

On the Deduction of Relationship in System Dynamics Modelling

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Abstract

In the construction of any type of model there is the problem of identifying and justifying relationships between variables. For certain types of models the structures of which are well-defined this problem reduces to one of determining the quantifiable aspects of a relationship (for linear programming models this is often the case). However, in the construction of a tailored system model, as with System Dynamics, the problem is two dimensional comprising the aspects of identification as well as quantification. When the system under study originates in an area of research the resolution of the problem is often very difficult if the model-builder is inexperienced. The purpose of the present paper is to demonstrate the resolution of the "problem" by describing an example from the authors own research.

Introduction

System Dynamics models involve the identification of relationships in the systems under study, so that a model is merely (!) a set of "links" between variables or factors. In many cases the identification and justification of particular relationships causes no great problems, as with, for example, the link between a production start rate and production finish rate. However, there are times when one is faced with the problem of identifying the relationships which cause the behaviour of a variable of particular interest, and no simple links appear to exist. "Information" links, rather than "physical" links often cause such problems, as the latter are usually subject to physical conservation considerations. Coyle (1977) lists six basic

methods of justifying the incorporation of particular links into a model:

- (i) Conservation considerations - following the analogous concept of conservation of current flow in an electrical network.
- (ii) Direct observation - modelling an actual decision process rather than the process which should exist.
- (iii) Instructions to that effect - usually used in the testing of particular links for their effect on model behaviour.
- (iv) Accepted theory - use of theory from some related discipline to guide the model-building process.
- (v) Hypothesis, assumption or belief - only used when there is no "hard" evidence concerning the existence of a link.
- (vi) Statistical Evidence - used to infer caused relationships from advanced statistical methods.

In practice the model builder uses such methods not only to justify given links but to identify the links initially, and usually it is a combination of these methods together with the model-builder's experience which prevail.

Even though it is possible to list methods which can be used to identify or justify a relationship, there are situations where an analyst may find that the identification problem is extensive. This is likely to occur in the modelling of "new" systems where the structure of the model is entirely dependent upon the modelling skill and ingenuity of the analyst, or researcher. This present paper describes the way in which the author tackled a particular identification problem and, whilst being in no way definitive on the subject, it is an example of the way that such problems may be resolved.

#### Background to the Problem

The area in which "the problem" originates is that of dynamic modelling of world shipping freight markets. Briefly, the overall objective of the work is to construct a system dynamic's model of world freight market so as to explain the observed functions in factors such as freight rates, orders for new ships, laid-up tonnage and chartering behaviour. For more details see Taylor ((1976) (i)).

During the model-building process it was found that, second to the demand for cargo capacity, the driving force in the system is the level of freight rates. Since the freight rate provides income it is to be expected that it would be a major factor in system behaviour. The relationships between freight rates and the various factors which are determined by the freight rates had been identified and modelled, but the relationship between the freight rate itself and its own driving force were unknown. This then was "the problem" - the task of determining a relationship which could be used to explain the variation in freight rates. A major constraint on the resolution of the problem was that most of the data or information to be used in the relationship must be generated within the overall model of the system. The exception to this is the "demand" for cargo carrying capacity and this is an exogenous input.

In the model, as in the real system, there are basically two freight rates to consider - one appertaining to the tanker market and one to the dry cargo market. There are, in fact, many freight rates in each of these markets, depending upon the exact route and ship size. However, since it is found that within each of these market sectors all freight rates are sympathetically linked - a depressed freight rate on one route usually produces a depression of rates on other routes - then all that is required for an indication of general freight rate behaviour is that one single freight rate be considered. "The problem", may now be seen to comprise two parts - the identification of relationships for the tanker market and the dry cargo market.

#### Resolution of the Problem

It has been argued by the author (See Taylor (1976 (ii))) that there exists a relationship between the degree of competition in the market and the level of freight rates. Sturmeay (1965) argues likewise and with a somewhat deficient demand/supply indicator, calculated by dividing "World Seaborne Trade" in Dry Cargo (Million metric tons) by "World Non-Tanker Tonnage" (in gross tons), excluding the U.S. Reserve Fleet, he shows that, generally, rising values of the indicator (that is, falling competition between shipowner) are associated with rising dry cargo freight rates).

In the context of the present work this analysis is useful in verifying the overall macro-behaviour which one would expect from economic theory. However, it does no more than that, and for the purposes for which a relationship be being sought it is not suitable for inclusion in the formulation of a market-model. A usable mechanism for the formation of spot charter rates must be obtained from other sources.

The concept of "competition" is very valuable and useful but it is also difficult to measure. Should one use a ratio of demand to supply? If so, there is the problem of obtaining historical data on demand and the simultaneous level of supply. In shipping the available statistics on "demand" turn out to be statistics on what has been "supplied", and the data is usually on such an aggregated level that it is useless for the identification of a "competition" indicator.

