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ECONOMICS OF CHANGE

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Change is most apparent in a multiple-use building, such as a community centre, which may, at different times, be used as a theatre, a church, an exhibition hall, and so on. In this article I shall be concerned with the ways in which such a building may change, and this at three levels. The first level is the level of *rearrangements* which are the routine changes properly implied by multiple use, and they should be optimized with respect to a *pattern of use.* Optimization at this level necessarily supposes this pattern to be constant in time. We shall also have to consider the possibility that this pattern changes, and to adapt the building to this requires change of a less superficial kind, namely of the second level, which is the level of *alteration.* Finally, it is a matter of basic morality (as long as it is not a part of Building Regulations) on the part of the designer, that he not only specify how and at what cost the building may be erected, but also how and at what cost it may be removed. This is the third level of change, that of *replacement* (possibly by something serving a very different purpose).

Replacement

Before being able to discuss the economics of the second and first levels, we must consider the implications of replacement. It is desirable to see to it that the rearrangements required by a certain pattern of user requirements take a minimum of time, effort, and materials, or in short, a minimum *cost.* It is always possible to bring down the cost of all possible changes simultaneously by introducing elaborate machinery (a revolving stage is an example). However, this requires a high capital investment, which is incompatible with economy of change at the third level. This criterion, therefore, limits the elaborateness of the building and provides a lower bound for the average cost involved in the rearrangements. It implies that we are faced with a situation where we can only make a particular rearrangement less costly at the expense of one or more others, and that to bring down all of them would require a higher capital outlay, which is uneconomic in terms of the life time of the building.

Rearrangement

At the level of rearrangement we can say that the building may be in any one of a set $a_1, \ldots, a_n$ of *states,* for instance theatre, church, exhibition hall, . . . in the case of the community centre.

Rearrangement means the transition from one state a_i to another state a_j, and we only identify those states as different if they require a deliberate rearrangement involving a positive cost b_{ij}, which we shall assume to be constant in time.

It is obvious that the more frequent transitions should be made less costly at the

In Sector, architecture and planning are considered as problem solving activities possessing evolving structures and changing approaches.

expense of the less frequent ones, to a certain extent. This means that the transition costs may be optimum with respect to a certain pattern of use, a vague notion that implies the existence of a somewhat less vague notion, namely that of a probability p_{ij} of the transition from state a_i to state a_j. The relation between the p_{ij}'s and the b_{ij}'s in the case where they are optimally matched was already solved in Shannon's fundamental memoir[1] on information theory. In fact, his theorem I implies that

$$p_{ij} = W^{-b_{ij}} . B_j/B_i \qquad i,j = 1, \ldots, n,$$

We do not need this result if we just want to compare two alternative designs, for instance with transition costs b_{ij} and b_{ij}^{-} respectively. In that case it is only necessary to decide which is the smaller of the average costs where W is the largest number such that the largest eigenvalue of the matrix $(W^{-B_{ij}})$ equals I, and where $(B_1, \ldots, B_n)'$ is the corresponding eigenvector.

$$\sum_i A_i \sum_j p_{ij} B_{ij} \qquad \text{and} \qquad \sum_i A_i \sum_j p_{ij} b_{ij}$$

where $(A_1, \ldots, A_n)'$ is the eigenvector corresponding to the largest eigenvalue of the matrix (p_{ij}). A necessary preliminary for systematic design, however, is that we at least know the relative sizes of costs in the optimal situation for a given set of p_{ij}'s. Systematic design will require a method analogous to the one invented by Huffman[2] for constructing optimal codes in information theory. In that way it will be no mere metaphor to say that the building is a coding of the information generated by the pattern of use.

Alteration

In this paragraph I would like to discuss the limits of the optimization described in the previous paragraph. The interesting thing is that it is apparently possible to optimize in the face of uncertainty with respect to the transitions to be expected. We did not suppose that a schedule valid for the entire useful existence of the community centre was available at the time of its design. Instead of a single schedule, we supposed that any of a number of different schedules were about equally likely, and that these had certain statistical properties in common. These were termed loosely "the pattern of use". It may be shown that, under certain conditions, the statistical regularities are adequately described by the set of transition probabilities p_{ij}.

This is an example of what Wiener considered an idea fundamental to cybernetics. He had in mind a system for the communication of messages. For different messages, the system necessarily performs with different degrees of efficiency. The idea is, that such a system should not be designed for one or another particular message, but for a whole ensemble of messages, where each occurs with a certain probability. Suc is also our aim here: the design should **not** be optimal for one or another particular schedule, but for a certain ensemble of schedules, which we supposed to be generated by the matrix of transition probabilities (p_{ij}).

Rearrangements constitute changes of a routine nature to the building. We should expect that after some years it becomes apparent that the actual pattern of use is n the one assumed during design and that thi may no longer be optimal. At the level of rearrangements, the uncertainty with respe to a particular schedule was coped with by supposing that the actual schedule would b generated by a fixed, and known, pattern use. If this pattern of use is unknown, we have uncertainty at a higher level, which w have called the level of alteration. In order to cope with this, alterations have to be made, that is, changes that go deeper than rearrangements and cannot be provided fo as explicitly in the design.

A possible approach could be to integrate the levels of rearrangement and alteration means of a technique used in implementin *adaptive* or *learning* networks. The followi example may illustrate the principle involved. A telephone exchange may be viewed as a network with many terminals, which are the subscribers' lines. Making a connection requires making a path through this network. There are paths with differen lengths and the more frequent connections should make use of shorter paths. This involves an optimization problem corresponding to our lowest level. Suppose now, that the structure of the network ma change (which is possible in the case of the telephone exchange being worked by a stored-program computer), then it may be programmed in such a way, that the next time a particular connection is made, it is along a path (say) one unit shorter than th previous time. This shortening is at the expense of some other, randomly chosen pair of terminals. The effect of this is that the more frequently used paths are more frequently shortened, and, consequently, t exchange will become automatically more and more efficient until a certain limit has been reached and we can say, in a very real sense, that the exchange has "learned" the pattern of use of its subscribers. Should th pattern change in time, the exchange changes with it. This latter change corresponds to our change at alteration lev

A similar technique in the design of the building would be to integrate the rearrangement and alteration levels, becaus the designer need not know in advance wh pattern of use is to be expected, but would instead provide an adaptive mechanism which ensures that the building will "learn" the pattern of use and adapt itself to chang in it.

[1] C.E. Shannon: The Mathematical Theory of Communication, University of Illinois Press, 194

[2] D.A. Huffman: A method for the construction minimum redundancy codes, W. Jackson (ed.): Communication Theory, Butterworths, 1953.

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