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OPTIMISATION IN THE TRANSPORT SECTOR: A MUCH NEGLECTED OBJECTIVE

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ABSTRACT:

Optimisation in transport evaluation problems is at present only attempted on a technical least cost basis. Three strata of transport optimisation are identifiable, regional, modal and technical, which provide a traditional framework for the development of more comprehensive optimisations. A rigorous approach to problem solving within these stratifications not only allows system analysis techniques to be applied to determine optimal solutions, but the formulation itself necessitates a clear statement of the objective and a cognizance of the broader implications of the problem and its solution.

OPTIMISATION IN TRANSPORT

INTRODUCTION

Optimisation may be defined as maximising or minimising, as appropriate, a measure of an objective. The objective is a statement of the problem, (e.g. to provide a service at least cost), which is described by a function of controlling parameters. The parameters used to model the objective function are subject to constraints which mathematically define their individual functional contributions to the objective.

Most speakers and delegates to this forum will recognise they are concerned with optimisation and that the above description is merely a formalisation of the elements of typical problems.

It is also self evident that before any rational analysis of transport planning problems can be undertaken, as in any application of scientific method, a full statement of objectives is required. This paper sets out to demonstrate that optimisation, in addition to increasing the planner's awareness of his objectives by requiring explicit statements about what they are and how they are to be measured, can be attempted over a traditional hierarchy of transport problems.

When optimising transport infrastructure and operations, the problems are so complex that only a sub-optimisation is usually practical. Sub-optimisation, where the objectives, parameters and constraints are limited to result in a manageable problem, is possible where the systems can be partitioned into a consistent subset. This paper identifies and outlines the inter-relationship between three such subsets or levels in transport planning. The strata are regional, modal and technical and correspond respectvely to the spheres of responsibility of transport directorates, modal authorities and branches within modal authorities, (multi-modal, modal, within mode). Each is a subset of the other and to approach optimisation within each strata the planner must be aware of the objectives associated with the higher levels.

BACKGROUND

In an economic sense, planned optimisation is not required where there is perfect competition in the market. In an ideal transport situation, operators in competition would meet demand with a self regulated efficiency near the optimum. The situation, particularly in the public sector, where the overall objective should be maximising or optimising public welfare, is far from the ideal(1). Transport

1 Defined by the 19th century economist Pareto as one in which, it is impossible to increase anyone's welfare further without decreasing that of someone else.

authorities certainly optimise in their planning. However, without competition incentives and obscure terms of reference, they tend to limit them to minimising initial cost. Rail, and to some extent road track structures are often superficially optimised on this basis with no consideration of future maintenance costs and replacement life.

Arbitrary standards and decision rules are possibly the greatest impediment to effective optimisation. Standards, unless continually reviewed, introduce a time hysteresis effect where optimisation considerations are pertinent to earlier reviews of application experience and thereby always anachronistic. Because standards and decision rules are usually associated with technical issues they tend to mask and frustrate consideration of their objectives and other higher global objectives. Finally, standards are not formulated to facilitate the system techniques described in this paper. There is no inbuilt flexibility to encourage optimisation within the design rules.

Optimisations, currently attempted on an informal semi-rigorous basis, usually lack a precise statement of the objectives and as a consequence the parameters are often inappropriate to the intended objective function. Parameters and objectives have been contracted to give manageable optimisation, which has resulted in the overall objectives becoming compromised and obscured. Optimisations simplified to minimise initial cost only, overlook, as alluded to before, other costs such as routine and extraordinary maintenance, replacement and social costs, which are usually appropriate and significant.

Despite this widespread lack of rigor in statement of objectives, choice of objective function parameters, and identification of costs, good judgement, gained by experience, results in many near optimal solutions. The transport planners, however, will not be able to rely on traditional solutions in the future. Increasing public scrutiny of the public sector and force of competition in the private sector during a period of economic difficulty, will necessitate a turn to optimisation and its accountable procedures.

