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ESTATUTO EDITORIAL

«Investigação Operacional», órgão oficial da APDIO cobre uma larga gama de assuntos reflectindo assim a grande diversidade de profissões e interesses dos sócios da Associação, bem como as muitas áreas de aplicação da I. O. O seu objectivo primordial é promover a aplicação do método e técnicas da I.O. aos problemas da Sociedade Portuguesa.
A publicação acolhe contribuições nos campos da metodologia, técnicas, e áreas de aplicação e software de I. O. sendo no entanto dada prioridade a bons casos de estudo de carácter eminentemente prático.
Serão também publicadas notícias da APDIO bem como informações sobre acontecimentos nacionais e internacionais relacionadas com a I.O.

Distribuição gratuita aos sócios da APDIO.

EDITORIAL • EDITORIAL • EDITORIAL

Investigação Operacional tem tido um papel importante na vida da nossa associação. Lançada logo após a fundação da APDIO a comissão directiva estava consciente que um empreendimento desta natureza, sendo um desafio à comunidade científica nacional, envolvia riscos. Apostámos nessa iniciativa e hoje, passados que são 2 anos, aqui estamos a apresentar o último número do terceiro volume. O índice cumulativo publicado neste número mostra que cerca de 70% dos artigos publicados são de autores portugueses. A variedade dos temas apresentados, própria de uma disciplina como a nossa, demonstra que a comunidade científica nacional respondeu ao desafio que lhe foi lançado. É também gratificante verificar que autores dos mais variados países continuam a submeter artigos para publicação na revista.

Simultâneamente, a institucionalisação do processo de revisão dos artigos, por especialistas na matéria, muito tem contribuído para o bom nível conseguido. De facto os revisores têm exercido a sua missão de uma forma exemplar, seleccionando os melhores artigos e sugerindo alterações que muito têm contribuído para a clareza e qualidade do texto final. A todos quantos colaboraram nesta iniciativa, autores, revisores e membros da comissão editorial, em especial ao seu presidente, quero expressar o meu sincero agradecimento. O apoio financeiro concedido pela Junta Nacional de Investigação Científica e Tecnológica foi determinante para a viabilização da revista.

As tarefas de edição de uma publicação com uma elevada componente científica e técnica é sempre tarefa difícil. No nosso país, as dificuldades económicas com que nos confrontamos tornam essa tarefa muito mais árdua. Apesar das dificuldades encontradas considero que a edição de Investigação Operacional foi uma das experiências mais compensadoras da minha vida profissional.

O próximo número marcará mudanças na comissão directiva da APDIO e na direcção da Revista já que razões de ordem pessoal me levam a ter que abandonar esse cargo. Faço-o convicta de que Investigação Operacional criou raízes e que estão criadas as condições para que continue a ser instrumento de comunicação eficaz. À nova direcção, que certamente irá contar com todo o apoio da nossa comunidade, desejo pleno êxito.

Isabel Themido

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LISTA DE REVISORES

1982/1983

O Director manifesta o seu apreço pelo valioso trabalho desenvolvido pelos revisores, que muito contribui para o sucesso desta publicação.

Clímaco, João Carlos

Coelho, J. Dias

Filho, Nelson Maculan

Guimarães, Rui Campos

Lopes, José A. Assis

Nápoles, Rui Barbesti

Machol, Robert E.

Oliveira, Rui Carvalho

Ritchie, Eric

Rodrigues, A. Guimarães

Sousa, Reinaldo Castro

Tavares, Luis Valadares

Vasconcelos, Bernardo Calafate

Zúquete, Eduardo

PARTICIPAÇÃO DA APDIO NA VIDA DA COMUNIDADE CIENTÍFICA INTERNACIONAL

Se existe domínio de actividade que, na actualidade, possa ser prosseguido independentemente dos progressos alcançados nos outros países, tal caso não é, por certo, o da investigação e do desenvolvimento científicos os quais dependem grandemente das interacções, das inovações e das descobertas feitas no conjunto da comunidade científica internacional.

Assim se compreende o interesse especial com que a APDIO tem considerado a sua participação nas actividades da comunidade de cientistas e técnicos dos diversos países interessados pela Investigação Operacional, e pelas Ciências Sistémicas, designadamente do Controle.

Uma vez criada a APDIO, definidos os seus objectivos e o seu conteúdo científico, tornou-se evidente que deveria ser o membro nacional das duas grandes Federações que, a nível mundial, congregam as Associações Científicas sobre :

a) Investigação Operacional → International Federation of Operational Research Societies (IFORS)

b) Sistemas e Controle → International Federation of Automatic Control (IFAC).

A eleição da APDIO como membro nacional destas duas federações processou-se rápidamente e a sua participação não tem sido apenas formal mas tem incluído efectiva colaboração na realização de actividades e na tomada de decisões. A título exemplificativo, menciona-se :

a) as colaborações e participações relativas à realização dos V e VI congressos da EURO e dos 9º e 10º congressos da IFORS incluindo--se já neste último uma comunicação sob a categoria de "national paper" a qual foi objecto de concurso nacional ;

b) colaboração e participação no próximo Congresso IFAC 84 (elaboração e selecção de comunicações, etc.) ;

c) participação activa em diversos grupos temáticos internacionais onde se devem destacar os relativos a :

- Decisão (EURO)
- Educação (IFORS)
- Recursos Hídricos (IFAC)
- Transportes (IFAC)
- Desenvolvimento (IFAC)

d) colaboração em actividades editoriais internacionais ("International Abstracts of Operational Research" da IFORS, European Journal of Operational Research, etc.).

Estas actividades têm sido desenvolvidas sem encargos significativos para a APDIO graças à disponibilidade e ao apoio oferecidos pelos próprios sócios envolvidos.

Por votação em Viena (1983) decidiu-se que o congresso EURO VIII terá lugar em Lisboa durante 1986.

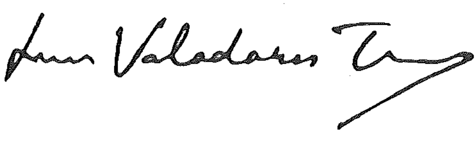
Também o próximo congresso da IFAC sobre Modelos Sistémicos em Recursos Hídricos será organizado pela APDIO em Lisboa, Out. 1985.

Mas desde o início da vida da APDIO, surgiu também com apreciável evidência a necessidade de incrementar o estabelecimento de ligações entre Associações de países latinos e, ou, de países menos industrializados, não só por virtude de apresentarem problemáticas específicas, mas também por se apresentarem frequentemente menos associados do que os seus irmãos industrializados.

É com este objectivo que surge uma nova associação de Sociedades de I.O., a ALIO (Associacion Latina-Americana de Investigacion Operativa) que já engloba a APDIO, a ICHIO (Chile), a SADIO (Argentina), a SEIO (Espanha) e a SOBRAPO (Brasil) prevendo-se o seu alargamento aos restantes membros da comunidade latino-americana no decurso do próprio congresso da ALIO (Agosto 84, Buenos Aires).

Sem dúvida que o estreitamento de contactos entre especialistas em I.O. ou Sistemas pertencentes a países em desenvolvimento muito contribuirá para explorar as potencialidades destas metodologias no sentido de ajudar a encontrar respostas ao grande desafio lançado sobre o cientista actual : o combate à discrepância extrema que se acentua entre condições de vida dos povos ricos e dos povos pobres.

