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This paper is adapted from the master's thesis of the third author completed under the direction of the first and second authors and submitted to the Department of Civil Engineering, Indian Institute of Technology, Kanpur, India. The second author prepared a paper entitled "Attractiveness of bus systems: An application of information integration theory" out of the thesis and presented at the International Conference on Transportation held at New Delhi, November 26-28, 1980. The present version was prepared by the first two authors in line with the suggestions of the reviewers. The authors are grateful to Professor N.K. Jaiswal for his encouragement and keen interest in this work. Preparation of this paper was facilitated by the Research and Publication fund of the Indian Institute of Management, Ahmedabad.

Abstract

Actual bus riders received information about frequency of service, fare, and comfort aspects of some bus systems and indicated how much they would like to travel in those buses. Information integration theory, which deals with multiple causation, was used to prepare descriptions of the bus systems. Analyses of the attractiveness judgments disclosed that the three attributes of the bus systems were integrated by a multiplying rule. Functional measurement of the subjective values of the three attributes did not correspond with their known physical values. Implications of these findings were discussed for transportation planning and for further research.

1. INTRODUCTION

The present research applied information integration theory to judgments of attractiveness of bus systems. Actual bus riders received information about fare, frequency of service, and comfort aspects of several buses, and indicated how much they would like to travel in those buses. The principal point of interest centered around the <u>integration rule</u>, that is, how the three pieces of information are combined in the evaluation of overall attractiveness of a bus system.

According to information integration theory (e.g., [1], [2]), much of the human judgment obeys the laws of algebra. Contingent upon the nature of judgment as well as stimuli entering into it, people follow adding, subtracting, multiplying, and dividing rules. Evidence for such algebraic integration rules has been found in so many experiments performed in diverse areas (e.g., [5]) that the concept of cognitive algebra provides a powerful, general framework for the study of any judgment. As choice of transportation mode requires an integration of several pieces of information, for example, cost, time, comfort, distance, etc, it may very easily be analyzed within the framework of integration theory.

Some recent studies have, in fact, shown that the attributes of bus transportation are coordinated according to algebraic rules. For example, Norman and Louviere ([13]) presented information about fare, frequency of service, and proximity to the bus stop to college students, and asked them to estimate their certainty as to whether one would take or would not take a bus with the characteristics given. The factorial plots of all the three two-way interactions, Fare x Frequency, Fare x Proximity, and Frequency x Proximity, from the three-way design, Fare x Frequency x Proximity, yielded linear fan patterns. By the logic of functional measurement (e.g., [3], [4]), the linear fan patterns were interpreted as signs of a multiplying rule.

In a second study, Norman([12])obtained judgments of bus descriptions prepared according to four independent three-way factorial designs — Fare x Walking Distance x Number of stops, Fare x Walking Distance x Time in Service, Fare x Number of Stops x Time in Service, and Walking Distance x Number of Stops x Time in Service. Support for the multiplying rule in this study was not as strong as in the earlier one ([13]). However, the factorial plots of the two-way interactions showed discrepancy from parallelism predicted by an adding-type rule. The author felt reasonable to conclude, therefore, that attributes in bus transportation are indeed combined by a multiplying process.

But the linear fan pattern is not unique to the multiplying rule. This pattern can also be produced by a conjunctive averaging rule with differential weighting (e.g., [1], [2]). If lower values of one factor and/or of another factor had greater weight, then the averaging rule would engender an approximate linear fan shape ([16]).

The main goal of the present research was to make distinguishing tests between multiplying and conjunctive averaging rules. A test between the two rules can be made by asking for judgments based on just one piece of information. If the multiplying rule operates, then judges will infer some value for the missing information and multiply it with the supplied information. Accordingly, the curve based on one piece of information will form part of the linear fan pattern. But if the averaging rule is used, then the curve based on one piece of information will cross over at least one of the curves based on two or more pieces of information (e.g., [8], [10], [15]). No such test was used by Norman and Louviere([13])or by Norman([12]).

The experiments reported here differed from the existing ones in two other respects. First, the factor of comfort was manipulated consistent with an Indian value for aram ([17]). Second, the subjects (respondents) were actual bus riders instead of the most easily available and often used college students. Also, the subjects differed in their annual income. This yielded greater generality of the results.

2. METHOD

2.1 Experiment 1

Stimuli and designs. The main stimulus design was a 3x3x3, Fare x Frequency of Service x Comfort, factorial that yielded descriptions of 27 three-characteristic bus systems. The three levels of fare were 50 paise, Rupee 1, and Rupee 1 and 50 Paise. The three levels of frequency of service were 15 minutes, 30 minutes, and 60 minutes. The comfort of the stimulus bus was defined by its seating arrangements, crowding, number of standing persons allowed, etc. The three levels of comfort were described by three verbal labels of not at all comfortable, okay, and very comfortable.

