1 INTRODUCTION

The process of design, regardless of the field in which it occurs, is nothing more or less than an exercise in problem solving. Even if a road designer has unlimited funds so that the road he ultimately produces is a dead straight line on a constant gradient between two known points in space, he would still have to do a few sums to work out what the bearing of the road is and its gradient. Unfortunately, unlimited funding is a myth and any engineer dedicated to sticking an object on the earth's surface overlooks the topography at his peril. Furthermore, conflicting demands for a limited resource, be it money, materials or land use generate a need for some or other form of trade-off. The nature of the trade-off and the extent to which objectives are achieved with a minimum of adverse side effects dictate the relative success or otherwise of the design. The intention of this lecture is to introduce a technique whereby problem solving can take place in a reasonably orderly and disciplined fashion.

2 SYSTEMS ANALYSIS

Systems analysis as a problem-solving technique first saw the light of day during the Second World War, when it had the grandiose name of operational research, a name that is still in use today amongst mathematicians. Their concern is however more with the exercise of optimising a solution to a problem rather than seeking a solution. For example, containerisation requires that empty containers be dropped off at certain points and then collected after the passage of some or other specified period of time by which time they, hopefully, would have been loaded. The haulier can increase his profitability by a substantial margin if he can plan his activities in such a way that the distance covered by his trucks in dropping and collecting containers is minimised.

The first application of operational research was however involved in the development of radar for use by the Royal Air Force. The problem was the detection, by whatever means, of the incursion of the Luftwaffe into British air space and time, in this case had two dimensions. In the first instance, the warning given to the Air Force had to be sufficiently early to allow them to get out over the Channel to intercept whatever was coming across, and in the second instance there wasn't much time available to develop a workable system. The problem was enormously complex because the technology required did not yet exist. Basic research had to be successfully completed, followed by applied research, which in turn preceded manufacture and commissioning

The British therefore spent a little time working out how best to approach the problem and what they came up with was operational research. Its first application was so successful that it has become widely adopted.

Engineers are invariably involved in dealing with systems, in our case transportation systems, and we tend to concentrate on the systems analysis aspects of operational research while the more mathematically inclined concentrate on the optimising aspects of the discipline.

3 THE STRUCTURE OF SYSTEMS ANALYSIS

Systems analysis is nothing more or less then the essence of common sense. All it really does is to force the analyst to follow a fixed sequence of events and to ensure that each step in the sequence is completed before the next is tackled. All would-be designers would thus be well advised to make systems analysis a deep-rooted part of their very natures so that it operates at an almost instinctive level.

Systems analysis comprises five basic steps. These are:

- ❑ Problem definition;
- ❑ Development of alternative solutions;
- ❑ Selection of the optimum solution;
- ❑ Implementation of the optimum solution; and
- ❑ Monitoring of the outcome of implementation

The steps follow in sequence but also allow for feedback loops from each step back to the first. It can occur that the development of a solution brings about insights that may modify the original problem definition. Once the selected solution is implemented, the situation is changed. For example, a road has been built and it opens up a new area for development. This leads to the development of a new set of problems that require definition and solution.

Problem definition lies at the heart of systems analysis and it will be discussed in detail in the next section of this lecture. It can generally be stated that the definition of a problem very often suggests possible solutions.

A PROBLEM DEFINED IS A PROBLEM SOLVED

Surprisingly enough, problems are frequently not properly defined before attempts at solution are essayed. A single sentence statement such as " We need a road from A to B" often constitutes the total approach to problem definition. As a result of this lack of definition it is not to be wondered at when the solution turns out to be less than an unqualified success.

The Japanese provide a telling illustration of successful problem definition. They were arguably the world leaders in the manufacture of wooden pencils and found that they were pricing themselves out of the market. Systems analysis was brought to bear on the problem, and they decided that, as a first step, the end product should be defined. The obvious definition is that a pencil is a device for writing. Not so obvious is the fact that this definition precludes the use of pencils for drawing. Finally, it was agreed that a pencil is a device for putting marks on other materials, principally paper. From this definition it follows that it must be possible for the human hand to hold the device in such a way that the substance used for making the marks protrudes beyond the hand.

Voila! The solution presents itself. The principal cost element in the wooden pencil is the graphite, which the Japanese have to import and, because of the need to hold the pencil, there is a short section of it which can never be used. Provide graphite thus only for two-thirds of the length of the pencil. The Japanese are once again world leaders in the manufacture of wooden pencils.

The above illustration suggests that problem definition can demand some subtlety.

It also serves to illustrate that a proper definition can assist in the derivation of alternative solutions. The fundamental function of making marks requires that the marking material be sufficiently soft to be eroded by the substance on which the marks are to be made and that there be an adequate contrast in colour between the mark and the substance. Graphite is soft and provides the required colour contrast, but is graphite the only material that can be used? Does the contrast have to be black on white?

The saga of the wooden pencil can be explored in some detail, but it may be more useful to consider problem definition as a general case.