O Presidente



Luis Valadares Tavares

BIBLIOTECA DE INVESTIGAÇÃO OPERACIONAL

Lembram-se os associados que podem utilizar a Biblioteca do CESUR, situada na sede da APDIO, onde podem consultar livros e revistas da especialidade e áreas afins. Os livros estão classificados nas seguintes grandes áreas temáticas -

I - Investigação Operacional (IO)
II - Estatística (ET)
III - Ciências da Computação (CP)
IV - Economia (EC)
V - Ciências do Desenvolvimento (CD)
VI - Matemática (MT)
VII - Engenharia e Ciências (EG)
VIII - Recursos Naturais (RN)
IX - Planeamento Urbano e Regional (UR)
X - Transportes (TP)
XI - Vários (VR)
XII - Gestão e Administração (GT)
XIII - Educação e Investigação (ED)

Dentro de cada grande área temática existe uma classificação mais detalhada que facilita uma mais rápida pesquisa bibliográfica. As subclassificações da área da IO são

IO-01 - Geral
IO-02 - Optimização
IO-03 - Fiabilidade e Manutenção
IO-04 - Filas de Espera
IO-05 - Previsão

10-06 - Simulação
10-07 - Stocks
10-08 - Teoria de Decisão
10-09 - Long Range Planning
10-10 - Redes e Grafos
10-11 - Sistemas
10-12 - Análise de Risco
10-13 - Casos de Estudo - Vários
10-14 - Teoria do Controle
10-15 - Modelação
10-16 - Scheduling

A Biblioteca dispõe de um sistema de gestão informatizado que produz listas temáticas actualizadas das publicações existentes dentro de cada área específica e tem à sua disposição as seguintes publicações periódicas :

European Journal of Operational Research
Journal of Operational Research Society
International Abstracts in O.R.
Journal of Forecasting
New Zealand Operational Research
Investigacion Operacional (Universidad de la Habana)
Pesquisa Operacional - Soc. Brasileira de Pesquisa Operacional
Management Science
Marketing Science
Interfaces
OMNI
NIBBLE
Practical Computing
Communications of the A.C.M.
Computer Graphics
ACM Transactions on Graphics
Computer Graphics Forum
International Statistical Review
Statistica Neerlandica
Transportation

INDICE CUMULATIVO DE INVESTIGAÇÃO OPERACIONAL

Volumes 1 a 3

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I.F.O.R.S.

INTERNATIONAL FEDERATION OF OPERATIONAL RESEARCH SOCIETIES

letter from the president

THE CLAIM OF PARENTHOOD

No. 13, January 1984

Many important planning techniques have been developed within the Operational Research (OR) community. It seems as if the most useful ones are now being used outside our community without their users acknowledging their debt to OR. Indeed, some of those who employ such techniques cite their very usefulness as illustrating the weakness of OR ! Such people fail to recognise any paradox when they state : "OR is useless theory, but we can really tell how to do it".

Examples :

Around 1957/58 network analysis techniques (such as CPM, MPM, PERT etc.) were developed within the OR community. They are now being applied by a variety of others who do not even know that these techniques came from OR and who do not have any understanding of OR. And quite a few network analysis societies have been established without any reference to OR.

Digital simulation techniques were developed and elaborated within the OR community. Today, simulation is profitably being applied in virtually every area of science and technology, and there are several simulation societies and journals without any (or at least any close) connections with OR societies and OR journals.

One of the most fertile fields of OR is inventory theory. Quite a bit of its substance can be found in inventory planning EDP packages designed outside the OR world, and again, without reference to OR.

Exponential smoothing and other forecasting techniques originated in OR, and are now in use without any links to our field.

The field of logistics is full of OR expertise and is developing quickly ; but it seems as if they have completely forgotten their relationship to OR.

Backtracting techniques were to quite an extent the result of pioneering OR efforts, particularly in connection with dynamic programming, branch and bound, search etc. Many of the fundamental ideas which emerged from these OR endeavours are now applied in the field of Artificial Intelligence (AI). However, no traces of their origins are revealed in the general AI literature.

It is as if the OR process acts as a centrifugal separator : powerful and substantial techniques are selected and thrown out, while the more esoteric techniques, lacking in substance, are retained and carefully guarded.

We should at least claim parenthood for the OR ideas and OR tools which are used by others. And we may do more : we may design the corresponding EDP packages ourselves, construct comprehensive planning systems ourselves, develop really applicable solutions ourselves - and tell everybody that the core of these products is principally OR.

We should not expect others to use our tools and ideas without due acknowledgement : such users ought properly to credit that the source of the power of these tools is a consequence of their OR roots.

Heiner Muller-Merbach
President of IFORS

Investigação Operacional
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PRODUCTION*

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Resumo

O artigo apresenta as técnicas matemáticas usualmente utilizadas para a gestão da produção e sugere que a sua utilização tem sido limitada já que, frequentemente não incluem aspectos cruciais da organização. Subsequentemente o autor argumenta que é a concepção global do sistema que determina o seu êxito e não a exececessiva sofisticação de qualquer dos componentes. São apresentados vários casos de estudo para ilustrar a exposição.

The paper presents the mathematical tools available for production planning and argues that the success of their applications has been limited mainly because they often fail to include crutial aspects of the operation. Furthermore the author defends that it is the design of the total system that determines its operational utility, not the exceptional mathematical sophistication of any individual component. Many case study examples are presented to ilustrate some points.

*This paper was presented at a Discussion Conference that took place in Chester, April 8/9 1976. The publication of the paper, after Prof. M.G. Simpson's death, was suggested by Prof. Rui Guimarães, a member of the editorial board of this journal. The abstract was added by the editor. Otherwise the paper has not been altered.

1 - INTRODUCTION

Some 10 years ago, I gave a paper on the same topic to a similar meeting and a clear starting point for my contribution today is thus at hand. Yet in going back to that earlier material, and reviewing reported developments since then, I have become increasingly disenchanted both with the structure I then adopted, and with the "technique" dominance of much of the subsequent contributions to our literature.

In the main section of my earlier paper (on batch production processes), I reviewed some of the many papers aimed at refining analyses of different production situations. These ranged from the simplest unconstrained cases to variants covering, inter alia :

- the complexities introduced when sets of items interacted in the production schedule
- the effect of uncertainties in demand in semi-continuous process production
- how to cope with known but changing demand patterns, and the effect on batch size calculations
- aggregate smoothing of resource levels to fit long-term demand requirements
- and the combinatorial problems of detail product sequencing.

Since then, many papers have emerged presenting further mathematical formulations of various problems, taking into account special characteristics of physical or organisational nature, and demonstrating how improved (even "optimal") specifications of production schedules can be determined. But how much of this mathematically oriented material has, in fact, been implemented ? And even where it has, how long has it stayed implemented, and what has been the overall effect on the total organisation of such largely local modifications ?

It is on such matters as the utility of such approaches, how we might employ our technical skills more effectively, and the overall improvement of company activities by the design and implementation of production planning and control systems that I propose to concentrate today. To fix ideas, I will make most of my comments in the context of batch production processes supplying customers from stock - though I suspect that many of the succeeding comments are equally applicable to other production contexts.

