# VERRIGTINGS 1971
## Deel 1b

# 42ste KONVENSIE

**18de tot 21ste OKTOBER 1971**

# KAAPSTAD

**Die Vereniging van Munisipale Elektrisiteits-ondernemings van Suidelike Afrika**

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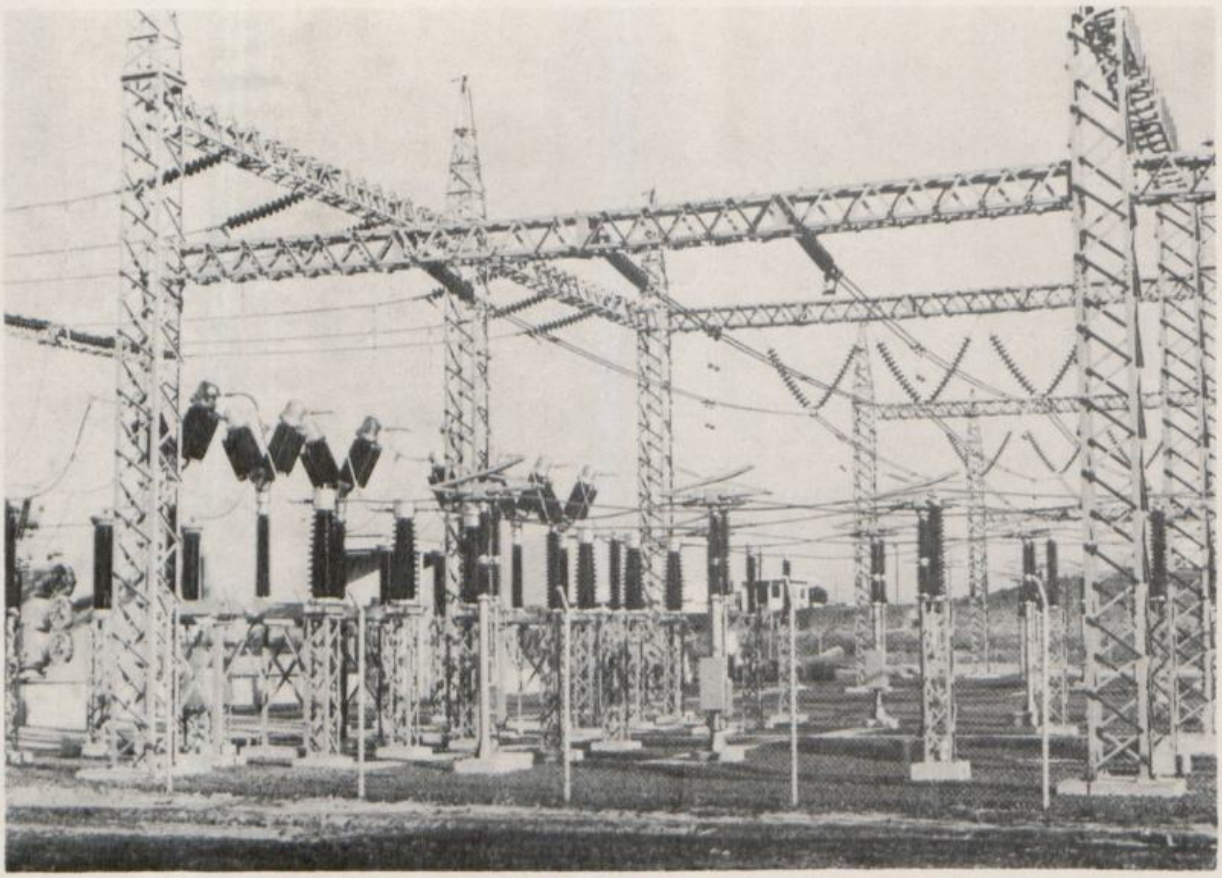

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# PROGRAMMING AND SCHEDULING AS MANAGEMENT AIDS WITH SPECIAL REFERENCE TO MUNICIPAL ELECTRICITY UNDERTAKINGS

by

P. J. BOTES, B.Sc. (Eng.), Pr. (Eng.), F.S.A.I.E.E.

## 1. INTRODUCTION

The position of PERT in modern management.

### 1.01 Management Techniques

The Town Electrical Engineer should act as full-fledged manager of his Council's Electricity Department. He is, therefore, a person who must obtain the best results by utilising the available labour to assist him in the execution of his task. Such a manager must possess a comprehensive knowledge of the management task. He must be able to visualise the logical course of execution of the programme of work by means of a detailed schedule of essential activities. In order to co-ordinate the effort of subordinate persons and to head straight for the objective by means of purposeful motivations the manager must execute the complete managerial task. The complete managerial task consists of :

1. Co-ordinated planning.
2. Co-ordinated organising.
3. Co-ordinated motivation.
4. Co-ordinated control.

As this aspect has been covered comprehensively in a previous paper, I shall confine myself to planning and control only and in particular to certain techniques and supporting aids which simplify the tasks of planning and control.

### 1.02 Co-ordinated Planning and Control

Every manager must do his own planning as far as possible because in the end he himself will be the person who must account for the execution thereof. The least a manager has the opportunity to do his own planning the least enthusiasm he will have for the plan and the weaker the co-ordination will be.

Planning can be defined as the determination in advance of future events and demands and the drafting of sound and effective plans of action to face those events and demands as they materialise.

Planning furthermore, includes activities which are connected to the determination of long and short term objectives, the compiling of estimates, pro-

# PROGRAMMERING EN SKEDULERING AS BESTUURSHULPMIDDELS MET SPESIALE VERWYSING NA MUNISIPALE ELEKTRISITEITSONDERNEMINGS

deur

P. J. BOTES, B.Sc. (Ing) Pr. (Ing) GSAIEI

## 1. INLEIDING

Die plek van PERT in moderne bestuur.

### 1.01 Bestuurstegnieke

Die Stadselektrotegniese Ingenieur behoort as 'n volwaardige bestuurder van sy Raad se Elektrisiteitsdepartement op te tree. Hy is dus 'n persoon wat die beste resultate moet verkry deur middel van die voordeligste aanwending van die persone wat hom by die uitvoering van 'n taak moet bystaan. So 'n bestuurder moet 'n afgeronde begrip van die bestuurstaak besit. Hy moet die logiese verloop van die uitvoering van 'n werkprogram kan visualiseer aan die hand van 'n gedetaileerde staat van noodsaaklike aktiwiteite.

Ten einde die pogings van ondergeskikte persone saam te snoer en deur middel van doelgerigte leiding op die doelwit af te stuur, moet die bestuurder die volle bestuurstaak uitvoer. Die volle bestuurstaak behels :

1. Gekoördineerde beplanning.
2. Gekoördineerde organisering.
3. Gekoördineerde aktiverende leidinggewing.
4. Gekoördineerde beheervoering.

Aangesien hierdie aspek meer breedvoerig behandel is in die voorafgaande referaat, sal ek my slegs bepaal by beplanning en beheervoering en in die besonder by sekere tegnieke en hulpmiddels wat die beplannings- enkontroletake vergemaklik.

### 1.02 Beplanning en Beheervoering

Elke bestuurder moet so ver moontlik sy eie beplanningswerk verrig aangesien hy die persoon is wat op die ou end rekenskap vir die uitvoering daarvan moet gee. Hoe minder die bestuurder geleentheid het om self beplanning te doen, hoe minder entoesiasme sal by vir die plan hê en hoe swakker sal die koördinering wees.

Beplanning kan gedefinieer word as die vooruitskatting van toekomstige gebeure en behoeftes en die opstel van gesonde en effektiewe planne van aksie om daardie gebeure en behoeftes tegemoet te sien soos dit gebeur.

Beplanning sluit verder werksaamhede in wat verbonde is aan die bepaling van lang- en korttermyn doelwitte, die opstel van begrotings, werkpro-

grammes of work, timetables of work and development of procedures and methods of work.

The following example illustrates the value of good planning :

In a municipal electricity undertaking with a growth rate of plus/minus 8% per year the present capacity of cables and transformers will be overloaded eventually. Precautionary methods must be taken to avoid a crisis. By enlarging installations too soon may involve unnecessary cost and dissipation. To co-ordinate the completion of re-inforcing schemes with the origin of the need calls for careful planning.

