, the substitution of appropriate EI practice for conventional practice increases the local content by 15,3% of the drainage structure component (113% increase), and by 3,1% of all work (33% increase).

If reverse substitution is done to eradicate the cost premium, then the percentage increase in employment creation and local profit content of the EI practice scenario is reduced from 33% to 15%.

## Analysis of Gakgabudi-Mokgalakwa road

### Alternatives analysed

The following techniques were specified in the contract documentation:

- No specifications or penalties or bonuses in respect of the production processes. However, a stone masonry causeway as well as some of the culverts (in total 26% of the structural component) were reserved for local entrepreneurs before tender stage.
- In-situ cast concrete cells were specified for the Dithokeng river crossing, considered in this analysis to be the conventional design.
- Prefabricated concrete box and pipe culverts were specified for road drainage culverts, used as conventional design in this analysis.

The following additional technique choices were considered:

- The COTA-selected mix of production processes is considered in respect of the work not reserved for local entrepreneurs.
- The conventional prefabricated concrete cells design is considered a theoretical alternative to the empowerment-friendly stone masonry arch causeway specified.
- As theoretical alternative, the in-situ cast concrete deck on masonry piers rather than the masonry arch (not feasible in this flat environment) is considered an empowerment-friendly alternative to the in-situ cast concrete cells bridge.
- Likewise, the masonry arch is considered an alternative to the specified prefabricated concrete box and pipe culverts only where technically feasible. A desktop assessment of the alignment and availability of stone indicates that this alternative is feasible for 50% of the culverts.
- For the other 50% of the culverts the in-situ cast concrete deck on masonry piers is economical only if a concrete floor slab is not required. This is feasible only in those localities where shallow rock-founding conditions prevail, based on the authors' knowledge of the area conservatively taken as 50% of the cases.
- Conventional cast in-situ concrete inlet and outlet structures for the existing cell structures extensions are regarded as theoretical alternatives to the empowerment-friendly stone masonry walls specified.

### Further input data to the analyses

The tendered schedule amounts of the lowest tender for the drainage structure

component as specified is comprised as follows:

- In-situ cast concrete cells bridge, including inlet and outlet structures R55 373
- Stone masonry arch causeway (reserved for local entrepreneurs) R113 941
- Prefabricated concrete rectangular and pipe culverts (of which 21% is reserved for local entrepreneurs) R1 124 250
- Inlet and outlet structures R29 379
- Other remedial and extending work R65 744
- Total for drainage structures component R1 388 687
- Indirect construction cost amounts to 8,6%, while the overhead costs are taken as 18%

Because inadequate project data was available, the analysis spreadsheet was used to determine the relative performance of the alternatives.

### Results

Replacing the in-situ cast concrete cells bridge with an in-situ cast deck on masonry walls increases the local content of this component by 11% at a cost saving of 5,5%.

By specifying stone masonry arches instead of prefabricated culverts as is normal current practice for the Mokgalakwa crossing, the local content of this component increased by 15% at a cost saving of 18%.

Replacing a portion of the prefabricated culverts with stone masonry arches and in-situ cast decks on masonry walls increases the local content of these components by 13% and 19% respectively at a cost saving of 21% and 4,1% respectively.

Lastly, if mass stone masonry is used instead of reinforced concrete for the inlet and outlet structures for the extension of existing structures, the local content of this component increases by 18% at almost the same cost.

### Conclusion

The effect of the above is that at a marginal cost saving on the total project cost, the replacements increase the local content by 13,3% of the drainage structure component (98% increase), and by 0,9% of all work (14% increase).

## GENERALISATION OF CIRCUMSTANCE TECHNIQUE CHOICES

### Hydraulic considerations

On the project in the mountainous area fast-flowing streams are encountered, so that the design had to aim at limiting the structure height in relation to the aper-

ture of the structure. A limiting factor is that the river profiles are deep and narrow. This renders the masonry arch bridge an obstruction to flow because of its wide thrust blocks in the absence of rock founding conditions, unless it is excavated into the river banks, which makes it uneconomical. Raising the arch onto piers is not feasible either, as it would cause deep flows that cause erosion downstream.

Other than this, hydraulic considerations did not constitute a limitation for the introduction of empowerment-friendly designs.

## Topographical considerations

The in-situ cast concrete deck on masonry piers is reliant on good founding conditions, as it becomes uneconomical as a substitute for the in-situ cast concrete cells structure if a reinforced floor has to be provided. For the three case study projects this affected the choice of design only in respect of 25% of the structures of one of the projects.

On the project in the flat area, the stone masonry arch with its thicker crown was not feasible as a replacement for prefabricated box and pipe culverts for 50% of the culverts. The road height at these stream crossings was too low, and lowering the structure was not possible because of the flat slopes across the road. However, the concrete deck on masonry piers was a feasible replacement for half of the remaining prefabricated culverts where good founding conditions prevailed.

On the project in the mountainous area, fills were too high to allow mass masonry walls to replace the reinforced concrete inlet and outlet walls with footings. On the same project, the river profiles of the larger structures were deep but very narrow. This rendered the masonry arch bridge not feasible because of its longer span relative to its hydraulic capacity. The in-situ cast cells structure was chosen above the less employment-enhancing ARMCO cell.

In all of the cases the empowerment-friendly designs were the appropriate technique choices.

## Socio-economic environment

In none of the case studies was the availability of local unemployed people or local entrepreneurs a limiting factor in the introduction of EI production processes. For only 25% of the culverts of only one of the projects was poor availability of stone for masonry a limiting factor. No other socio-economic factors were such that they presented limitations.

As confirmation that it is considered practical by engineers and contractors to engage local entrepreneurs to construct the drainage structures on a road construction project, in one of the projects



the engineer set aside a substantial portion of the work for this purpose, while in another an alternative tender was received that would replace the conventional prefabricated culverts with masonry culverts, to be done by local entrepreneurs.

## CONCLUSION

COTA is the only acknowledged methodology in the selection of the most appropriate technique alternative under a specific set of circumstances. After a review, a number of deviations are recommended and a revised methodology recommended, termed COTA-C. It was demonstrated in this paper for the circumstance-related evaluation of empowerment-friendly versus current practice in road drainage structures.

It was concluded that the use of empowerment-friendly designs along with labour-based production processes is generally technically feasible, financially viable, and practical from a project management point of view. This conclusion was made after investigating this for a range of hydraulic, topographical and socio-economical conditions that are encountered in the rural underdeveloped areas of South Africa. This was demonstrated to be so, not only for isolated low-level bridges and maintenance on low-traffic rural roads, but also for the drainage structures component of road construction projects.

The paper confirms that current practice in respect to design specifications is not necessarily cost-effective if compared to proven innovative and empowerment-friendly alternatives. Current practice is generally not supportive of the objectives associated with EI practice. While government policy makes the use of appropriate standards compulsory, the technical feasibility of the empowerment-friendly alternatives has been confirmed by recent publications in this journal. There thus remains no grounds for objections to implementing such alternatives.

## RECOMMENDATION

In the light of the above conclusions, it is recommended that the government-declared policy that EI techniques, local resourcing, and capacity building should be the norm should be enforced in this sector. To distinguish appropriate EI techniques from labour-extensive techniques, it is cautioned that per definition, EI techniques are economically viable and conform to accepted quality requirements. It is recommended that technique choices be based on a scrutinising COTA analysis, towards which the generalisation of circumstance technique choices determined in this paper are an initial contribution.

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