2 - THE CONTRIBUTION (?) OF MATHEMATICAL MODELS

Perhaps the most successful area is that of sales forecasting where, from analyses of historical data, it is clear that exponential smoothing methods and its variants are often very satisfactory, taking into account both seasonality and trends with relatively limited data requirements. There have, of course, been many notable applications of such procedures and this must represent one of our better technical achievements. Yet in most instances we must allow the opportunity for manual overrides - for there are many cases where significant changes in the sales pattern, quite unpredictable from past events, can only be fed into the system by such interventions. But this very safeguard has often been the cause of the eventual withdrawal of formal forecasting systems. Often we do not fully appreciate the context in which such systems are used and unless genuine acceptances of the procedures is gained and/or careful controls are imposed, the manual interventions may take the system over. Thus those responsible for the day-to-day working of the forecasting procedure may try to out-guess the formal forecasts, or those manipulating the forecasts further down-stream in the organisation (where other constraints often mean that some flexing of the forecasts must be undertaken whatever method of generation is used) may bend them differentially again according to intuitive feelings for the "real" pattern of future events. In either case the formal system may lose credibility and may fall eventually into dis-use even if it could be shown that the manual forecasts themselves are typically much less accurate. We clearly know far too little about the context in which such systems may be used and the environment they need to flourish. While it would be foolish not to allow for manual overrides in most situations, we are certainly less competent at predicting the implementation/acceptance aspects (and thus to control them), then we are to handle fluctuations in the sales patterns as such.

Turning to medium-term planning, I dwelt at length in my earlier paper on some of the approaches which have been proposed - from mathematical programming models to linear decision rules developed by Holt et al. Since then, further variants have emerged and great technical ingenuity has been displayed to enable non-trivial problems to be handled. Thus, the range of theoretical possibilities has been extended to cover different numbers of production facilities, numbers of products, and the lenght of the time horison and algorithms produced which can generate solutions. Even with these advances, however, the cost of using such models to plan at the detailed item level is very high. Indeed the model detail and the computational complexities which have developed seem to be aimed more at the Ph.D. thesis mill than as contributions to the practical problems of production planning. Both the data requirements and the sheer computational task are immense and the only successful applications seem to be those using a much simplified version of those models and planning at an aggregate level only. Again, however, this leads to implementation problems for the results generated must still be broken down to detail product level for use, and much of the theoretical gain tends to be eroded. Clearly the utility of such models is very limited without the careful design and provision of procedures which incorporates these detail steps and successfully puts the work into a broader context. Moreover, the long-term acceptance of such procedures is prejudiced by their real or apparent inflexibility and by the uncertainty on the part of the user as to how he should take into account variations indicated by extraneous factors - fears of labour or material shortages, for example. Without a full understanding of the model structure and of how such unprogrammed events may be incorporated, the user will remain suspicious of their real value.

The combinatorial nature of problems arising in detail scheduling and sequencing has, of course, presented the theoreticians with their most challenging problems. Indeed, only in the simplest cases involving quite unrealistic small problems can any of the optimising approaches evolved be applied. Thus ingenuity has been displayed in devising effective heuristics which yield "good" solutions, usually checked out by extensive simulations. There are now available computer packages embedding such heuristics which have been successfully implemented for scheduling at the detail level. And while these are often succesful in themselves I shall return to consideration of such procedures in a broader context.

Common to virutally all problems in the area, and usually linking the various aspects together (or more often perhaps keeping each area at arms length from the other) are the aspects of inventory control. The analysis of inventory systems is perhaps the most worked over of all the O.R. technical areas. Yet all too often a particular area of inventory tends to be analysed in isolation with little consideration of the effects of the control exercised elsewhere in the system. In general the choice of the type of control scheme (reorder point systems or cyclical review, for example) has much more impact on the total system than the precise determination of optimal control parameters as such. Yet, how much research do we see which cavalierly accepts the general systems structure and gives all its attention to the detail. Thus, we find examples of replenishment systems for materials or for finished goods being suggested which take very little account of the interactions between these and the production system itself. Ideally, of course, the arrival of raw materials should be linked to when it is next required on a production line - and the production process geared to produce finished goods consistent with the order pattern. But all too often the existence of an out-of-stock position is treated as a penalty in its own right - quite at odds with the real raison d'être for inventories which should exist solely to provide a service within the system. A notable case of tail wagging dog. Our technical abilities in the handling of complex demand and lead time distributions and multi--location inventory systems would often seem to have outstripped our understanding of the wider system effects of installing the procedures resulting from such analyses.

Throughout the area, therefore, I suggest that we have tended to concentrate on analysing those aspects of problems for which mathematical tools are available or for which we feel that we can successfully handle the technical problems involved. The narrowness of this approach, both in terms of the related functions within an organisation and the implementation problems of effecting any permanent change has often led to O.R. studies being relatively ineffective.

3 - OVERALL SYSTEM REQUIREMENTS

For a company in the environment concerned, some systems must exist for at least the following functions :

Sales Forecasting : where from an "intuitive feeling" by a marketing manager, or from formal analysis, some forward estimates of future sales must be generated. These should take into account all the various sales profiles if several different markets are concerned and the interactions between items if these exist - either of mutual support or of possible conflict. Furthermore such forecasts must be provided at individual product line level even if aggregate forecasting is a useful stage in the total analysis.

Medium-term production planning : some estimates must be provided of the resource levels required, and how best to accommodate any significant variations in load - by forward stocking, by sub-contracting, or by varying the capacity.

Materials procurement : dependent on provisioning lead-times, material requirements must be arranged to match the future production programme. Clearly, the nature of the decision is very different according to whether materials are common to a wide range of products or are peculiar to specific items - in which case some estimates of production patterns by individual product level are necessary specified both in quantity and in time.

Short-term scheduling : we must specify precisely what products will be made in what quantities in the immediate future. At this level the "nitty gritty" really becomes important - the actual material availability, current production resource levels, short-term pressures of depleting finished goods stocks, and the coupling of operatives, production items and specific operations. Again, some system (or systems) must cover all these aspects whether they are formal and mechanistic or given over to an individual responsability.

Order processing, stock allocation and despatch : a self-evident function, but a crucial one, the effectiveness of which is largely dependent on the status of finished goods stocks. Provision must be made to take into account in process goods and for specifying what actions should be taken in the event of stock shortage - for example, whether or not to despatch part orders and how to handle any back orders arising.

All these functions are familiar enough, and I list them mainly to underline the fact that all of them must exist and that there must be some overall connectivity between them. Thus materials procurement normally follows sales forecasting and medium-term production flows and confidence in the information provided must exist for any effective system to be created. As suggested earlier, O.R. studies have often been able to show how significant gains might be made in individual functional, areas, but without adequate integration into the wider context of the system success is bound to be limited. Such integration needs to cover not only the technical interactions of data transfer, etc, but also such matters as the confidence of those individuals involved in, and responsible for, the operation of the system. Only in such conditions are modifications likely to have any real likelihood of long-term acceptance. And only in such an environment are manual interventions likely to be injected in the mechanistic elements of the process to an appropriate degree and later withdrawn when circumstances revert to "normal", with confidence in such elements unimpaired.