Being in control the manager must exercise care that the activities continue in accordance with the plan of action previously laid down, by —

(a) evaluating and comparing the progress of the work and results with the plan;

(b) appropriate action where deviations occur;

(c) if need be the setting of new scheduled dates and the making of adjustments;

When a project consists of multi-phases it becomes more and more difficult for the manager to exercise control over the progress of work by means of personal supervision, reports and meetings. Such processes are time consuming and direct the attention rather to what has been done instead of emphasising that which should have been done. For this reason techniques such as network-programming and scheduling of activities have been developed which help the manager to pay special attention to those events that require his urgent attention, instead of concerning himself with those events which do not require his attention, or that will not affect the scheduled date of the project. The discriminating use of the management-by-exception system speeds up the flow of work and saves money.

### 1.03 Programming and Scheduling

Programming is the process of compiling events in sequence and which is designed to arrive at objectives. It provides a step by step approach to direct the necessary action to a pre-determined objective. Scheduling is the process of compiling a duration of time for activities which must be executed. It usually forms an integral part of programming.

### 1.04 Network Programming

One of the modern programming techniques that has been developed is the so-called network programming better known as PERT (Programme Evaluation and Review Technique). Basically PERT and other associated techniques such as C.P.A. (Critical

gramme, werkroosters en die ontwikkeling van prosedures en werkmetodes.

Die volgende voorbeeld gee die waarde van goeie beplanning aan :

In 'n munisipale elektrisiteitsonderneming met 'n groeitempo van + – 8% 'n jaar sal die kapasiteit van kabels en transformatore mettertyd oorlaai word. Tydige maatreëls moet getref word anders sal krisisse ontstaan. Deur te vroegtydig installasies te vergroot kan onnodige koste en verkwisting meegebring word. Om die voltooiing van versterkingsskema te laat saamval met die ontstaan van die behoefte daaraan, kos fyn beplanning.

Onder beheervoering of kontrole moet die bestuurder toesien dat die werksaamhede voortgaan in ooreenstemming met die plan van optrede wat neergelê is, deur :

(a) die vordering van die werk en resultate wat behaal word te vergelyk met die plan en te evalueer;

(b) toepaslik op te tree waar afwykings voorkom;

(c) desnoods nuwe doeldatums te stel en aanpassings te maak;

Wanneer 'n projek uit multi-fases bestaan, raak dit al moeiliker vir die bestuurder om deur middel van persoonlike toesig, verslae en vergaderings oor die vordering van werke, beheer uit te oefen. Sulke prosesse is tydrowend, en vestig eerder die aandag op wat gedoen is, in plaas van die klem te laat val op dit wat reeds gedoen moes gewees het. Gevolglik is tegnieke soos netwerkprogrammering en skedulering van werksaamhede ontwikkel wat die bestuurder help om sy aandag alleen toe te spits op daardie fasette van 'n projek wat sy aandag dringend nodig het, in stede daarvan om hom besig te hou met daardie fasette wat nie sy dringende aandag nodig het nie, of wat nie die voltooiingsdatum van 'n projek sal beïnvloed nie. Die oordeelkundige gebruikmaking van die uitsonderingsbeheerbeginsel laat die werk vlot en spaar geld.

### 1.03 Programmering en Skedulering

Programmering is die proses om aktiwiteite in volgorde op te stel en wat ontwerp is om doelwitte te bereik. Dit gee 'n stap vir stap benadering om die nodige aksie te stuur na 'n vooraf opgestelde doelwit.

Skedulering is die proses om 'n tydsduur van aktiwiteite wat uitgevoer moet word op te stel. Dit is gewoonlik 'n integrale deel van programering.

### 1.04 Netwerkprogrammering

Een van die moderne programmeringstegnieke wat ontwikkel is is, die sogenaamde netwerkprogrammering, beter bekend as PERT (Programme Evaluation and Review Technique) basies kan PERT en aanverwante tegnieke soos C.P.A.- (Critical Path

Path Analysis), and C.P.S. (Critical Path Scheduling), etc., can be defined as a management planning and analysis tool which makes use of a graphic display (called a network), to depict the essential relationships between various tasks comprising a complex development programme. It is an aid in describing and co-ordinating that which has to be done in order to arrive at the objectives of a project successfully and in time.

The overall value of PERT is that it forces the person doing the planning to do it properly and to consider the entire project fully.

## 2. PERT — THE TECHNIQUE OF PROGRAMMING

### 2.01 Scope

PERT (Programme Evaluation and Review Technique) also known as C.P.A. (Critical Path Analysis) or C.P.S. (Critical Path Scheduling), and associated techniques of programming originated during the mid 1950's as a result of the need for improved planning and progress evaluation techniques to help managers control the utilisation of manpower, material and facilities and to accomplish better co-ordination.

By September, 1957, and from the initial effort of using a computer, the Critical Path Method (C.P.M.) evolved.

Concurrently, in 1957 by research of the "U.S. Navy Special Projects Office", the PERT-technique was developed with which the development of the Polaris Ballistic Missile programme could be evaluated. It is claimed that this has contributed to the fact that the project was completed more than two years prior to the initial planned date. An estimated 250 contractors and 9 000 sub-contractors participated in the Polaris programme.

It must be emphasised that PERT was not designed to replace management or methods of planning such as Gannt Charts, but rather to supplement these planning tools and to give management better information upon which to base decisions.

If, however, planning is not done systematically and comprehensively PERT will fail as it is only an aid and cannot take the place of careful planning.

PERT should be applied in any project which consists of multi-phases and where the continuous control over planning is difficult.

### 2.02 Basic Elements of PERT

The PERT network consists of two basic ele-

Analysis), en C.P.S.- (Critical Path Scheduling), ens., gedefinieër word as 'n bestuursbeplanning en ontledingswerktuig wat gebruik maak van 'n grafiese voorstelling, genoem 'n netwerk, om die noodsaaklike verwantskap tussen verskillende take van 'n komplekse ontwikkelingsprogram aan te dui. Dit is 'n hulpmiddel ter omskrywing en koördineering van dit wat gedoen moet word om die doelwitte van 'n projek suksesvol en betyds te bereik.

Die grootste waarde van PERT lê daarin dat dit die beplanner dwing om deeglik te beplan en die hele projek vooraf deeglik te deurdink.

## 2. PERT—TEGNIEK VAN PROGRAMMERING

### 2.01 Bestek

PERT (Programme Evaluation and Review Technique), ook bekend as C.P.A. (Critical Path Analysis) of C.P.S.- (Critical Path Scheduling) en aanverwante tegnieke van programmering het ontstaan in die middel vyftiger jare as gevolg van die behoefte aan verbeterende tegnieke om beplanning en die vordering van werke te evalueer, om bestuurders te help met die beheer in die gebruik van mannekrag, materiaal en fasiliteite en om beter koördinering te bewerkstellig.

Teen September 1957, en deur vir die eerste keer gebruik te maak van 'n rekenoutomaat het die "Critical Path Method" (C.P.M.), tot stand gekom in Amerika.

Terselfdertyd in 1957 deur die navorsing wat gedoen is deur die „U.S. Navy Special Projects Office", het die PERT-tegniek tot stand gekom waarmee die vordering met die Polaris ballistiese projektielprogramme geëvalueer kon word. Daar word beweer dat dit daartoe bygedra het dat die projek meer as twee jaar vroeër as die aanvanklike beplande datum afgehandel kon word. Ongeveer 250 kontrakteurs en 9000 subkontrakteurs het deelgeneem aan die Polarisprogram.

Dit moet benadruk word dat P.E.R.T. nie ontwikkel is om bestuur of die metodes van beplanning, soos deur die gebruik van Gantt-kaarte, ens., te vervang nie, maar eerder ontwikkel is om die beplannigsmiddele by te staan en om aan die bestuur beter inligting te verskaf waarop besluite geneem kan word.

As beplanning egter nie sistematies en volledig gedoen is nie, sal PERT faal aangesien dit slegs 'n hulpmiddel is en nie die plek van goeie beplanning kan inneem nie. PERT behoort aangewend te word in enige projek wat uit multi-fases bestaan en waarvan die deurlopende beheer oor beplanning moeilik is.

### 2.02 Basiese Elemente van PERT

Die PERT-netwerk bestaan uit twee basiese ele-

ments, a milestone and an activity which are symbolised by a circle O and an arrow ⟶ respectively.