OPTIMISATION OBJECTIVES AND OBJECTIVE FUNCTIONS

The pre-requisite step in an optimisation process is to determine the objectives. This is not always straight forward and it is even more difficult to choose the parameters which define the objective function. Most problems confront the planner with a multitude of issues which, as suggested by Marglin (1963), can be usually categorised into the following:

- Pure economic efficiency, the maximisation of returns on investments regardless of to whom they may accrue or at what cost.

- Redistribution of income, the promotion of the welfare of particular interests at the expense of others, such as governmental investments in public works and reclamation in particular areas of the country.

- The fulfilment of desires which cannot be justified through their economic benefits, but which are 'found' to be 'worthwhile' i.e. in the public interest, such as defence, education, recreation or parklands (and the mobility provided by transport).

A typical example in transport planning (where many issues arise within Marglin's classification) is the problem of reacting to the impending depletion of the world's known liquid petroleum reserves.

- Should all energy resources be conserved or just liquid petroleum?

- Should we be trying to reduce the country's imbalance of energy payments or limit the potentially inflationary effect of allowing the market to adjust to increased energy costs?

- Is the goal to ensure that there is no disadvantage in the welfare sense or loss of public good by a change in life style brought about by a reduction of our current preferred level of mobility?

Each issue in turn may be cast into several objectives with each one resulting in a different solution to the original nebulous need to do something.

The selection of objective parameters necessarily requires a theoretical understanding of the inter-relationships and sufficient information to relate them to that objective function. This selection process is itself an optimisation problem with the objective of producing the most reliable solution. Diminishing marginal returns take effect introducing uncertainty when attempts are made to introduce far reaching and complex issues with imperfect information into the analysis. To examine the relevance of parameters and hence objective functions liaison is required between those performing the optimisation and the people responsible for or affected by its implementation. There are often conflicting interests, e.g. in the case of railways between vehicle track designers and the operations and maintenance staff who have to live with the design decisions. The liaison link is also required to ensure feedback on decisions so that future attempts at optimisation are improved.

The objective has to be modelled as a function of the chosen parameters before any optimising analysis can be attempted. This function must give a measure of the objective but also be amenable to an optimising procedure. The measure need not necessarily be in terms of cost, as the objective may be of service or some other measure of transport planning efficiency such as generalised cost[1]. To enable the transport planner to predict how people will choose a service or choose among alternatives the value of the service 'in use' or utility must be known. Adam Smith was the first to present this notion. He said:

> "The word VALUE, it is to be observed, has two different meanings, and sometimes expresses the utility of some particular object, and sometimes the power of purchasing other goods which the possession of the object conveys. The one may be called value in use; the other value in exchange".

A rational man can be presumed to wish to maximise his utility. Von Neumann and Morgenstern, in their classic work (1944), were the first to present these concepts on a theoretical basis. Their utility theory enables planners to provide a measure (utility function) which can be used to predict what the demands for an element of (or even the whole) system will be.

Utility theory applied to transportation involves difficult concepts and problems of application. Several are presented below:

- In welfare maximisation, Pareton optimality by definition requires disaggregated knowledge of individual behaviour. The aggregation necessary for practical optimisation disguises important issues such as who pays and who benefits.

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1 Where a value is placed on such things as time and convenience to transform all parameters to dollar values.

- Consumer surplus[1] is used as a monetary proxy of the utility of a good or service. The underlying assumption is that the demand function can be considered as an expression of the users' indifference between the utility of the good and money. This is only true when the product of the system has monetary values determined by the market.

- Externalities such as environmental damage and noise, which all influence welfare, are difficult to quantify in terms of utility and especially in terms of money. Until environmental damage functions are developed, pollution will not be included in utility functions and consequently optimisations. These parameters may be included in future rigorous optimisations; until this time their influence can only be dealt with subjectively.

- In joint user situations[2], it is difficult to apportion costs and benefits of a facility, its operation and its control, and ensure cross-subsidisations are properly accounted for in the utility function. Where joint costs exist the objectives must be rationalised to recognise the realities of the situation. An example of cross-subsidisation is the inequities of private and commercial cost recovery for roads.