By not creating such environments, much of the potential contribution of O.R. studies has been lost - though happily, of course, there are notable exceptions. But, while we may be content manipulating the technical problems, the life of the company must proceed. Production plans need to be generated regularly, items produced, and orders despatched. To support these functions, commercially oriented data processing systems have offered coverage across all the functional areas listed above with the critical aspects of materials supply, stock recording, order processing and despatch (which we may find rather dull) firmly embedded in overall working systems. Thus, while we have perhaps become highly involved in the technical challenges within one segment (of aggregate planning, or of detail schedulling) the area has been taken over by the overall package. Clearly, such packages must try to accommodate a large number of different companies and different types of operation, and it was inevitable that the early systems, in particular, were very much "lowest common denominator" type systems. These provided an adequate service, but were clearly not able to take into account any special characteristics arising in particular installations. Thus, it has been easy for us to point to technical deficiencies in such systems and show how improvements could be achieved - if only theoretically. But achieving such improvements is quite another matter. For the inflexibility of many packages, and their sometimes tight data structures (and even finding out precisely how they do work) has made modifications to take account of local circumstances very difficult to insert. Thus, while some of the human and overall problems of effecting change have often been reduced, there has certainly been significant technical loss.

Later developments of packages have strengthened the claims to the area with various options now offered in terms of alternative sales forecasting, stock control and aggregate planning procedures, for example. Thus, the level of the lowest common denominator is rising somewhat, though needs can still not be met precisely in general, and compromises still have to be struck between the data needs, the facilities available and the operating costs of such systems still preserve the overall working system concept, and typically have a structure which matches the set of common functions listed above, employing a logic which is comprehensible to those utilising the system outputs.

4 - DO WE NEED CUSTOM-BUILT PROCEDURES ?

In the circumstances outlined above, is there any real merit in developing special purpose programmes with all the costs in effort and elapsed time which inevitably will be involved ? To what extent does the commonality between organisations operating in this area dominate individual peculiarities? Given that overall optimisation is merely "pie-in-the-sky", what gain is there in seeking optimal or near optimal procedures within specific functional areas ?

My view is coloured by observations in several production companies over the last few years in each of which there seemed to be a few aspects which essentially dominated the total situation - both in terms of formulating plans and in day to day control.

The first of these concern a clothing manufacturer supplying high fashion merchandise from stock to the retail trade. A feature of the house style was the development of ranges of garments with a common design theme - which was normally reflected in the decorative lace trimmings. These trimmings were always exclusive designs made to the manufacturers own requirements of high cost and most importantly, from our point of view, involving significant supply lead-times. The volatility of the market and the hazards of style acceptance, coupled with the material lead-time, meant that the effectiveness of production planning and control essentially hinged on the sales forecasting and the material lead-time aspects. Although aggregate planning and detailed production line loading were, of course, essential activities almost any rational method would give satisfactory solutions to the former, while the complexities of the latter could only be sensibly resolved at shop floor level. Essentially, therefore, only two types of information were critical in establishing the key decisions of how much to make of each line item - particularly at the "run out" stage when one range was being phased out of production to make way for its successor. But note that, in this context, forecasting techniques of a special type are needed in estimating the future sales profiles of each product rather than an average sales level.

The second concerns a manufacturer of sheet plastics, and involves the usual wide range of finished products in terms of colour, physical characteristics, and surface finishes. With a substantial commonality in the raw materials used, effective solutions essentially depended on the utilisation achieved from the high cost capital equipment. Dominant stages were the preparation of base plastic material and the subsequent embossing process with important sequential aspects in each - of colour at the first, and of embossing pattern at the second. Coupled with the large product range and significant variability in the demand, the critical decision here was that of short-term product sequencing and the choice of batch sizes which would keep balanced finished stocks while minimising the production line down-times associated with product changes. Again, if this central problem could be solved satisfactorily, the rest of the pattern essentially fell into place.

My final example comes from the printing industry and of a company in a very seasonal business indeed - that of producing greetings cards (which is, of course, dominated by the Christmas trade, despite efforts to stimulate Mother's Day, Easter, etc.) Though a large number of designs were produced each year, again to sell from stock, the seasonal peaks were, of course, essentially the same for all products. Thus, a combination of optimal production strategies for each product separately was bound to give rise to extremely uneven demands on the production facilities. These comprise several stages, but the major constraint was at the critical printing operation with very long set-up times on expensive plant. The scope for varying production capacity throughout the year to match the seasonal demand was very limited. Thus, the central problem was toplan the batch production of each item across the year (from 1 to 5 batches might be indicated according to the total volume required) within the printing constraint and in the light of successively more accúrate sales forecasts becoming available as the selling season progressed.

I have given some detail of these three cases in order to illustrate the point that many problems do have special features - and often these features dominate technical effectiveness of planning and control systems. In such cases it is clearly not justifiable, even if it were practical, to build overall optimising models. Generally, it will be much more efficient to identify such critical features and to design the overall system around a good, if not optimal, procedure for handling these critical aspects. But again, of course, the other functions in the total system must be adequately covered and effective links forged between them.

It has been suggested elsewhere that it is only the exploitation of the special features of problems that permits of their solution at all. This philosophy seems well suited to those production planning and control situations which do not fit into the satndard mould (and this is most problems, perhaps) and offers a potencial beyond that which any completely standard package can provide.

5 - A CASE STUDY

But how should we go about this task of identifying the aspects which it is worthwhile handling, and of devising procedures which take such aspects into account well enough ? I offer as an example the excellent paper by O'Malley et al (3).

The problem tackled was one having all the complexisties a masochistic mathematician might yearn for ; a plant producing electronic components to stock with many customers and many products. Expected demand for most products varied substantially from period to period, in addition to the usual inherent uncertainty. Production was allocated to one of several similar lines, with each line handling a number of products within any period ; each line needed to be internally balanced within each time period. The well-known "learning curve" effect was sufficiently pronounced for the ratio of the total work content represented by any production batch to the size of the batch itself to vary significantly from batch to bactch. Overtime working was available while the size of the labour force could be flexed to some degree in order to accommodate variations in the demand on production facilities. Clearly any overall model building exercise was bound to run into the sands and the philosophy adopted is reflected in the following extract :

> "A distinguishing aspect of our treatment is that our emphasis is on the development of an operational system as a managerial aid to shop scheduling. In this system we utilize several mathematical theories to resolve specific problems. But the emphasis is on the combination of these isolated solutions to form a unified entity".

The essential characteristics of the approach were as follows : Firstly, the line balancing problem was assigned to shop floor level (where I am sure the foreman were very skilled in such planning problems) while to ensure that the finished goods inventory system only generated demands on the production facilities when there was a real need for replenishment, account was taken of any safety stock of pre-allocated stocks which were in fact still available to provide some cover against uncertainties.

From forecast demand levels and making adjustments for safety stocks, in process work, etc., nett future requirements were determined for each item. These indicated very uneven demands on production such that a fixed batch size policy would clearly have been inefficient. Thus the Wagner - Within dynamic lot size model was used to calculate the "optimal" production schedule for each item independently. These were then converted into labour hours required, taking into account the learning curve aspect and the total hours required in each time period calculated by aggregating across all products. Naturally the total load emerging was quite uneven from period to period and a linear programming model was used to smooth production, exploiting overtime and labour force changes where desirable, and ensure that no production back--logs resulted. This L.P. formulation deliberately turned its back on such exotic features as non-linearities in over-time rates, work force changes, etc., or indeed the essential integer outputs required from the solution. These simplifications yielded an extremely compact model which could be solved readily on the small in-house computer. Rounding off the solutions to integer form was carried out as a separate heuristic procedure, again ensuring that cumulative demand would be satisfied and minimising the changes in the work force and the resulting solution represented in terms of man hours available by time period. Finally, the amendments required to the previously computed production schedules item by item (which now, of course, were not necessarily consistent with the smoothed production capacity output) were calculated via another heuristic which minimised the number of alterations required and ensured that no additional production batches were scheduled.