**2.03 PERT / Milestone**

A PERT-milestone signifies an important point or instantaneous occurrence in a project and is always the start or completion of an activity. It does not expend any time and consumes no production resources.

The circle which symbolises a milestone is indicated as follows :

'N MYLPAAL.
AN EVENT.

The number of the milestone is written in the top portion of the circle and is always numbered in sequence from left to right and from top to bottom as indicated in Figure 1 :

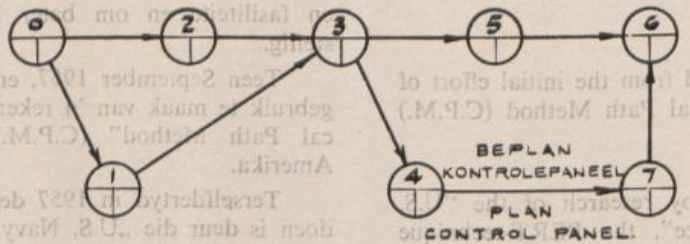



Figure 1

This method of numbering is essential when a computer is used.

**2.04 PERT /Activity**

There are two types of activities, viz. real activities and dummy activities.

**A real activity** represents the necessary work which must be accomplished to progress from one PERT-milestone to another. It expends time, manpower, equipment and production resources.

It is symbolised by a solid line and arrow on the diagram, thus—

'N WERKLIKE AKTIWITEIT.
AN ACTUAL ACTIVITY.

The length of it is of no significance. The direction of the arrow can point from left to right, upwards or downwards but not from right to left.

mente, naamlik, 'n mylpaal en 'n aktiwiteit wat voorgestel word deur 'n sirkel O en 'n pyl ⟶ respektiewelik.

**2.03 PERT / Mylpaal**

'n PERT-mylpaal dui 'n belangrike punt of oomblik in 'n projek aan en is altyd die begin of voltooiing van 'n taak. Dit neem geen tyd in beslag nie en verbruik geen produksie-middele nie.

Die sirkel wat 'n mylpaal voorstel word soos volg verdeel :

Die nommer van 'n mylpaal word in die boonste gedeelte van die sirkel geskryf en word altyd van links na regs en van bo na onder in volgorde genommer soos aangedui in Figuur 1 :

Figuur 1

Hierdie metode van nommer is noodsaaklik wanneer van 'n rekenoutomaat gebruik gemaak word.

**2.04 PERT / Aktiwiteit**

Daar is twee tipes aktiwiteite, naamlik, 'n werklike aktiwiteit en 'n skyn-aktiwiteit.

**'n Werklike aktiwiteit** verteenwoordig die nodige werk wat gedoen moet word om van een PERT-mylpaal na 'n ander te vorder. Dit neem tyd in beslag en verbruik mannekrag, materiaal en produksiemiddele.

Dit word deur 'n soliede lyn en pyl op die diagram aangedui :

Die lengte daarvan dra geen betekenis nie. Die rigting van die pyl kan links na regs, opwaarts of afwaarts wees, maar nie van regs na links nie.

An activity is identified by specifying its preceding milestone number together with its succeeding milestone number, for example in Figure 1 activity A is called activity (2, 3).

To simplify identification even further the activity is written next to the line and arrow which indicates the activity. In Figure 1 the activity (4,7) represents "Plan Control Panel" and is written next to the line and arrow as indicated.

**A dummy activity** expends no time or costs and is only used to retain the logic of the network as well as to ensure the unique identification of every activity.

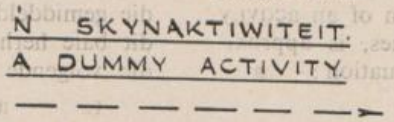
It is symbolised by a dash line and arrow on the diagram :

Identifikasie van 'n aktiwiteit word gedoen deur die eersgenommerde mylpaalnommer tesame met die daaropvolgende mylpaalnommer te noem, byvoorbeeld in Figuur 1 word aktiwiteit A aktiwiteit (2,3) genoem.

Om indentifikasie verder te vergemaklik word die aktiwiteit langs die pyl wat die aktiwteit aandui geskryf. In figuur 1 stel aktiwiteit (4,7) voor- „Beplan Kontrolepaneel", en word langs die pyl geskryf soos aangedui in Figuur 1.

**'n Skynaktiwiteit** impliseer geen tyd of koste nie en word slegs gebruik om die logika van die netwerk te bewaar en om die unieke identifikasie van elke aktiwiteit te verseker.

Dit word deur 'n stippellyn en pyl op die diagram aangeteken :




Between milestones 1 and 3 in Figure 2 there are two activities which run parallel, the activities start at milestone 1 and end at milestone 3 :

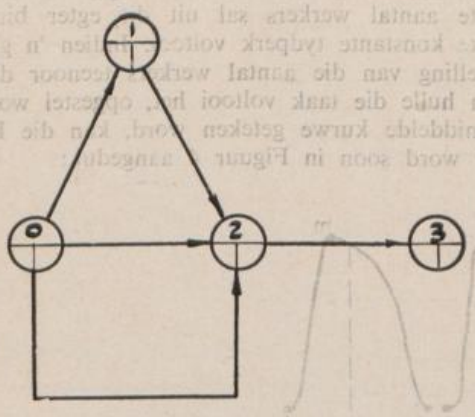



Figure 2.

Consequently the identification of activity (1,3) is confusing.

This problem can be eliminated by the use of a dummy activity as illustrated in Figure 3 :

The activities can now be identified as activities (1,4) and (1,3).

### 2.05 Time Estimates for Each Activity

Time estimates (expressed in days, weeks or months), must be done by an individual who is fully conversant with the specific activity. Three time estimates are made as follows :

**Optimistic Time**—Symbol (a) i.e. the minimum time in which an activity is completed, a result which

Tussen mylpaal 1 en 3 in Figuur 2 is daar twee aktiwiteite wat parallel verloop, die aktiwiteite begin albei by mylpaal 1 en eindig by mylpaal 3 :

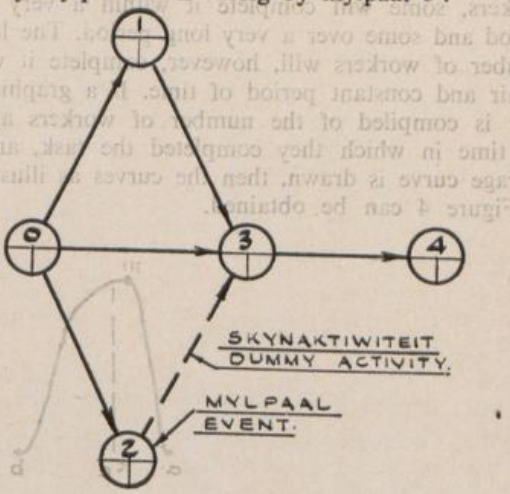



Figure 3.

Gevolglik is identifikasie van die aktiwiteit (1,3) verwarrend.

Hierdie probleem word oorbrug deur die gebruik van 'n skynaktiwiteit soos aangetoon in Figuur 3 :

Die aktiwiteite kan nou geïdentifiseer word as aktiwiteite (1,4) en (1,3).

### 2.05 Tydskattings vir elke Aktiwiteit

Tydskattings (uitgedruk in dae, weke of maande), moet gemaak word deur iemand wat ten volle vertroud is met die bepaalde aktiwiteit. Daar word drie tydskattings gemaak, naamlik—

**Optimistiese Tyd-** simbool (a) d.w.s. die kortste moontlike tyd waarin die aktiwiteit voltooi kan word,

can only be obtained if usually good "luck" is experienced and everything "goes right the first time."

**Most likely Time**—Symbol (m) i.e. the normal time in which an activity is completed, a result which is obtained when the activity is repeated many times under similar circumstances.

**Pessimistic Time**—Symbol (b) i.e. the maximum time in which an activity is completed, a result which is only obtained under the most adverse conditions and when everything "goes wrong".

**The mean elapsed time** — Symbol ($t_e$)

From the abovementioned time estimates the $t_e$ i.e. the mean elapsed time the duration of an activity will take if it is repeated many times, is approximated by means of the following equation:

$$te = \frac{a + 4m + b}{6}$$

This is calculated statistical equation.

If the same task is given to a large number of workers, some will complete it within a very short period and some over a very long period. The largest number of workers will, however, complete it within a fair and constant period of time. If a graphic display is compiled of the number of workers against the time in which they completed the task, and an average curve is drawn, then the curves as illustrated in Figure 4 can be obtained.