Optimisation can be performed within a framework of higher objectives providing the objective statement, parameters and their constraints of the sub problem are compatible with the overall objectives. It is possible to optimise comfort in terms of cost and at the same time optimise a transport service objective which might include other parameters such as frequency of service, safety, travel time and charge. An iterative procedure is required for this technique. Before the overall objective optimum can be determined and used to provide the objectives for lower component optimisations, a near optimisation of that component must have been determined. Implicit in this iterative procedure is the knowledge of all the interrelationships between optimisation and sub-optimisation.

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1 Consumer surplus can be defined as the difference between what the consumers are willing to pay for a good or service and what they actually pay.

2 Two or more transport modes sharing the same infrastructure or controlled by the same organisation and thereby having common overheads.

OPTIMISATION TECHNIQUES

There are many recognised techniques for determining optimal solutions. The application of these techniques is dependent on the form of the objective function and the constraints which apply to its defining parameters. The mathematical programming techniques are deterministic procedures which apply when the objective function has the following attributes:

- There is a single attribute to measure utility.
- The functional relationship between the parameters utility is known with certainty.

If these attributes do not pertain, stochastic techniques can be used. These techniques are particuarly suited to optimisation in transport planning because they allow recognition of the inherent uncertainities. Statistical decision analysis and the theory of games are two techniques in this category. An example of their use is the probabilistic or system approach to the design of pavements now under development in the United States. Baysian techniques can be used to extend decision analysis by using all knowledge available by including subjective conditional probabilities.

As problems increase in difficulty and uncertainty is introduced the reliability of the solutions decreases. In very complex, essentially statistical, processes direct optimisation solutions are not possible at all. Mathematical simulation can be used in these situations to develop possible utility functions which are interpreted by the analyst for optimal solutions.

OPTIMISATION IN TRANSPORT PLANNING

In transport the traditional approach to planning can be categorised into a hierarchy of three strata:

- Regional, where the objectives are related to maximising social welfare or achieving national goals in the public good(1). The issues are usually multimodal and the concern of coordinating transport authorities.
- Modal, where the objectives are related to maximising users welfare, modal share of the market and utilisation. The issues are by definition modal particular and are the concern of operators.

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1 Public good may be defined as indivisible services or products such as defence or clean air.

- Technical, where the objectives are related to minimising cost and the optimisations closely allied to the operations of various branches within an operating authority.

There is an existing 'demarcation of transport' planning issues based on this classification. Because of this traditional demarcation, the inter-relationships required to establish a consistent set of objectives, parameters and constraints for optimisation are understood. The type of issues associated with this classification and their demarcation may be examined by considering the transportation of coal for export. The transportation costs of mined coal from a region to the coast for export has a widepsread impact on employment and the general economic welfare of the region. There are secondary influences on the general standard of transportation to the region if rail or road track has to be upgraded and also on the country's export trade. At the modal level the transportation cost allowed for in contract prices for the coal and the required delivery rate affect the mode chosen and its relative viability to other modes due to that mode's improved utilisation. Finally, all the above can affect the size of hopper railway wagons and the standard of track design and operations.

The planning issues at each stratification should not be considered as conflicting. Undeniably, the ultimate goal in transport planning is to maximise public welfare; even private operators are regulated to achieve this. Sub-optimisation[1], which is subject to a welfare maximisation can be achieved on the basis of the proposed stratifications by taking a broader perspective when formulating objective functions and consistent measures of utility. Objectives which provide the necessary link between sub-optimisation at each level can be established on an iterative basis (over many years if necessary) so that each successive sub-optimisation leads to welfare maximisation.

To ensure that sub-optimisations at each level have consistent measures of utility all social costs and benefits should be included in the objective function unless specifically excluded by the controlling objectives. Costs should be normalised in terms of the value[2] of investment funds at

1 Sub-optimisation will be, for the purpose of this paper, used to describe optimisation within one of the identified planning classifications which at the same time optimises an objective at a higher level.

2 The time value that is imputed to money for the purposes of comparison i.e. the opportunity cost for capital discount rate.

the evaluation year[1]. Any subsidisation should be fully recognised in the objective statement so that no short fall of costs occurs in the ultimate welfare optimisation.