I have described this study in some detail, for it seems to me a splendid example of how to moderate mathematics with common sense in providing meaningful and acceptable solutions for management and leaving some aspects of the system virtually untouched. Again, quoting from the paper

> "In retrospect, while we believe in the use of the best possible analytical tools in the design of production systems such as the one described in this report, we wish to emphasize that experience tends to indicate that the sucess of the operational system is crucially dependent on the correct balance between the various components of the system, and is less dependent on the degree of sophistication of any particular element. In essence, it is the design of the total system that determines its operational utility, and not the exceptional mathematical sophistication of any individual component".

6 - COST EFFECTIVENESS

The emphasis given in the above example (by me partly, I must confess) was on achieving adequate technical solutions to the problem of securing an efficient overall systems design. But if we are to make our maximum contribution in the area, we must, I believe, pay relatively more attention to the benefits to be obtained from the stresses of changing a system in any way - the benefits often measured in financial terms, of course, though other criteria may also be important. Again, we have sometimes tended to reduce costs within one financial area without examining the resultant effects elsewhere in the organisation. As far as I am aware, there are few published examples of attempts to analyse such matters comprehensively. But one has appeared relatively recently by Braat (1). The paper describes the specification and overall optimisation in cost terms of a planning system which comprises :

- forecasting demand and determination of nett requirements
- medium-term planning to determine production capacity required
- short-term control for stocks, material procurement, and production scheduling.

The study formally recognises the links between the control procedures adopted in the different functional areas - in particular those between the amount of flexibility allowed in capacity planning (essentially the damping coefficient in the response function) and the control frequency in the short-term scheduling system. Thus the key design parameters in the total system are shown to be

- safety stock levels
- production batch quantities
- capacity flexibility
- short-term control frequency.

These are then computed so as to minimise the total cost including those of data processing subject to providing a specified service level. Although the analysis is rather more extensive than most firms would care to contemplate, the methodology adopted, and reflected in

"Rather we have based the choice of the control system on such practical arguments as simplicity, implementability and robustness of the decision rules, combined with knowledge of existing Operational Research techniques (and the advantages and disadvantages of these techniques)"

and later developed in

"in designing large complex control systems we found it best to first decide on the structure of the control system and then optimize this system by means of setting the values of the control parameters"

both supports the thesis presented earlier and extends it into the area of financial measurement.

7 - PRACTICAL WAYS FORWARD ?

Though the approaches taken by O'Malley et al and by Braat are useful pointers, they imply a level of original research which is beyond the capacity of those firms without access to significant analytical skills. So must they "fall back" nevertheless on the package which most clearly needs - if they can identify it ? Is it possible that initial "quick and dirty" analyses aimed at identifying those functional areas which are critical in determining the firm's economic well-being (in the sense of section 4 above) can help us to isolate those areas in which we can be of most real benefit - and divert us from those which we either know how to tackle, or find intellectually stimulating. For, if so, we can to some degree cut our cloth to suit the situation with the level of analytical detail itself keyed to the perceived gains as well as constrained by its availability.

But we must still ensure the integrity of the total system, and surmount the problems of confidence and acceptability discussed earlier. Perhaps we may be able to couple the advantages offered by standard packages in terms of discipline, coverage, and integration with an exploitation of special characteristics within situations. For some more recent packages are now offering even greater flexibility not only in terms of available options, but are constructed in modular form any or all of which may be employed. This, of course, is in very welcome contrast to the armour-plated systems with which we were once presented. Thus the IBM S.T.E.P.S. System (2) which is aimed specifically at the consumer package goods industries comprises six independent programmes

- production planning
- materials planning
- cash requirement
- plan comparison
- plan validation
- batch recording.

These can be used individually or in combination, according to choice, with the user able to replace any segment by any other routine he feels more appropriate in his circumstances. Such developments may offer us the best of several worlds.

Perhaps I may close with some comments by Harvey Wagner (4).

> "... I want to mention four problems that operations researchers could usefully study to advance today's.state of the art.
>
> 1. It would be helpful to have some practical analytic models that could be used to diagnose how much improvement potential exists in an existing production-and inventory-planning system, before designing and testing an alternative system.
>
> 2. It would be valuable to have analytic approximations that could estimate the operating characteristics and economic results of a proposed system without having to resort to lengthy computer simulation.
>
> 3. It would be worthwile to have some rules of thumb, developed from analytic studies, to guide the basic design of a production-and inventory-planning system.

4. It would be insightful to examine approaches of behavioural scientists that could facilitate the implementation of new management planning and control systems.

I hope that some readers will turn their attention to these vital and difficult research areas".

And I hope that some light may be shed (or at least some heat generated) on the points I have raised in our ensuing discussions.

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ON THE OPTIMIZATION TASKS OF A DATA BASE ADMINISTRATOR

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Resumo

Este artigo descreve as tarefas básicas do administrador de uma base de dados e apresenta as técnicas matemáticas usualmente utilizadas na alocação óptima de ficheiros. Um novo modelo, baseado na programação quadrática, é proposto e os resultados da sua aplicação comparados com os de outras técnicas de alocação de ficheiros. Conclui-se que a intervenção directa do administrador da base de dados na alocação de ficheiros permite diminuir considerávelmente o tempo de acesso.

This paper presents some essential tasks of a data base administrator. The mathematical tools for the optimal assignment of data base areas are discussed and a quadratic integer programming model is constructed, and the practical experiments and results of the model testing are compared with some other area assignment methods. Remarkable advantages can be obtained in data access times if the data administrator intervenes in the area allocations of the data base.

1 - INTRODUCTION

Physical organization and restructuring of a data base are generally left without proper attention. If the data base design is logical, a working Data Base Management System (DBMS) is generally created by letting the routines of the operating systems take care of part of the physical organization of the data base. But considerable improvements could be made if information about the special relations between different parts of the data base, in various application, was used to optimize physical storage assignments. The fact is that only very few - if any - data base management systems are able to collect the statistical information required by the optimization of physical organization, and to use such information to accomplish the restructuring.

In this paper we first discuss the aims presented by the Codasyl Data Base Task Group, according to which, centralized control of the physical assignment of data should be possible for a data base administrator. The task of a data base administrator is to reserve capacity from the storage devices for the assignment of logical files whilst taking into consideration the time and storage space requirements of using each data base.

It is assumed that information contents, data structures, access methods and storage devices have been fixed in the data base design process. The physical file organization task is thus reduced to assigning areas on the storage devices in an optimal order. In the data base terminology area means the physical storing space for a logical file ; areas can be divided into pages of the same size. In this paper we do not discuss file organization but the relations between files. So access transitions between files become essential. In chapters 2 and 3 the literature on physical file organization is reviewed. A complex overquadratic model for a data base optimization problem is defined in chapter 4. Some theoretical and practical results of different studies are compared in chapter 5, and the methods presented here are shown to compete favorably with them.

2 - PHYSICAL ORGANIZATION OF DATA BASES

Martin (1976, pp.80-82) distinguishes the positions of a data base administrator, and of a systems programmer as follows :

a) The logical data base description or schema is a chart of the entire logical data base. This is the overall view of the data seen by the data base administrator or those systems analysts who see the entire data base.

b) The physical data base description is a chart of the physical layout of the data on the storage devices. This is the point of view of the systems programmers and the systems designers who are concerned with performance. It describes how data are positioned on the hardware, how they are indexed or located, and what compression techniques are used.