There were three two-factor designs also: Fare x Frequency, Fare x Comfort, and Frequency x Comfort. The levels of the two factors of each design were the same as in the main three-factor design. Each design produced nine two-characteristic buses, and so there were 27 two-characteristic bus systems.

There were nine one-characteristic buses also. Three were based on one of the three levels of fare; three were based on one of the three levels of frequency of service; the remaining three were based on one of the three levels of comfort factor.

In addition, there were four three-characteristic, six two-characteristic, and six one-characteristic filler bus systems. They had information more extreme than the regular levels of the three factors. These extreme stimuli were intended to serve as end anchors. This precaution was taken to ensure that data for model testing come from the interior of the response scale([1]).

Twelve practice examples were also constructed. Of the 12 practice examples, four had 3 characteristics, four had 2 characteristics, and the remaining four had just one characteristic. These practice examples were intended to enable the subjects develop a uniform scale and to orient them toward the use of the entire scale of judgment ([5]).

Description of each bus system was typed on separate index card, and the cards were presented to each subject in different shuffled orders.

Response scale. A graphic rating scale was used to measure the subject's attraction toward each bus system. This scale contained a series of 31 holes, .5 cm in diameter and spaced 1 cm apart on a 4 cm wide wooden bar. The extreme left hole was labeled LOW and the extreme right hole was labeled HIGH on the subject's side. These holes had digits, 1-31, written on the experiment's side. The subject indicated his liking for a bus system by inserting a pointer in the appropriate hole. The number assigned to those 31 holes were treated as rating scores.

Subjects. The subjects consisted of 24 male adults. They all were bus users, and were employed at the Indian Institute of Technology, Kanpur, India. Twelve subjects had monthly income below Rs. 500/-; the other twelve subjects had monthly income around Rs. 1,000/-. These subjects were selected according to their income, and were approached by the experimenter for study. Each subject spent approximately 2 hours on the experimental task.

Procedure. Each subject was run individually in a small room of a student hall of residence. The task was introduced as dealing with judgments of attractiveness of several bus systems which were likely to be operated by a private travel company for the campus community. It was emphasized that some bus systems would be described by three characteristics, some by two characteristics, and some by only one characteristic. The subject was instructed to base his liking for each system only on the information given about it. He was asked to render his liking judgments along the wooden bar put in front of him.

After instructions, the experimenter gave 12 practice examples described earlier to each subject. The subjects who were good in English received the typed cards and rated them one by one. Subjects who were not good in English were read the Hindi translation of the information typed on each card by the experimenter. The subject was asked to form an opinion of each bus system and to indicate how much he would like to travel in that bus. During the practice, the experimenter ensured that the subject understood the task, and that he learned the use of the entire judgment scale. Any misunderstandings resulted in the subject being given further instructions and practice.

After practice session, the experimental stimuli along with the filler ones were presented to each subject twice in different shuffled orders. Information on each card was presented in two different sequences in order to avoid any effect of order of presentation of information. The two orders of presentation were balanced over equal number of subjects of each income group. Data from both replications of the designs were analyzed.

Once the subject rated all the stimuli twice, the experiment was terminated. The experimenter thanked the subject for his cooperation, and answered all the querries by the subject.

2, Experiment 2

Experiment 2 was conducted as a reliability check on the results of Experiment 1. Experimental designs, instructions, procedures, etc., therefore, remained similar to those of Experiment 1. However, each subject rated the stimuli thrice which permitted a more sensitive test of the model. Subjects were twenty-four male adults from the same population as in Experiment 1.

3. RESULTS

3.1. Graphic Analyses

Figure 1 shows two-way graphs for Frequency of Service x Fare, Fare x Comfort, and Comfort x Frequency of Service effects from the main three-characteristic design of Experiment 1. In each graph, the levels of the factor listed on the horizontal axis are spaced according to their marginal means of the factorial design. This spacing allows the linear fan pattern to appear. If the three attributes were integrated in accord with the multiplying rule, then the three-solid curves of each graph should exhibit nonparallelism. More specifically, the graphs of the left side and right side should show convergence, whereas the graph of the center should show divergence. Also, the dashed curve (NS) which is based on only the factor listed on the horizontal axis should form part of the nonparallel converging or diverging family of curves.

Figure 1 about here

Figure 1 indicates that all the three graphs are not consistent with the requirements of the multiplying rule. The graph in the left side exhibits near-parallelism instead of the predicted convergence. Perhaps information about frequency of service and fare were integrated by an adding-type rule. The other two graphs have nonparallelism of the forms specified by the multiplying rule.

It seems that subjects followed the compound adding-multiplying model in evaluation of bus systems.

Figure 2 presents graphs for data obtained in Experiment 2 whic required each subject to rate the stimuli thrice. With this slight change in method, nonparallelism in graph for Frequency of Service x Fare effect seems to have been obtained. The other two graphs have substantial nonparallelism just as in Figure 1.