'n resultaat wat alleenlik verkry kan word indien uiters goeie toestande verkry word en alles reg kom met die eerste probeerslag.

**Mees Waarskynlike Tyd-** simbool (m) d.w.s. die normale tyd waarin 'n aktiwiteit gewoonlik voltooi word, 'n resultaat wat verkry word as die aktiwiteit verskeie kere onder dieselfdie omstandighede uitgevoer word.

**Pessimistiese Tyd-** simbool (b) d.w.s. die langste moontlike tyd waarin die aktiwiteit voltooi kan word, 'n resultaat wat alleenlik verkry kan word in die slegste toestande en wanneer alles verkeerd verloop.

**2.06 Die Gemiddelde Tyd** — Simbool ($t_e$)

Van bogenoemde tydskattings word $t_e$, d.w.s: die gemiddelde tyd wat die aktiwiteit sal duur indien dit baie herhaal sou word, bereken met behulp van die volgende formule:

$$te = \frac{a + 4m + b}{6}$$

Hierdie formule is 'n bekende statistiese formule.

Indien aan 'n groot aantal werkers dieselfde taak opgelê word, sal sommige die taak in 'n besonder kort en ander 'n besonder lank tyd voltooi. Die grootste aantal werkers sal uit dit egter binne 'n redelike konstante tydperk voltooi. Indien 'n grafiese voorstelling van die aantal werkers teenoor die tyd waarin hulle die taak voltooi het, opgestel word, en 'n gemiddelde kurwe geteken word, kan die kurwes verkry word soon in Figuur 4 aangedui:

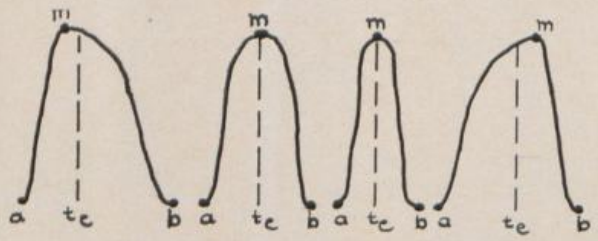



Figure 4.

Figuur 4

In Figure 5 it is illustrated how the mean elapsed time $t_e$ is shown on an activity in a network

$a = 10$
$m = 11$
$b = 18$
$t_e = 12$

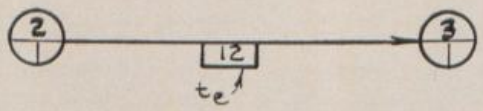



Figure 5.

In Figuur 5 word aangetoon hoe die gemiddelde tyd $t_e$ op 'n aktiwiteit in 'n netwerk aangebring word:

$a = 10$
$m = 11$
$b = 18$
$t_e = 12$

Figuur 5

**2.07 Earliest expected Completion Time**

After the mean elapsed time $t_e$ of every activity

**2.07 Vroegste Moontlike Tydstip**

Nadat die gemiddelde tyd $t_e$ van elke aktiwiteit

in the network has been determined it is possible to establish the earliest expected completion time ($T_E$) on which a milestone can be reached. $T_E$ is calculated by summing all the $t_e$'s in each path of activity leading to the milestone. The greatest sum of activities is chosen as the $T_E$ of the established milestone.

The $T_E$ is always shown in the right-hand corner of the circle as illustrated—

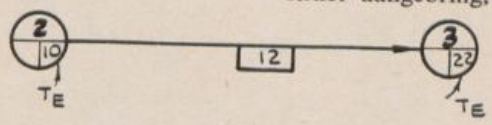



Figure 6.

In the following network it is illustrated how the values of $T_E$ are obtained.

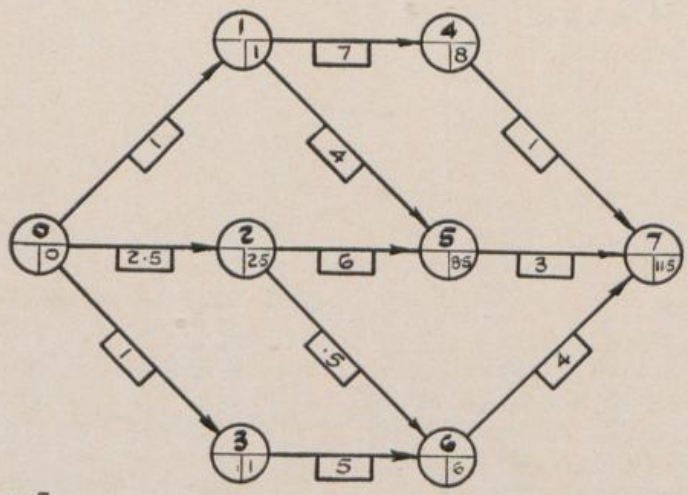



Figure 7.

**2.08 Scheduled or Contractual Times** ($T_S$)

The scheduled or contractual time is the time determined by the management or customer and can be shorter than the earliest expected completion time $T_E$ on which a milestone can be reached. If no time is specified by the management the contractual time ($T_S$) is the same as the earliest expected completion time ($T_E$) on which the last milestone can be reached, i.e., $T_S = T_E$

**2.09 Latest Allowable Time** ($T_L$)

The symbol $T_L$ is used for the latest allowable time to reach a milestone without delaying the completion date of the project.

When a scheduled date ($T_S$) for the last milestone (or completion date of the project) of a network exists the $T_L$ is equal to $T_S$

$T_L$ is computed by working in reverse from the

in die netwerk bepaal is, is dit moontlik om die vroegste moontlike tydstip ($T_E$) te bereken waarop 'n mylpaal bereik kan word: $T_E$ word bereken deur al die $t_e$'s op elke aktiwiteitsbaan wat tot die mylpaal lei, bymekaar te tel. Die grootste waarde word geneem as die $T_E$ van die bepaalde mylpaal.

Die $T_E$ word altyd in die regterhoek van die sirkel aangebring, aldus—

Figuur 6

In die onderstaande netwerk word aangedui hoe die wardes van $T_E$ bepaal word.

Figuur 7

**2.08 Geskeduleerde- of Kontraktyd** ($T_S$)

Die geskeduleerde of kontraktyd is die tyd deur die bestuur of die verbruiker aangegee, en dit kan korter wees as die vroegste moontlike tyd $T_E$ waarop 'n mylpaal bereik kan word. Indien geen tyd deur die bestuur gespesifiseer word nie, is die kontraktyd ($T_S$) dieselfde as die vroegste moontlike tyd ($T_E$) waarop die laaste mylpaal bereik kan word, d.w.s $T_S = T_E$

**2.09 Langste Toelaatbare Tyd** ($T_L$)

Die simbool $T_L$ word gebruik vir die langste toelaatbare tyd vir die bereiking van 'n mylpaal sonder om die voltooiingsdatum van die projek te vertraag.

Indien 'n geskeduleerde datum ($T_S$) bestaan vir die laaste mylpaal (of die doeldatum van die projek) van 'n netwerk dan is $T_L$ gelyk aan $T_S$:

$T_L$ word bereken deur vanaf die laaste mylpaal

last milestone to the first. To establish the $T_L$ for a milestone the $t_e$ is subtracted from the ensuing milestone. If more than one value of $T_L$ is obtained then the smallest value obtained is taken as the $T_L$ of the event.

$T_L$ is always shown in the left-hand corner of the circle as illustrated in Figure 8 :

terug te werk na die eerstes. Om die $T_L$ vir die mylpaal te bereken word die $t_e$ afgetrek van die mylpaal wat daarop volg. Indien meer as een waarde van $T_L$ verkry word, word die kleinste waarde geneem as die $T_L$ van die gebeurtenis.

$T_L$ word altyd in die linkerhoek van die sirkel aangebring, soos aangetoon in Figuur 8 :

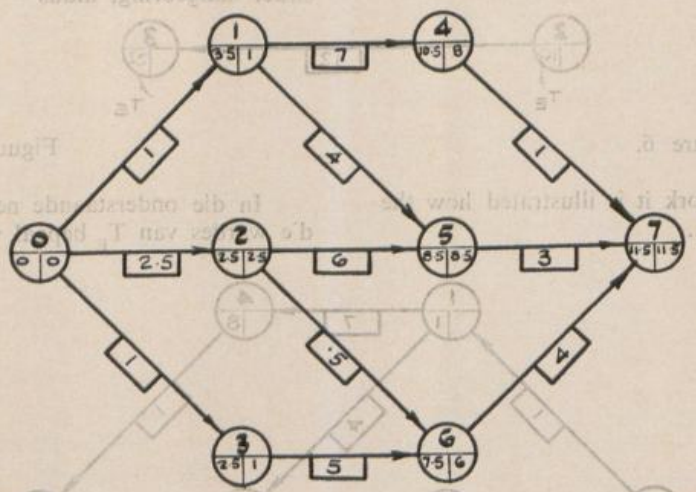



Figure 8.