The Codasyl Data Base Task Group, on the contrary, also attributes the physical assignment of data to the data base administrator.

Palmer (1974) has outlined a data independent organization. A superschema is a description of the physical structure of data, which consists of : structure, strategy aimed at the optimization of use, storage section, and statistics. Of these the storage section gives the absolute addresses of records on the devices and a definition of data base keys. DBMS records the frequencies of various transactions directed to the data base. The physical mapping model of Bracchi et al. (1974) corresponds to the structure and storage section of Palmer's superschema.

Schwartz (1972) has proved many optimization goals presented in DBMS design to be contradictory. These include for instance quick access to data, and minimal use of storage; high load factor of auxiliary storage, and minimization of data transfer. Olle (1974) assumes that the data independency will sooner or later make it possible for a DBMS itself to organize and optimize storage structures and physical assignments. To implement his, Schwartz (1972) presupposes that the number of queries and changes directed to the value of a certain type of data has been controlled. Furthermore, the access paths and frequencies of the different types of query must be taken into consideration according to Savolainen (1975). In fact, these systems have long been developed (e.g. Soderstrom and Arrhenius (1974), Kondo et al. (1977), Stocker and Dearnley (1974) ; see also Chandy (1977), Hoffer (1975), Wong (1980), Martin (1977), and Senko (1977)).

According to Chen and Yao (1977) the organization of data in the storage must be effected as follows :

a) access paths must be selected so that the response time to the queries of the users is most profitable

b) keys must be selected so that they can be used as indices

c) the size of buffers and the algorithm for compensation of pages must be selected

d) different parts of the data base must be allocated to the storage devices.

Tasks a, c and d are connected with each other. In the following sections we will concentrate on task d of Chen and Yao, which is the last stage in the physical design of a data base. As the access times and costs of different types of storage device are unequal it generally leads to a cost/performance trade-off problem. The allocation of a data base to different types of storage device has often been studied (see the surveys in Savolainen (1975) and Chen and Yao (1977)). Also channel balancing prcblems are in some cases connected with assignment tasks, as shown by Savolainen (1975).

3 - OPTIMAL AREA ASSIGNMENT

Optimal file allocation and ordering methods for deciding the positions of data base areas on magnetic disc storage have been studied by Verne (1972), Savolainen (1973, 1974, 1975, 1977), Grossman and Silverman (1973), Kondo, Yoshida and Kato (1977), and Wong (1980). Most of these studies also include significant practical test results.

In Canberra, at the IBM Systems Development Institute in 1971-72, Verne (1972) applied several "ad hoc" methods and an exact method, dynamic programming, to optimize the allocation of data base areas using statistics of access sequences, i.e. transition frequencies between files, collected in an appropriate period of time. He limited his tests mainly to comparing the efficiencies of various methods. As could be expected, the dynamic optimization method was in practice, not suitable for solving big problems due to the high storage capacity required.

In our analysis, let us first define file areas, i.e. pages, to be equal size. Let the bijective mapping Q^s be a permutation mapping of the initial sequence of pages $(F_1,F_2,\ldots,F_n)$. Thus the function $q^s(i) = j$ (marking: $q_i^s = j$) can be interpreted as follows : page j is in location i of the sequence s. If $A = [a_{ij}]$ is the transition frequency matrix, then the page sequencing problem is to find a sequence permutation of pages on disc cylinders that minimizes the expression :

$$K(A) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} a_{q_i^s q_j^s} (j-i) \qquad (1)$$

This function is a good approximation for access times in certain types of disc storage. The access times are independent of arm transition directions, and therefore each element a_{ij} of the upper triangle matrix A corresponds to the transition sums between files F_i and F_j. In the following, let us assume the data base files to be of unequal size $W = [w_i]$. Thus each file F_i consists of several, w_i, pages. This is a generalization of the quadratic assignment problem which has not previously been discussed in the OR literature, as far as we know. In this problem the distance matrix does not include only constants as in an ordinary quadratic assignment problem, but also values which are functions of various assignments. The task is to find a permutation that minimizes the following objective function

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} a_{q_i^s q_j^s} \left[\sum_{\substack{m=i+1 \\ j>i+1}}^{j-1} w_{q_m^s} + \frac{1}{2} w_{q_i^s} + \frac{1}{2} w_{q_j^s} \right] \qquad (2)$$

This can be reduced by a constant to the following simple form :

$$K(W,A) = \sum_{i=1}^{n-2} \sum_{j=i+2}^{n} a_{q_i^s q_j^s} \sum_{m=i+1}^{j-1} w_{q_m^s} \qquad (2.1)$$

Compared with the conventional quadratic assignment problem the distance elements are in the form :

$$d_{ij} = d(Q^s, i, j) = \sum_{m=i+1}^{j-1} w_{q_m^s} \qquad (3)$$

In our research it has been delightful to see that the solution of this generalized problem is not essentially any more difficult than that of a conventional quadratic problem. Some empirical applications of this method will be discussed later together with the corresponding results by Kondo, Yoshida and Kato.

4 - MULTISTORAGE CASE

The basic problem of optimizing a file sequence based on transition frequencies has been enlarged to cover several similar disc storage devices. Hence, at the same time it must be decided to which device each file is assigned and in which sequence the files on each device are ordered. From the figures in the whole transition matrix A and from the assignment of files to different devices, we obtain the transition frequencies $A' = [a'_{ij}]$ for each particular device :

$$a'_{ij} = a_{ij} + a_{ji} + \sum_{\substack{r,s \\ F_r, F_s \notin F^k}} (a_{ir} q_{rsk} p_{sj} + a_{jr} q_{rsk} p_{si}) \qquad (4)$$

where $F_i, F_j \in F^k$, i.e. files F_i and F_j are located on storage device G_k, and q_{rsk} reveals the total probability of transition in the data access sequence from file $F_r \notin F^k$ to file $F_s \notin F^k$ without calling at device G_k in between. A sufficiently accurate approximation for the probability q_{rsk} can be obtained from matrix A. The probability of direct transition from file F_s to file F_i is p_{si} (p_{sj} denoting the same for file F_j). In (4) sum $\sum_{r,s}$ is called the adjustment part of frequency a'_{ij}.

Of course, $a'_{rs} = 0$, if files F_r and F_s are located on different devices.

The transition frequencies a'_{ij} can in practice be estimated as follows :

$$a'_{ij} = a_{ij} + a_{ji} \tag{4.1}$$

$$+ \sum_{F_r \not\in F^k} (a_{ir}p_{rj} + a_{jr}p_{ri}) \tag{4.1a}$$

$$+ \sum_{F_r, F_s \not\in F^k} (a_{ir}p_{rs}p_{sj} + a_{js}p_{sr}p_{ri}) \tag{4.1b}$$

$$+ \dots$$

(4.1a) represents the number of transitions between files F_i and F_j through one file, F_r (not assigned to the same device as F_i and F_j), (4.1b) represents the same transitions through two files F_r and F_s, etc. Practice has shown that sufficient accuracy for the adjustment part can often be achieved by using only the two first lines of formula (4.1). See the example in Appendix A.