Since demand itself is not directly measurable then the next step is to consider the existence and importance of some proxy variable - some factor which is a reflection or manifestation of demand and its variations. At any given time it is possible to consider the existence of instantaneous levels of shipping supply and demand. To one extent or another the long term supply of tonnage usually exceeds the demand, the difference between the two constituting the "spot market" - that is, the tonnage of shipping which is available for immediate chartering. It is to be expected that, as this tonnage left over after chartering depends upon both the demand for tonnage and the supply of tonnage, then it would seem reasonable that there would be a relationship between the spot market tonnage and the spot freight rate. Since the absolute supply of spot market tonnage will vary not only with the dynamic behaviour of the system but also in line with long term trends in ship-building, a more appropriate measure of supply on the spot market is the ratio of absolute supply (in deadweight tons) to total fleet tonnage (in deadweight tons). Thus, the relationship between this spot market proportion and the value of the spot freight rate may be analysed, if data is available. If such a relationship does exist - and if it is a fairly clear-cut relationship - then it should provide a method for determining, within the model of the system, the value of the spot rate.

For the tanker market it is possible to derive data on the amount of tonnage on the spot market and on voyage charters - not separately but in a single figure. This is the only data which can be determined from published statistics. Hence, the comparison, graphically, of the joint variation in spot market freight rates and the relative proportion of "spot" and "voyage" tonnage is possible. Figure 1 shows the available empirical evidence for such a relationship using the tanker freight rate (in "worldscale" - an indexed value based on the actual transportation costs of a given cargo of crude oil over a particular route) for the route Persian Gulf - West for tankers in the range 40,000 - 99,999 dwt. It can be seen that a clear relationship does exist between the two parameters, conforming to the theoretical pattern expected from economic theory, the non-linearity of the relationship being characteristic of economic behaviour in competitive markets.

Thus for the purposes of the work of modelling the freight markets we can re-define the spot market as comprising not only tonnage available for immediate charters but also that tonnage which is currently on voyage charters, and it is possible to relate the value of the spot market freight rate to the available tonnage, which can be computed within the model.

One further point concerning the relationship above may usefully be considered; this is the position of the "turning point" on the curve of Figure 1. The location of this point is seen to be at a value of approximately 10% on the spot market supply scale. Above this point the relationship is relatively inelastic so that the freight rate is not very sensitive to small changes in the supply of tonnage. On the other side of the turning point, however, the relationship is very elastic, a small change in supply producing relatively large changes in the freight rate. The positioning of this turning point is thus very important and it is necessary that the relationship used to "model" the real system does not incorporate an incorrect data point. It is an accepted belief in the tanker market that, generally, the "normal" fraction of the fact on the spot market is in the region of ten percent, coinciding with the normal freight rate of worldscale 100. This is confirmation that the relationship as shown in Figure 1 is acceptable for use as an indicator of freight rate behaviour.

As a summary of the process undertaken in obtaining the required relationship for the tanker market we have:

- (i) A theoretically expected pattern
- (ii) the testing of a possible relationship of hypothesis using available data.
- (iii) confirmation of the hypothesis with respect to the form of the relationship.
- (iv) confirmation of the positioning of the empirical curve from the accepted belief of those involved with the "real" system.

We can never be one-hundred percent sure about the "correctness" of the derived relationship but, as with the problem of validating any model, if the inductive/ deductive processes are correct then this lends credibility to the results of an analysis. Notice that point (iv) in the process as summarised could, in isolation, be very misleading - "beliefs" are not particularly strong foundations for quantitative models - but when it becomes additional information in the identification process then it becomes very useful.

Up to this point the identification of a satisfactory relationship (for the tanker market) has involved a procedure which is, more or less, what we can call the "scientific method". If it were not for the lack of data the same procedure could be applied to the dry cargo market. However, no statistical data exists for the examination of the supply vs. freight rate relationship in this market, and we have to use other information in order to estimate the form of the relationship, if such a relationship does exist. Knowledge of the overall system is invaluable here and it is possible to use both the similarities of the tanker and dry cargo markets, and their dissimilarities. With respect to the former two pieces of information are useful; firstly, the dry cargo bulk market is continually moving closer and closer toward the tanker market, with the use of large vessels, large cargoes and long routes. An increasing proportion of dry bulk cargo is carried by vessels operating in consortiums or by private merchant owners, the total tonnage in this form of use being analogous to the tanker tonnage owned by the oil companies. A decreasing amount of dry cargo bulk tonnage is operating on the "spot market", moving this market sector closer to the tanker sector in terms of structure and behaviour. All of this indicates that the two markets are sufficiently similar to allow us to conclude that empirical evidence of a particular aspect of

behaviour in one market should be a good indicator of the empirical evidence which should be expected from the other market. Thus, we should expect that the relationship between spot market supply and freight rate for the dry cargo market would be of the same form as that found in the tanker market. Having argued that the form of the relationship is now known, the second piece of information can be used to indicate the position of the "turning point" from elasticity to inelasticity. This is, that there is approximately twenty percent of the dry cargo bulk fleet in the spot market at any time. If this is taken as the "normal" fraction then it can be used to position the turning-point.