Figuur 8

### 2.10 The Most Critical Path

Path 0, 2, 5 and 7 in Figure 8 is the longest path in terms of time. This path is called the most critical path. Any change in the time required to complete an activity on this path will inevitably have an effect on the completion date. This path is usually shown in red to indicate the critical path.

The significance of determining the critical paths is to focus the management's attention to those activities which are affecting the completion date of the project. In large complex programs where network programming is not used these factors are usually difficult to isolate and as a result non-critical tasks are emphasised while the critical tasks are overlooked. As changes to the network occur the critical path may shift from one path to another.

### 2.11 Slack Events

All other paths (excluding the most critical path) are called slack paths. In Figure 8 four slack paths exist (0, 1, 4, 7) (0, 1, 5, 7) (0, 2, 6, 7) (0, 3, 6, 7). Slack is measured in terms of negatives, zero, or positive slack.

Positive slack indicates an ahead-of-schedule condition. Negative slack indicates a behind-schedule condition. The slack $S_E$ is determined by subtracting

### 2.10 Die Mees Kritieke Baan

Baan 0, 2, 5 en 7 in (Figuur 8) is die langste baan in terme van tydeenhede. Hierdie baan word genoem die mees kritieke baan. Enige verandering in die tydsduur van 'n aktiwiteit geleë in hierdie baan sal noodwendig 'n invloed uitoefen op die voltooiingsdatum. Hierdie baan word gewoonlik in rooi aangedui om die kritieke baan uit te beeld.

Die kritieke baan of bane is belangrik om te bepaal aangesien dit die bestuur se aandag vestig op daardie aktiwiteite wat die voltooiingsdatum van die projek affekteer. In groot komplekse-programme waar nie gebruik gemaak word van netwerkprogrammering nie, is hierdie faktore moeilik isoleerbaar en gevolglik word meer aandag aan nie-kritieke take gewy terwyl die kritieke take nie die nodige aandag kry nie. Indien daar veranderings in die netwerk aangebring word mag die kritieke baan verskuif van een baan na 'n ander.

### 2.11 Slaptes

Alle ander bane (mees kritieke baan uitgesluit) word genoem slapbane. In Figuur 8 is daar vier slapbane, naamlik— (0, 1, 4, 7) (0, 1, 5, 7) (0, 2, 6, 7) (0, 3, 6, 7). Slapte kan gemeet word in terme van negatief, nul en positiewe slapte.

Positiewe slapte beteken dat uitvoering voor die program plaasvind. Negatiewe slapte dui aan vertraging in die program: Die slapte $S_E$ word bereken deur

the earliest expected completion time of a milestone from the latest allowable completion time.

$$T_L - T_E = S_E$$

For milestone 1 $S_E = 3.5 - 1 = 2.5$ units of time. Milestone 1 therefore, has a slack of 2.5 units of time and activity (0, 1) which is scheduled to take 1 unit of time can take 2.5 units of time longer to complete without affecting the completion date of the project.

### 2.12 Computing the Probability to reach a Milestone on a Scheduled Date

The greater the difference between Pessimistic and Optimistic times estimates the less likely it is that any particular value of an activity will be achieved. Statisticians use a term called **"variance"** which is circumscriptive.

If the variance is large, there is great uncertainty about the time for the completion of an activity.

If the variance is small, the estimate will be fairly precise so far as the time at which the activity will be completed is concerned.

The symbol for the variance is $\sigma^2$ and the estimating equation is $\sigma^2 = \left(\frac{b - a}{6}\right)^2$

The symbol $T_S$ is used to indicate the contractual time or scheduled time of the completion of a project. Other activities in the network may be considered as very important for the allocation of a completion date.

Consequently a $T_S$ will be allocated to these strategic activities.

It would be a tremendous aid to the management if a way exists to calculate the possibility of reaching a milestone on a planned date.

Statisticians use the following probability factor—

$$Z = \frac{T_S - T_E}{\sqrt{\sum \left(\sigma_{TE}\right)^2}}$$

Z can be either positive or negative.

By taking the computed value of Z the probability $P_R$ can be determined from Table A*:

The answer must, however, be multiplied by 100 to obtain percentage.

In Figure 3 the probability factor for milestone 5 can be computed as follows:

$$T_S - T_E = 8.5 - 8.5 = 0$$

die vroegste moontlike voltooingstyd van 'n mylpaal af te trek van Langste Toelaatbare Tyd.

$$T_L - T_E = S_E$$

Vir mylpaal 1 is $S_E = 3.5 - 1 = 2.5$ tyd eenhede.

Mylpaal 1 het dus 'n slapte van 2.5 tydeenhede en taak (0,1) wat geskeduleer is om 1 tydeenheid in beslag te neem kan 2.5 tydeenhede langer neem om te voltooi sonder om die voltooiingsdatum van die projek te beinvloed.

### 2.12 Berekening van die Waarskynlikheid om 'n Mylpaal op 'n Beplande Datum te Bereik

Hoe groter die verskil tussen Pessimistiese en Optimitiese tydberamings, hoe groter is die onsekerheid wat aan die uitvoering van die aktiwiteit toegeskryf kan word. Die statistici het 'n term daarvoor wat genoem word **„varians"**, wat omskrywend is.

Indien die varians groot is, is daar groot onsekerheid omtrent die tyd wat dit sal neem om die aktiwiteit te voltooi.

Indien die varians klein is, sal die beraming taamlik akkuraat wees met betrekking tot die werklike tyd wat dit sal neem om die aktiwiteit te voltooi.

Die simbool vir die varians is $\sigma^2$ en die formule wat gebruik word is $\sigma^2 = \left(\frac{b - a}{6}\right)^2$

Die simbool $T_S$ word gebruik om die kontraktyd of geskeduleerde tyd van die voltooiing van 'n projek aan te dui. Ander aktiwiteite in die netwerk mag van besondere belang geag word om 'n voltooiingsdatum aan toe te ken.

Aan hierdie strategiese aktiwiteite sal gevolglik 'n $T_S$ toegeken wees:

Dit sal 'n groot hulp wees vir die bestuur indien daar 'n manier bestaan om die warskynlikheid te bepaal of 'n mylpaal op 'n beplande datum bereik kan word.

Die Statistici gebruik die volgende waarskynlikheidsfaktor, naamlik—

$$Z = \frac{T_S - T_E}{\sqrt{\sum \left(\sigma_{TE}\right)^2}}$$

Z kan positief of negatief wees.

Deur die berekende waarde van Z te gebruik kan van Tabel A*, die waarskynlikheid $P_R$ bepaal word.

Die antwoord moet egter met 100 vermenigvuldig word om dit in persentasie vorm te kry.

In Figuur 3 kan die waarskynlikheidsfaktor vir mylpaal 5 as volg bepaal word:

$$T_S - T_E = 8.5 - 8.5 = 0$$

i.e. Z in the abovementioned equation = 0

From the table it can be seen that the probability to reach this milesone on time will be 50%.

### 2.13 The use of Computers with the application of PERT

Where there are a great many activities to be taken into account it is impossible to process and maintain the same estimates and critical path without the services of an electronic computer. The role of electronic computers in PERT-programming is of such significance that there are standard or library programmes available for it.

### 2.14 Basic Requirements for the Preparation of a PERT-network

1. A list of all the activities, not necessarily in sequence of performance must be prepared;

2. The establishment of a network can then be simplified by answering the following questions

   (a) What must be done before a start can be made with every particular phase ?

   (b) What can be done simultaneously ?

   (c) What follows in sequence; or now that this phase has been accomplished what can be done further to expedite the project ?

### 2.15 PERT — Cost

Another type of PERT is the PERT cost programme in which costs for every task is determined. This method makes it possible to establish the best plan for considering costing time and risk each in their relationship of importance.