OPTIMISATION ON A REGIONAL BASIS

Most major transport projects in particular rail and road projects, have a regional impact intended or otherwise. Consumers of transport do not perceive the results of technical or modal optimisation in an isolated context, but in the way it affects their transport convenience. Transport, in providing a means of moving people, raw materials and processed goods, affects interaction, work opportunities, and consequently job opportunities and standards of living. Conversely, an issue such as providing reliability of a specialised service in a region, does affect the mode chosen and the technical standards to which track and vehicles are designed and operated.

Optimisation at this level requires attention to cost, capacity, accessibility and quality. The objectives are diverse, ranging from national interests to the local delivery of essential perishables. Some of the issues which can be optimised at this level are the degree to which transport modes should be subsidised (if at all) to achieve regional objectives and how best to allocate funds between modes.

The problems are essentially multimodal and through optimisation at this level the optimal task of each mode and the required efficiency in achieving their tasks can be determined. This is particularly true of regional road and rail problems, where a balance between institutional and private enterprise objectives must be struck.

Regional optimisation is also a sub-optimisation because transport decisions at this level are affected by national resource considerations and where appropriate the constraints arising from this wider consideration should be applied.

OPTIMISATION ON A MODAL BASIS

As stated previously, regional optimisation will decide modal price, capacity, accessibility and quality. At the modal level, objectives are therefore related to minimising cost subsidisations or maximising profit,while meeting capacity, accessibility and quality objectives. Capacity

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1 The year that applies to analysis and optimal selection of the system under analysis.

involves the consideration of speed (travel time), and quantity (number of lanes or tracks). Accessibility parameters affect the route selection, the number of stations or access points and the feeder modes. Comfort and reliability are the main quality parameters. As stated earlier, increasing emphasis is being placed on environmental factors such as pollution, visual impact, and noise. Because the cost of the mode is determined in regional optimisations the emphasis of optimisation at this level is maximising efficiency through quality of design, planning of operations and utilisation.

The parameters of modal optimisation and their constraints are related to the technical inputs to the mode and its operation. Resulting from the necessary iterative link between the stratifications proposed, modal optimisation in turn affects technical sub-optimisation. For example, modal cost, efficiency, capacity and attractiveness, which all influence the marketability of the mode, provide the technical objectives of performance and cost.

OPTIMISATION ON A TECHNICAL BASIS

Optimisation at this level has been achieved only recently in some fields, notably in the aircraft industry where, because of the size of the investment and competitiveness in design and operation, very specific objectives are set. Road and rail track have been optimised to limited objectives, however there is considerable scope to broaden the objectives to include many of the modal and regional issues.

Some of the parameters involved in typical optimisations are the standard of design, construction and maintenance; the design life, staging time for upgrading and supplementation; loading (frequency and magnitude), dynamic effects, materials availability and quality.

The current practise of basing the utility function on cost minimisation is appropriate. The costs must however include obvious costs such as construction, maintenance and operation costs, as well as less tangible costs such as replacement and extra ordinary maintenance. The social costs such as time, accidents, etc., are not always included at this level as they are the subject of higher level optimisations which provide the objectives for the technical optimisation, e.g. speed of operation and standards of safety in this case.

The constraints which apply to the objective functions at this level of optimisation are usually technical in the engineering sense and not related to transport.

CONCLUSION

Potentially there are considerable benefits to be gained by formulating the solution of transport evaluation problems in a framework amenable to optimisation. Not only can system analysis techniques be applied to determine optimal solutions, but the formulation itself necessitates a clear statement of the objective and cognizance of the broader implications of the problem and its solution.

Technical sub-optimisation is a starting point in transport optimisations. At first there will be uncertainty attached to the objectives; constraining parameters will be aggregated; and the methodology unproven. Decision processes in transport planning because of their complexity will always be iterative (whether deterministic or otherwise) and any awareness of the issues which extend beyond the bounds of encapsulated sub-optimisation will lead ultimately to the maximisation of social welfare.

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