Let us now define the file assignment problem as follows : Assign coherent files F_1, F_2, ..., F_n to similar disc storage devices G_1, G_2, ...,G_m so as to minimize the total travel of the access mechanisms between files in the devices without exceeding the capacity restrictions of the devices. We shall now state the formal objective function of this problem, which is to be minimized. Let

$$q^s_{it} = k \tag{5}$$

indicate that file F_k has been assigned to device G_t, and to location i in the "total sequence" Q^s, which is formed of all the files $F=\{F^t, t=i,2,\dots,m\}$ with files F^1 of device G_1 being the first ones in the sequence Q^s, files F^2 of device G_2 being the second, etc. For illustration see Appendix A. This total sequence is a permutation

$$Q^s = \{Q_t^s,\ t = 1, 2, \ldots, m\} \qquad (6)$$

which defines both the assignment to different devices and sequencing on each particular device (cf. Appendix A). Note here that as far as the optimization problem is concerned, mutually equal permutations can be formed from permutation Q^s by reversing one or more subpermutations Q_t^s or by changing the mutual sequence of subpermutations Q_t^s, $t = 1, 2, \ldots, m$.

The total travel of the access mechanism defined by sequence Q_t^s of the set of files F^t assigned to disc storage G_t, and computed from transition frequencies a'_{ij}, can now be expressed as follows :

$$K(F^t, Q_t^s) = \sum_{\substack{i<j \\ F_{q_i}, F_{q_j} \in F^t}} a'_{q_{it}^s q_{jt}^s} \sum_{\substack{u=i+1 \\ F_u \in F^t}}^{j-1} w_{q_{ut}^s} \qquad (7)$$

The objective function of the file assignment problem which is to be minimized and has previously been expressed in words, can thus be given in the following overquadratic form :

$$K = \sum_{t=1}^{m} \min_s K(F^t, Q_t^s). \qquad (8)$$

As restrictions there are the capacities

$$\sum_{F_i \in F^t} w_i \le C \text{ for all } t = 1, 2, \ldots, m.$$

The problem has been proved NP complete in Savolainen (1977). To solve the problem a branch-and-bound type method and several quick heuristics were constructed. 710 tests were made on UNIVAC 1108 and Honeywell H1644 computers. Part of the test results concerning the one-device case can be seen in tables 1-4 in Appendix B. The testing of the methods showed that in practice it was essentially easier to solve this overquadratic problem than to minimize the objective function (2.1). This is due to the fact that for a fixed number of files, the number of permutations with different values of the objective function (8) is considerably smaller. In particular a simple interchange algorithm proved to be very efficient in solving the overquadratic problem. However, this algorithm was proved heuristic by Savolainen (1977) due to existing local optimum sequences.

5 - PRACTICAL TESTS AND COMPARISONS

Kondo, Yoshida and Kato (1977) have presented an efficient exchange heuristic to solve almost analogical overquadratic file assignment problems. The efficiency of that method was illustrated by practical test results on an on-line system consisting of 6 disc storages and 38 files with over 99 per cent of the access frequencies concentrated on 11 files. File access and transition data were collected from an actual system sited in a plant. Kondo, Yoshida and Kato determined a suitable initial allocation and sequence for the files and afterwards applied their method. In the circumstances the total seek-time was reduced by about 33 per cent. The result is noteworthy, even though the test prearrangements explain in part this good result. The testing was done with a H-8700 computer. It was then discovered that the calculation time limits the application of this method, in practice, to situations where there are several disc storages in the data base and 20 files at the most.

The studies carried by the author concerning the benefits obtained through optimization show that :

a. Even in a case where there was only one disc pack and 5 files of equal size in the data base, the results obtained were good. It is very simple to prove that for the objective function (1) the expected value is

$$E(K(A)) = \frac{2}{n(n-1)} \left(\sum_{i<j} a_{ij} \right) \left(\sum_{i<j} (j-1) \right). \qquad (10)$$

The value of the objective function corresponding to this "random sequencing" was used as a comparative figure when measuring the benefit obtained by optimization. Compared with the average random sequencing of files, optimization of the sequence reduced the sum of access times by approximately 29 per cent.

b. If queries concerning the data base systematically require a certain chained access path through the set of files, then the sum of the access times is by optimization reduced by $100 \frac{n-2}{n+1}$ per cent compared with the expected value of the random file sequence. With five files this figure is 50% and with eight files 66.7%. When the activities and transition frequencies of files are concentrated on only part of the files, the above shows that the more concentration the more total benefit can be obtained from optimization. Likewise a great variety of file sizes has an effect similar to that of the chaining of access transitions.

c. When testing the assignment of data base files to several disc storage devices, the sizes of files were randomly chosen from an uniform distribution between $[1, 20]$. Compared with an average file sequence, the optimum sequence reduced the sum of access times by approximately 72 per cent.

6 - SUMMARY

These amazingly high reductions in access time are a challenge to the data base administrator.

Today, the software of any known DBMS or computer operating system with which the DBMS has been implemented, does not collect,during operation, cumulative data on the transition frequencies necessary to implement the above described physical optimization of the data base. It usually assigns the file areas or pages to the devices in the order of their creation. However, the operating system of most computers does include a possibility that the DBMS administrator determines the assignment of areas. Further, it is easy to collect the data of transition frequencies for example by a tracing method.

We have noticed that when using large data base management systems, the optimization of file assignment may mean a saving of one to two hours a day in the performance times of programs per computer. This also means that the wearing of hardware is postponed and, particularly, that the average response times of the system are considerably reduced.

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APPENDIX A - A NUMERICAL EXAMPLE

An example of a data base file assignment on three disc storage cylinders is presented. Transition frequencies $a_{ij} = 0$ are not included in figure below. Transition frequencies within each particular device a'_{ij} were obtained from formula (4.1) ; only (4.1.a) was considered for the adjustment part. Assignment and sequence permutation Q^s is (5 3 9|1 7 8|6 2 4).