### 2.16 Value of PERT

The most significant value of the PERT system is that it forces management at all levels to plan their work.

After a PERT-network has been developed and the latest allowable date $T_L$ and the earliest possible date $T_E$ have been calculated for every milestone it can be used as a basis for determining contractual dates and as the programme progresses actual completion dates as well as expected completion dates can be compared with the latest allowable dates to establish the status of the programme, objective and milestone.

Thus PERT provides a means by which planning (through network preparation), scheduling (through PERT calculations) and control (through comparing dates of milestones and activities), can be done.

d.w.s. Z in bostaande formule = 0

Van die tabel kan dus gesien word dat die waarskynlikheid om hierdie mylpaal op datum te bereik 50% is.

### 2.13 Gebruik van Rekenaars by die Toepassing van PERT

Waar daar met 'n groot aantal aktiwiteit rekening gehou moet word, is dit onmoontlik om sonder die dienste van 'n elektroniese rekenaar die tydskattings en kritieke baan te verwerk en in stand te hou. Die rol wat elektroniese rekenaars by PERT-programmering speel, is so groot dat standaard- of biblioteekprogramme daarvoor beskikbaar is.

### 2 14 Basiese Vereistes in die Opstel van 'n PERT-netwerk

1. 'n Lys van al die aktiwiteite moet opgestel word, nie noodwendig in volgorde van uitvoering nie;
2. Die daarstelling van 'n netwerk kan dan vergemaklik word deur die volgende vrae te beantwoord :

   (a) Wat moet gedoen word voordat 'n aanvang gemaak word met elke besondere fase ?

   (b) Wat kan gelyktydig gedoen word ?

   (c) Wat volg in volgorde; of noudat hierdie fase bereik is, wat kan verder gedoen word om die projek te bevorder ?

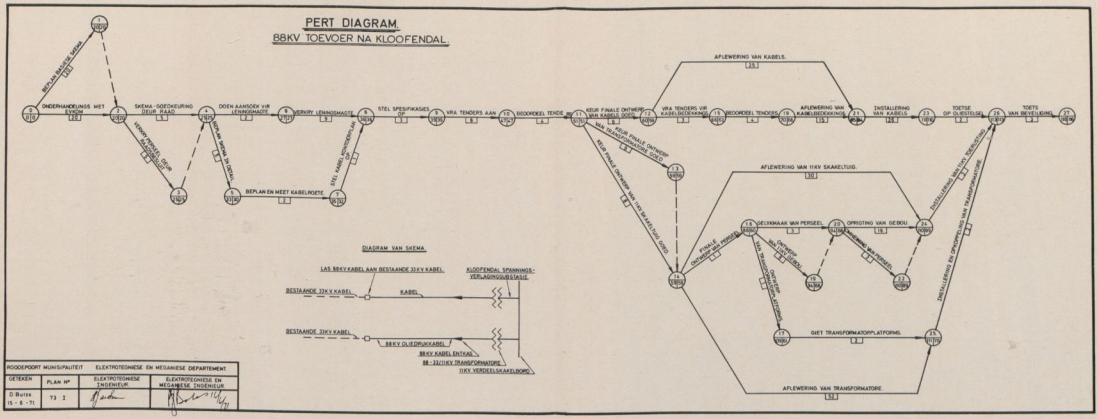
### 2.15 PERT—Koste

'n Ander tipe van PERT is die PERT-kosteprogram waarin beraamde kostes vir elke werk gedoen word. Hierdie metode maak dit ook moontlik om die beste plan te bepaal waarin koste, tyd en die risiko elk oorweeg word volgens hul orde van belangrikheid.

### 2.16 Waarde van PERT

Die belangrikste waarde van die PERT-sisteem is dat dit bestuur op alle vlakke forseer om hul werk te beplan. Nadat 'n PERT-netwerk ontwikkel is en die laaste moontlike datum $T_L$ en die vroegste moontlik datum $T_E$ bereken is vir elke mylpaal, kan dit gebruik word as 'n basis om kontrakdatums vas te stel, en soos die program uitgevoer word, kan die werklike voltooingsdatums en ook verwagte voltooingsdatums met die laaste toelaatbare datums vergelyk word om die stand van die program, doelwit en mylpaal van die program te bepaal.

Gevolglik verskaf PERT 'n metode waarvolgens beplanning (deur die voorbereiding van die netwerk), Skedulering (deur PERT-berekenings) en kontrole (deur datums te vergelyk van mylpale en aktiwiteite), gedoen kan word.


PERT DIAGRAM
88KV TOEVOER NA KLOOFENDAL
BEPLANNINGS WERK
KENNISNEMING MET KLIENT
ONDERHANDELINGS MET KLIENT
SKEMA GOEDKEURING DEUR RAAD
DOEN AANSOEK VIR LENINGSMAGTE
VERKRY LENINGSMAGTE
STEL SPESIFIKASIES OP
VRA TENDERS AAN
BEOORDEEL TENDERS
KEUR FINALE ONTWERP VAN KABELS GOED
VRA TENDERS VIR KABELDEKKINGS
BEOORDEEL TENDERS
AFLEWERING VAN KABELS
INSTALLERING VAN KABELS
TOETSE OP OLIESTELSEL
TOETS VAN BEKLEDING
AFLEWERING VAN KABELS
AFLEWERING VAN 11KV SKAKELTUIG
GELYKMAAK VAN PERSEEL
OPRIGTING VAN GEBOU
GIET TRANSFORMATORPLATFORMS
AFLEWERING VAN TRANSFORMATORE
BEPLAN EN MEET KABELROETE
STEL KABELONTWERP OP
KEUR FINALE ONTWERP VAN SKAKELTUIG GOED
KEUR FINALE ONTWERP VAN TRANSFORMATORPLATFORMS GOED
INSTALLERING EN AFWERKING VAN TRANSFORMATORE
DIAGRAM VAN SKEMA
LAS 88KV KABEL AAN BESTAANDE 33KV KABEL
KLOOFENDAL SPANNINGS-VERLAGINGSBANKE
BESTAANDE 33KV KABEL
KABEL
BESTAANDE 33KV KABEL
88KV OLIEDRUKKABEL
88KV KABEL ENDKAS
88 - 33/11KV TRANSFORMATORE
11KV VERDEELSKAKELBORD
ROODEPOORT MUNISIPALITEIT ELEKTROTEGNIESE EN MEGANIESE DEPARTEMENT
GETEKEN
PLAN Nº
ELEKTROTEGNIESE INGENIEUR
MEGANIESE INGENIEUR
D. Buiss
15 - 8 - 71
73 1

### 2.17 Benefits from the use of PERT

Exceptional benefits derived from the use of PERT are the following:

1. It provides rapid and consistent communication of information;
2. It integrates particulars of progress and/or schedule changes;
3. It focusses management attention on the critical areas (promotes management by exception);
4. It provides complete revised planning documents quickly and cheaply.

From the foregoing it is obvious that PERT is an important aid to the management and in particular with planning and evaluation.

## 3. PRACTICAL APPLICATION

### 3.01 In General

PERT and associated techniques are already used on a large scale in the U.S.A. and the United Kingdom. In the Republic of S.A. it is already used progressively by State and semi-State institutions as well as the private sector.

### 3.02 Application of PERT in the Municipality of Roodepoort

The Town Clerk of Roodepoort, Mr. J. S. du Toit, convinced the Council and Heads of Departments of the benefits in the use of PERT network programming.

The co-ordination and control over housing schemes in which several departments of the Council are involved is simplified and provide the Town Clerk, as manager, with continuous information regarding the progress of the entire project.

### 3.03 Application in the Electricity Department

PERT-network programming is ideally suited for the multi-phase type of projects which are executed by electricity undertakings. Network programming is invaluable to the departmental heads of undertakings which design, install and put into operation their own schemes.

The accomplishment of a 88 000/11 000 volt step-down station must be planned at least two years before it is put into service.

It embraces estimating in advance, design of suitable scheme and reports to the Council for:

(a) the acquisition of suitable premises;

(b) the approval of the scheme;

(c) the approval of the application for borrowing powers.

### 2.17 Voordele in die Gebruik van PERT

Besondere voordele in die gebruik van PERT is die volgende:

1. Dit verskaf 'n spoedige en aanhoudende kommunikasie van inligting;
2. Dit verskaf volledige gegewens van die vordering en/of skeduleverandering;
3. Dit fokus bestuur se aandag op die kritieke dele (uitsonderings prinsiep van bestuur);
4. Voorsien gou en goedkoop volledige hersiende beplanningsdokumente.