Having defined the problem, it is necessary to develop as many solutions as the designer's imagination permits. This follows because it is only in the classroom that a problem has a single correct solution. In engineering, there are invariably numerous possible ways of resolving a problem. The "best" solution can only be found by exploring all the options and comparing them. It can also happen that one generation's optimum solution is not that of a succeeding generation, so that history could have the effect of turning a right answer into a wrong answer.

As a case in point, the settlement of Black workers remote from their place of employment was at one stage perceived as the answer to White urban safety. The fact that a politically silenced majority was required to spend more time travelling to and from the workplace than actually working was regarded with indifference. Times changed; the Black majority rules and the previous “correct” solution has been consigned to the scrap heap.

At some stage, the game has to stop, and a decision made regarding the selection of solution to be implemented. Invariably, this decision is not for the designer to take, and it is important that the decision maker be presented with all the options including the consequences of the adoption of one option over another.

4 PROBLEM DEFINITION

Problem definition commences with a goal that has to be achieved. This is usually of a broad philosophical nature such as the enhancement of the quality of life of the community and as such can be contained in a single sentence although achievement of the goal may require substantial periods of time.

In order to achieve the stated goal, a variety of objectives may be called for. Enhancement of the quality of life may require a lessening of noise in urban areas, a reduction in air pollution, an elimination of visually intrusive objects such as industrial smokestacks, etc. It follows that the extent to which the individual objectives are met dictates the extent to which the goal is achieved.

The moment that reference is made to the extent to which any objective is achieved, it becomes clear that a measure of the objective is required. A criterion must be set. If it is not possible to set such a criterion, the objective is valueless and the likelihood of achievement of the goal lessened. Furthermore, the criterion itself must be measurable or there is no way whereby various levels of achievement of a criterion can be determined. In the case of noise pollution in an urban residential area, a criterion could be the number of decibels measured at a point some distance away from the centreline of the road.

In comparing various solutions to a problem, staying with the example of noise pollution, a straight comparison of various noise levels would provide an indication which of the various solutions proposed is the best. However, it is possible that all the solutions give rise to a noise level or, alternatively, reduce noise to a level that is, in an absolute sense, unacceptable. The analyst must therefore lay down a standard, e.g. 70 dB measured at a point 30 metres away from the centreline.

Having defined the goal, the objective, the criterion and the standard, an observer is finally in a position to go out and take a measurement on the basis of which it can be said that the standard has been met so that the criterion is satisfied, and the objective thus achieved. To the extent that the objective supports the original goal, the analyst can then say that the solution proposed addresses the envisaged goal.

It very seldom happens that the path from goal to standard does not split. A single goal can be achieved by pursuing more than one objective and any one of these objectives can be subject to more than one criterion. Noise may be measured in decibels, but another feature of sound is its pitch. A high-pitched scream could be more upsetting than a bass rumble, even though the dB level is the same. A constant tone can, after a time, be ignored although the same cannot be said for an intermittent noise. It is thus possible that noise pollution may have to be described in terms of three different criteria.

The analyst's problem has now become more complex. The likelihood that one solution will meet all criteria better than another is low. One solution may produce a lower noise level but at a far higher pitch than another and the question then to be addressed is 'Which of the solutions is the better?' In systems analysis there is a need to compare apples and bananas, and this is achieved by the use of value functions. A value function is typically a multiplier which equates one criterion to another and, more often than not, is determined on a fairly subjective basis. For example, it could be said that a marginal number of decibels gives rise to a reduction of x % in the value of adjacent properties, whereas a marginal increase in pitch causes a y % decrease in property values. Use of such a value function makes it possible to secure a comparison between the two criteria of noise.

No problem exists in a vacuum and the analyst MUST not lose sight of the environment in which it occurs. The environment includes social, economic, political, and natural factors. Taking a road connecting a blue-collar residential area to an industrial area via an otherwise upper crust residential area is not likely to be greeted with acclaim. Similarly, a beautifully curvilinear alignment may have to be sacrificed if its achievement means taking it through a swamp. As part of the process of problem definition, it is necessary to identify all the external factors that may possibly impinge on the problem solution. Solutions developed must then be tested against this environment to see if it can accommodate them.

As stated initially, no designer ever has a free hand in developing his problem solution. Various restraints are brought to bear on the matter, the chief of which are usually financial. Apart from the fact that there is never enough money to satisfy the wilder excesses of the designer, the problem solution must also be economic. In short, the community must be able to show a profit on what is ultimately implemented.

A solution to congestion may be found in adding lanes to a freeway, but the cost of construction must be weighed up against the value of savings in time, reduction in accidents which carry a penalty in terms of fatalities, injuries and property damage and the value attached to convenience and so on.

It may be found that instituting a mass transit facility using existing infrastructure could be a more cost-effective answer to the congestion on the freeway. In this case, the solution is provided not by the geometric designer but by an expert in mass-transit operation which highlights the fact that a proper process of systems analysis tends to be multi-disciplinary in nature. One of the parts of the process not dealt with the above exposition is that it is necessary to identify all the disciplines and interest groups that can have an effect on the ultimate problem definition and development of alternative problem solutions.