A =

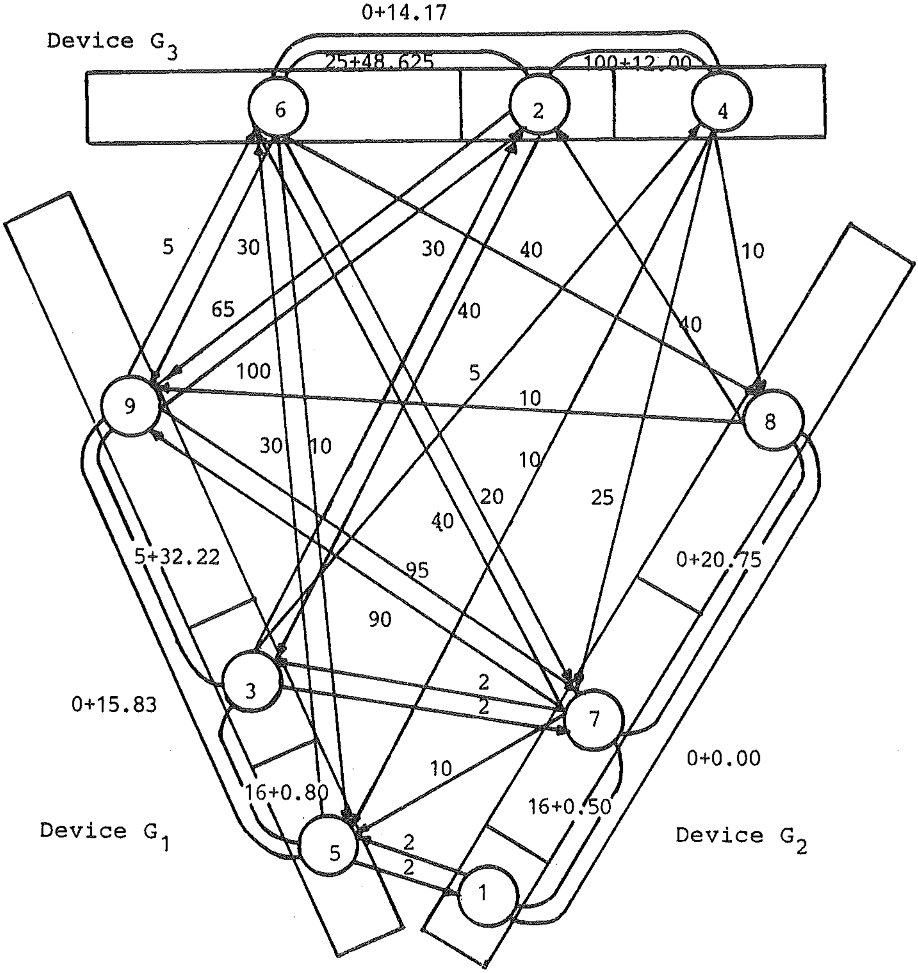
	1	2	3	4	5	6	7	8	9
1	0	0	0	0	2	0	8	0	0
2	0	0	40	70	0	25	0	0	65
3	0	30	0	5	8	0	2	0	5
4	0	30	0	0	10	0	25	10	0
5	2	0	8	0	0	30	0	0	0
6	0	0	0	0	10	0	20	40	30
7	8	0	2	0	10	40	0	0	90
8	0	40	0	0	0	0	0	0	10
9	0	100	0	0	0	5	95	0	0

P =

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	1/5	0	4/5	0	0
2	0	0	1/5	7/20	0	1/8	0	0	13/40
3	0	3/5	0	1/10	4/25	0	1/25	0	1/10
4	0	2/5	0	0	2/15	0	1/3	2/15	0
5	1/20	0	1/5	0	0	3/4	0	0	0
6	0	0	0	0	1/10	0	1/5	2/5	3/10
7	4/75	0	1/75	0	1/15	4/15	0	0	3/5
8	0	4/5	0	0	0	0	0	0	1/5
9	0	1/2	0	0	0	1/40	19/40	0	0

i	1	2	3	4	5	6	7	8	9
w_i	30	40	40	50	80	90	100	140	150

c = 280 K = 21944.06



0+14.17
Device G_3
25+48.625
100+12.00
6
2
4
5
30
30
40
10
65
40
40
100
5
10
9
8
30
10
10
20
25
40
5+32.22
0+20.75
95
90
3
2
2
7
0+15.83
0+0.00
10
16+0.80
16+0.50
Device G_1
Device G_2
5
2
2
1

Appendix B

TEST RESULTS OF THE PROPOSED MODEL FOR A ONE-DEVICE CASE

Table 1. Time consumption of different solution algorithms for the problem defined by function (1). Times are milliseconds and central processing unit times of a time sharing computer UNIVAC 1108 with some minor inaccuracies caused by time sharing. See also table 2.

	n	Branch-and-bound	Branch-and-bound without back-tracking	Sub-sequence extension algorithm	Bacon's device	Inter-change algo-rithm	Activity algorithm
AVERAGE	4	52	40	5.0	25	30	6.5
	5	216	102	10	51	74	7.8
	6	957	241	16	91	161	9.9
	7	7645	468	26	164	306	12
	8	113922	796	33	229	477	14
MIN	4	36	38	4.8	22	25	6.2
	5	99	93	8.6	44	53	6.8
	6	232	197	13	75	109	9.4
	7	1278	406	22	133	199	11
	8	27948	718	31	187	325	13
MAX	4	85	55	6.8	36	58	8.4
	5	464	145	12	74	126	9.2
	6	1992	303	26	126	315	11
	7	26469	550	36	221	644	14
	8	280920	961	41	283	1116	16
STANDARD DEVIATION	4	10	3.0	0.52	2.4	7.8	0.37
	5	80	9.2	0.99	6.7	24	0.38
	6	437	20	2.2	12	59	0.52
	7	5210	37	3.1	19	133	0.47
	8	67329	53	2.7	20	202	0.52

Table 2. Efficiency of heuristic algorithms if n = 8. Tests are the same as in Table 1. Efficiiency is defined as the quotient of the optimal value of the objective function and the value produced by the algorithm.

Effi-ciency	Branch-and-bound with-out back-tracking	Subsequence extension algorithm	Bacon's device	Inter-change algo-rithm	Activity algorithm
1.00	19	5	2	3	5
0.98-0.99	21	7	5	9	8
0.95-0.97	7	17	6	12	18
0.90-0.94	3	18	14	19	15
0.80-0.89	-	3	23	7	4

Table 3. Efficiency of heuristic algorithms if n = 7. Tests are the same as in table 4.

Efficiency	Br.-a.-b. without backtr.	Subseq. extens. algor.	Inter-change algor.	Activ. algor.	Comb. heurist. algors.
1.00	20	1	45	6	47
0.98-0.99	16	1	5	18	3
0.95-0.97	6	2	-	14	-
0.90-0.94	7	16	-	10	-
-0.89	-	30	-	2	-

Table 4. Time consumption of algorithms for the problem defined by function (2). Times are seconds and central processing unit times of Honeywell H1644.

	n	Branch-and-bound	Permutation algor.	Br.-a.-b without backtr.	Subseq. extens. algor.	Interchange algor.	Activity algor.	Combin. of heur. algors.
AVERAGE	4	0.25	0.08	0.19	0.16	0.16	0.05	0.47
	5	1.53	0.67	0.53	0.09	0.51	0.08	1.28
	6	6.64	5.98	1.32	0.16	1.37	0.12	3.22
	7	39.23	55.88	3.00	0.25	2.79	0.16	6.21
	8	224.84	671.94	6.39	0.36	7.84	0.21	13.05
MIN	4	0.13	0.07	0.17	0.03	0.11	0.03	0.41
	5	0.60	0.66	0.50	0.08	0.36	0.07	1.08
	6	2.45	5.93	1.25	1.15	0.80	0.09	2.47
	7	21.23	55.65	2.55	0.23	1.87	0.15	4.96
	8	87.92	668.61	5.96	0.36	5.23	0.19	12.98
MAX	4	0.37	0.09	0.20	0.07	0.28	0.07	0.62
	5	2.75	0.69	0.58	0.10	0.73	0.10	1.51
	6	11.67	6.02	1.40	0.17	2.01	0.13	3.90
	7	77.35	56.07	3.23	0.27	4.11	0.23	7.92
	8	402.29	676.36	6.67	0.37	10.31	0.22	17.86
STANDARD DEVIATION	4	0.056	0.0075	0.0084	0.0062	0.029	0.0067	0.035
	5	0.44	0.079	0.019	0.0081	0.096	0.011	0.11
	6	1.99	0.043	0.036	0.0083	0.28	0.0086	0.33
	7	12.09	0.34	0.12	0.0071	0.61	0.013	0.71
	8	124.0	6.25	0.32	0.0058	2.02	0.016	4.68

INDICE

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