Looking now to the differences between the two markets it is possible to "shed more light" on the form of the relationship. The major difference between the two markets lies in the mix of vessels and routes in the markets. The large number of routes and the wide range of vessel sizes in dry cargo leads to a market which, in general, is much less sensitive to changes in supply than the tanker market. Hence it would be expected that the tanker relationship would exhibit greater elasticity below the turning-point. This provides further assistance in estimating the shape of the dry cargo relationship.

The approximations to the tanker and dry cargo spot-market supply versus freight index curves, as used in the model, are shown in Figures 2 and 3 respectively.

#### Conclusion

The determination of relationships can sometimes appear to be difficult, if not impossible. This is particularly true for those cases where empirical data is virtually non-existent, and is totally insufficient for the testing of hypotheses. However, as this paper has shown it is often possible to deduce the form of a relationship, as well as its existence. Other, quantitative, aspects of the relationship are sometimes available when the analyst has a good knowledge of the system, enabling use to be made of information, which, in isolation, would not normally be considered as very important, or even reliable.



#### Acknowledgements

The author wishes to thank Dr. R.G. Coyle at whose suggestion the present paper has been written.

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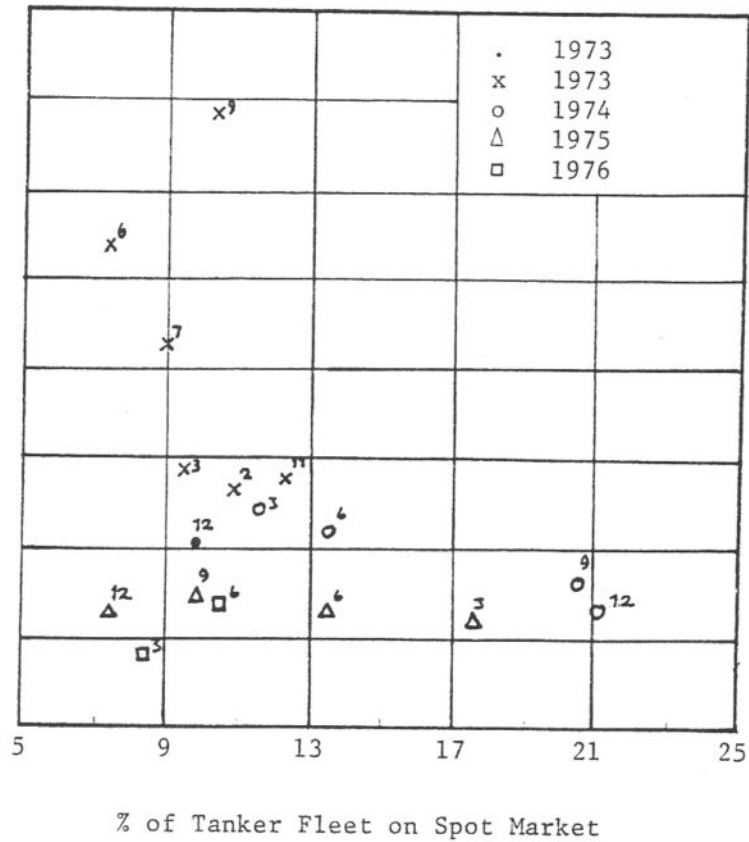


Figure 1: Effect of Spot Market Supply on Freight Index - Tanker Market.

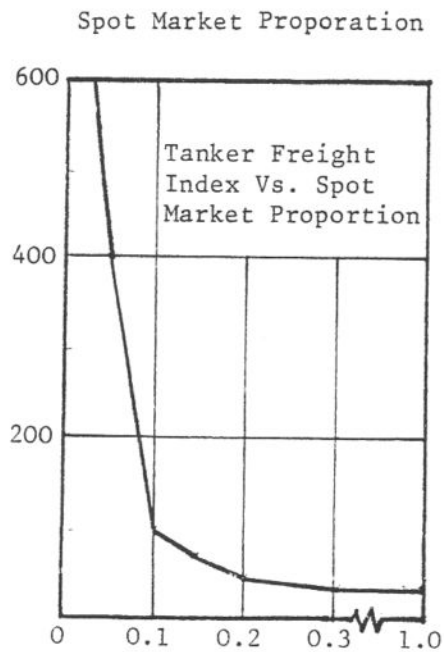


Figure 2

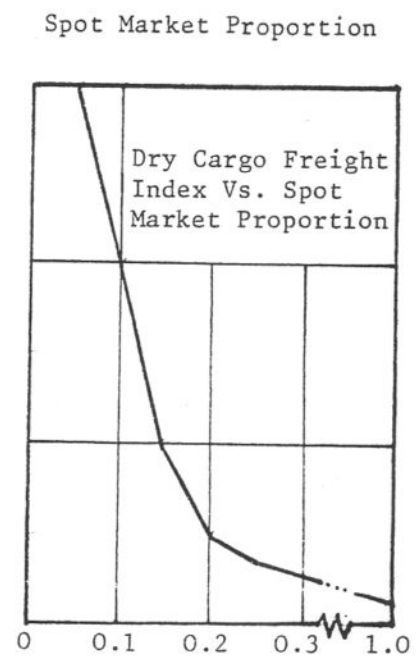


Figure 3