Uit die voorafgaande is dit dus duidelik dat PERT 'n belangrike hulpmiddel is vir die bestuur en in die besonder met beplanning en waardebepaling.

## 3. PRAKTIESE TOEPASSING

### 3.01 In die Algemeen

PERT en aanverwante tegnieke word reeds op groot skaal in die V.S.A. en die Verenigde Koninkryk gebruik. In die Republiek word dit reeds in toenemende mate gebruik deur Staats- en semi-Staatsinstellings en in die privaatsektor.

### 3.02 Gebruik van PERT in die Munisipaliteit van Roodepoort

Die Stadsklerk van Roodepoort, mnr. J. S. du Toit, het die Raad en Hoofde van departemente oortuig met die voordele verbonde in die gebruik van PERT-netwerkprogrammering.

Die koördinasie en kontrole oor behuisingskemas waar in verskeie departemente van die Raad betrek is word vergemaklik en lewer aan die Stadsklerk as bestuurder aanhoudende inligting oor die vordering van die algehele projek.

### 3.03 Gebruik in die Elektrisiteitsdepartement

PERT-netwerkprogrammering is besonder geskik vir die multi-fasige tipe projekte wat deur elektrisiteitsondernemings uitgevoer word. Veral in die ondernemings wat hul eie skemas ontwerp, installeer en in werking stel is die waarde van netwerkprogrammering van onskatbare waarde vir die departementshoof.

Die daarstelling van 'n 88000/11000 volt spanningsverlaging-substasie moet ten minste twee jaar voor die ingebruikneming daarvan beplan word. Dit behels vooruitskatting, ontwerp van geskikte skema en verslae aan die Raad vir:

(a) die verkryging van geskikte persele;

(b) goedkeuring van die skema;

(c) goedkeuring van die aansoek om leningsmagte.

Furthermore, it embraces technical reports about the application for borrowing powers to the Provincial Authorities, acquisition of approval for borrowing powers, acquisition of suitable premises, determining routes of cables, compiling, distribution and acceptance of tenders with taking into account the various delivery periods of cables, transformers and switchgear, design and erection of substation building, installation of the equipment, testing and finally the switching on.

Quite a few of these activities can progress simultaneously, others can only be executed after certain tasks have been completed. To obtain good control and co-ordination network programming is essential.

It is obvious that a PERT-network can be altered quite a lot during the course of time because of circumstances beyond control, but with the aid of the PERT network proper attention can always be paid to the critical path.

Included with this paper is a PERT-network which has been compiled for the implementation of a future 30mva 88/11kV stepdown station at Kloofendal, Roodeport.

To execute the project over a few years and for practical and economical reasons 88-kV cables are installed but used at 33-kV for three to four years.

### 3.04 Personnel Problems related to the Establishment of PERT

Any employee is usually against any new establishment and techniques. This is common practice as it cannot be expected from a person who has been doing specific type of work for a period of ten or fifteen years to all of a sudden accept a new method according to which he has to perform his task. Furthermore, if that new technique is setting completion dates, something which they have never had in the past, then the Departmental head can expect problems.

It is, therefore, necessary for the head to convince his senior personnel of the advantages which can be obtained from PERT, and of utmost importance, he must create enthusiasm with his sub-ordinates. Subsequently the worker must be informed that the implementation of completion dates will not affect him detrimentally because he himself will be setting those dates.

It will also be essential for the departmental head to check the organizing framework of his department in order to improve the communication line. By creating less levels the communication will be improved.

By implementing PERT without introducing it to the personnel and without explaining their responsibilities to them can create chaos.

Verder behels dit ook tegniese verslae oor die aansoek om leningsmagte aan die Provinsiale Owerhede, verkryging van goedkeuring van leningsmagte, verkryging van nodige persele, bepaling van die roetes van kabels, opstel, uitgee en aanname van tenders met inagname van die verskillende afleweringstydperke van kabels, transformatore en skakeltuig ,ontwerp en bou van substasiegebou, uitvoering van dieinstallering van die toerusting, toetswerke en ten laaste die finale aanskakeling.

Heelwat van hierdie funksies kan gelyktydig ver loop, andere kan eers uitgevoer word nadat sekere take afgehandel is. Om goeie beheer en koördinasie te verkry is netwerkprogrammering 'n vereiste.

Dit is vanselfsprekend dat 'n PERT-netwerk met die verloop van die tydperk heelwat gewysig mag word as gevolg van omstandighede buite beheer, maar met behulp van die PERT-netwerk kan die nodige aandag altyd toegespits word op die kritieke pad.

Ingesluit by hierdie referaat is 'n PERT-netwerk wat opgestel is vir die daarstelling van 'n toekomstige 30-mVa 88/11kV spanningsverlagingsubstasie te Kloofendal, Roodepoort.

Om die projek oor 'n aantal jare uit te voer en om praktiese en ekonomiese redes word 88-kV kabels geïnstalleer en teen 33-kV gebruik vir drie tot vier jaar.

### 3.04 Personeelprobleme betrokke met die Instelling van PERT

Enige werknemer is outomaties gekant teen enige nuwe instelling en tegnieke. Dit is doodnatuurlik aangesien 'n mens nie kan verwag dat 'n persoon wat 'n spesifieke werkverrigting oor tien of vyftien jaar doen nou skielik moet inval met 'n nuwe metode waarvolgens hy sy werk moet uitvoer nie. As daardie nuwe tegniek nog doeldatums daarstel, iets wat hulle nooit in die verlede gehad het nie, dan kan die departementhoof probleme verwag.

Dit is dus nodig vir die hoof om sy senior amptenare te oortuig van die voordele verkrygbaar uit PERT, en van uiters belang, hy sal entoesiasme moet opwerk by sy onderhoriges. Hierna moet die werker ingelig word dat die daarstelling van doeldatums hom nie nadelig beïnvloed nie aangesien hyself daardie datums gaan vastel.

Dit is ook noodsaaklik vir die departementhoof om die organisatoriese opset van sy departement na te gaan om die kommunikasielyn te verbeter. Deur minder vlakke te skep sal die kommunikasie verbeter word.

Deur die PERT-netwerk in te voer sonder om dit aan die personeel bekend te stel en sonder om aan hulle hulle verantwoordelikhede te verduidelik, kan chaos skep.

### 3.05 Examples of PERT network

PERT networks take up quite an amount of paper and is difficult to bind in with this report and for this reason PERT networks, except for the single example included, will only be presented with the submission of this paper.

### 3.06 Summary

PERT is a useful planning and control aid, which if used discreetly, can involve big savings by means of progressive performance. It requires the manager and his helpers to be trained in the use thereof and to co-operate mutually. As in other instances the danger to exaggerate PERT always exists. PERT diagrams may get so complicated that it can only be compiled by a computer. When it is kept in mind that the benefits, derived from the diagrams, are to compensate for the cost, then this danger is eliminated.

### 3.07 Acknowledgement to the Town Council of Roodepoort.

I wish to express my gratitude to the Town Council of Roodepoort for the means which were put at my disposal for compiling this paper. I wish to thank the Town Clerk in particular for his support.

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K. G. Lockyer-Pitman
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by Federal Electric Corporation
6. Critical Path Analysis, Problems and Solutions
K. G. Lockyear-Pitman

### 3.05 Voorbeelde van PERT-netwerke

Aangesien PERT-netwerke heelwat papier in beslag neem, en dit moeilik ingebind word by hierdie referaat, sal PERT-netwerke, net vertoon word by die voorlegging van hierdie referaat; behalwe vir die enkele voorbeeld aangeheg.

### 3.06 Samevatting

PERT is 'n nuttige beplannings- en beheerhulpmiddel wat, indien dit oordeelkundig gebruik word, groot besparings deur middel van vinnige werkverrigting kan meebring. Dit verg dat die bestuurder en sy helpers in die gebruikmaking daarvan geskoold sal wees en onderling sal saamwerk. Soos met ander dinge is daar die gevaar dat PERT oordryf word. PERT-diagramme mag so ingewikkeld gemaak word. dat dit slegs deur middel van 'n rekenoutomaat opgestel kan word. Wanneer daar 'n gedagte gehou word dat die voordele wat uit die diagramme verkry word, moet opweeg teen die koste, word hierdie gevaar uitgeskakel.

### 3.07 Dank aan die Stadsraad van Roodepoort

Ek wil my dank uitspreek aan die Stadsraad van Roodepoort vir die middele wat tot my beskikking gestel is om hierdie referaat op te stel. In die besonder dank ek die Stadsklerk Mnr. du Toit vir sy hulp.

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## TABLE OF VALUES OF THE STANDARD NORMAL DISTRIBUTION FUNCTION

| Z | O | Z | O |
|---|---|---|---|
| .0 | .5000 | – 3 | .0013 |
| .1 | .5398 | – 2.9 | .0019 |
| .2 | .5793 | – 2.8 | .0026 |
| .3 | .6179 | – 2.7 | .0035 |
| .4 | .6554 | – 2.6 | .0047 |
| .5 | .6915 | – 2.5 | .0062 |
| .6 | .7257 | – 2.4 | .0082 |
| .7 | .7580 | – 2.3 | .0107 |
| .8 | .7881 | – 2.2 | .0139 |
| .9 | .8159 | – 2.1 | .0179 |
| 1.0 | .8413 | – 2.0 | .0228 |
| 1.1 | .8643 | – 1.9 | .0287 |
| 1.2 | .8849 | – 1.8 | .0359 |
| 1.3 | .9032 | – 1.7 | .0446 |
| 1.4 | .9192 | – 1.6 | .0548 |
| 1.5 | .9332 | – 1.5 | .0668 |
| 1.6 | .9452 | – 1.4 | .0808 |
| 1.7 | .9554 | – 1.3 | .0968 |
| 1.8 | .9641 | – 1.2 | .1151 |
| 1.9 | .9713 | – 1.1 | .1357 |
| 2.0 | .9772 | – 1.0 | .1587 |
| 2.1 | .9821 | – .9 | .1841 |
| 2.2 | .9861 | – .8 | .2219 |
| 2.3 | .9893 | – .7 | .2420 |
| 2.4 | .9918 | – .6 | .2743 |
| 2.5 | .9938 | – .5 | .3085 |
| 2.6 | .9953 | – .4 | .3446 |
| 2.7 | .9965 | – .3 | .3821 |
| 2.8 | .9974 | – .2 | .4207 |
| 2.9 | .9981 | – .1 | .4602 |
| | | – .0 | .5000 |
| | .9987 | | |

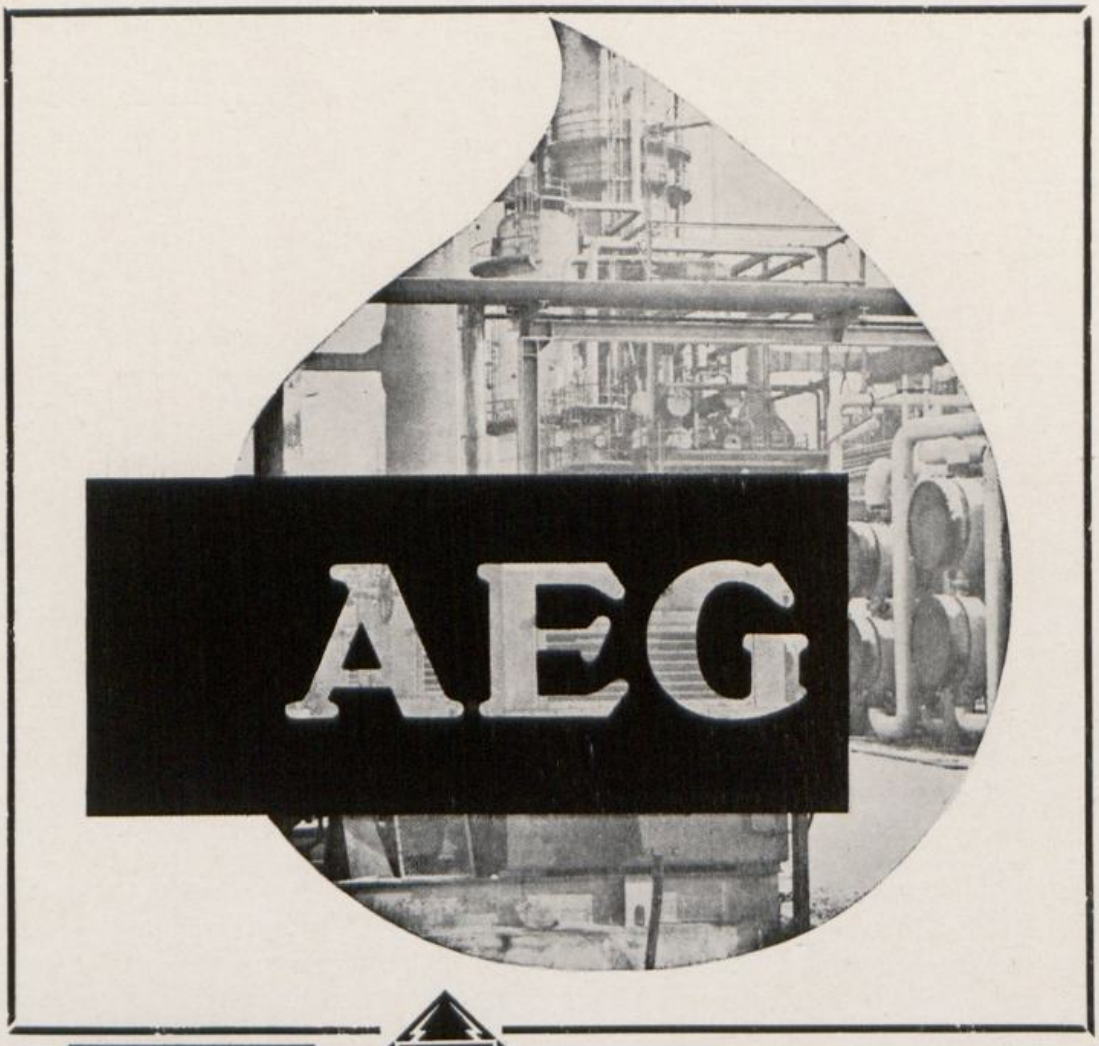
* This is a standard table that can be found in most mathematics and statisics handsbooks.



## TABEL VAN WAARDES VIR DIE STANDAARD NORMALE VERSPREIDINGSFUNKSIE

| Z | O | Z | O |
|---|---|---|---|
| .0 | .5000 | – 3 | .0013 |
| .1 | .5398 | – 2.9 | .0019 |
| .2 | .5793 | – 2.8 | .0026 |
| .3 | .6179 | – 2.7 | .0035 |
| .4 | .6554 | – 2.6 | .0047 |
| .5 | .6915 | – 2.5 | .0062 |
| .6 | .7257 | – 2.4 | .0082 |
| .7 | .7580 | – 2.3 | .0107 |
| .8 | .7881 | – 2.2 | .0139 |
| .9 | .8159 | – 2.1 | .0179 |
| 1.0 | .8413 | – 2.0 | .0228 |
| 1.1 | .8643 | – 1.9 | .0287 |
| 1.2 | .8849 | – 1.8 | .0359 |
| 1.3 | .9032 | – 1.7 | .0446 |
| 1.4 | .9192 | – 1.6 | .0548 |
| 1.5 | .9332 | – 1.5 | .0668 |
| 1.6 | .9452 | – 1.4 | .0808 |
| 1.7 | .9554 | – 1.3 | .0968 |
| 1.8 | .9641 | – 1.2 | .1151 |
| 1.9 | .9713 | – 1.1 | .1357 |
| 2.0 | .9772 | – 1.0 | .1587 |
| 2.1 | .9821 | – .9 | .1841 |
| 2.2 | .9861 | – .8 | .2219 |
| 2.3 | .9893 | – .7 | .2420 |
| 2.4 | .9918 | – .6 | .2743 |
| 2.5 | .9938 | – .5 | .3085 |
| 2.6 | .9953 | – .4 | .3446 |
| 2.7 | .9965 | – .3 | .3821 |
| 2.8 | .9974 | – .2 | .4207 |
| 2.9 | .9981 | – .1 | .4602 |
| | | – .0 | .5000 |
| | .9987 | | |

* Hierdie is 'n standaard tabel wat verkry kan word in die oorgrote meerderheid van wiskundige en statistieke- handboeke.

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