<u>Figure 2 about here</u>

As the dashed curve of each panel forms part of the family of nonparallel curves, the obtained nonparallelism confirms the multiplying rule but infirms the conjunctive averaging rule. The conjunctive averaging rule requires the solid curves to be nonparallel as they in fact are. But it requires the dashed curve to cross over at least one of the three solid curves (e.g., [8], [10], [15]). Since this did not happen, the conjunctive averaging can be ruled out an alternative interpretation for the obtained nonparallelism in Figures 1 and 2.

2. <u>Statistical Analyses</u>

The linear fan pattern means that the interaction term in analysis of variance is statistically significant. Furthermore, the entire interaction effect resides in just the Linear x Linear trend (e.g., [3], [4]).

In Experiment 1, tests[1] of interaction with *df* of 4 and 92 yielded *F* ratio of 1.47, 7.20, and 3.10 for Frequency of Service x Fare, Fare x Comfort, and Comfort x Frequency of Service effects, respectively. As expected, the first interaction term was non-significant, but the other two were statistically significant ($p < .05$).

In Experiment 2, all the three interaction terms yielded statistically significant *F* ratios. And the Frequency of Service x Fare, Fare x Comfort, and Comfort x Frequency of Service effects had all concentrated in only Linear x Linear trend, *F* (1, 92) = 4.76, 18.20, and 8.18 in order. The respective *F* for the residual of the three effects were 1.87, 0.50, and 0.55 with *df* of 3 and 92, and they all failed to reach the acceptable level of statistical significance. These results from analysis of variance tests provide quantitative support for the linear fan patterns evident in the three graphs of Figure 2.

.3. Functional Scale Values

Success of the multiplying model allows the application of functional measurement to estimate the subjective values of the

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[1] When repeated measurements are taken on the same group of subjects, the subjects are treated as a crossed random variable in analysis of variance. This allows separate estimates of error term for each of the sources of variance. Each treatment source is tested against its corresponding error term. All the F ratios reported in this paper were calculated according to this model of analysis of variance. For details, see Anderson ([5]) and Winer([18]).

three types of information used in this study. These estimates, which are simply the marginal means of the factorial design (e.g., [3], [4]), are on validated linear (equal-interval) scales.

The estimated scale value for the three levels of fare, comfort, and frequency of service factors are shown on horizontal axis of Figures 1 and 2. In the left graph, the levels of fare are spaced according to their subjective, psychological values. It is obvious that the difference between 50 paise and Rupee 1 is much larger than that between Rupee 1 and Rupee-1-and-50-paise. Along the comfort dimension shown in the center graph, okay seems to be much closer to very comfortable level than the expected neutral point. The right graph shows subjective values for time intervals. The difference between half an hour and one hour is psychologically not much different from the difference between 15 minutes and 30 minutes. All these estimates of subjective values do not correspond with their known physical values of the stimuli. This result is of direct practical relevance, for it shows that planning of transportation cannot be made just by knowing physical values of the attributes of a system. It is important to know how the attributes are perceived by the riders, and information integration approach allows functional scaling of personal values within the framework of a general model.

The usefulness of these functional scale values may be illustrated by using them to predict the responses in the 9 cells of each of the two-way interaction table (i.e., the nine points of each of the three graphs of Figure 2). If the multiplying rule is correct, as has been claimed here, then each predicted response equals the product of the corresponding row and column means divided by the grand mean ([7]). The mean obsolute deviations between predicted and observed responses were 0.26, 0.13, and 0.12 for Frequency of Service x Fare, Fare x Comfort, and Comfort x Frequency of Service two-way interactions, respectively. These deviations are negligible along the 31-point scale. It can thus be concluded that multiplying model provides a reasonably good account for the data of Experiment 2.

3.4. Other Results

Two other results also deserve mention. First, the income level of the subjects interacted with the comfort factor in Experiment 1 but not in Experiment 2. No reliable effect of income factor on attractiveness of bus systems was thus found. Second, all the two-characteristic bus systems were judged according to an adding-type rule. None of the three two-factor designs obtained statistically significant interaction term. This suggests that the multiplying rule is invoked in attractiveness judgments of only complex bus systems.

4. DISCUSSION

4.1. Multiplying Model

The principal finding of the present research is that attractiveness of complex bus systems obeys a multiplying rule. Support for multiplying process was unambiguous in Experiment 2. The failure to yield multiplying operation between frequency of service and fare in Experiment 1 was perhaps because of the lower statistical sensitivity. It should be noted that Experiment 1 required the subjects to judge the stimuli only twice, where as Experiment 2 required three judgments of the stimuli.

Evidence for multiplying process may not be considered as novel, for Norman and Louviere ([13])and Norman ([12]) also obtained it. What is novel and important about the present research is that it employed distinguishing tests (e.g., [8], [10], [15])between multiplying and conjunctive averaging models, and that these tests confirmed the multiplying rule but infirmed the alternative conjunctive averaging rule. These results thus put the multiplying rule on a more solid ground than did the extant literature. In addition, the present research extended the generality of multiplying model to a general population of bus riders and to a new informational dimension of <u>comfort</u> valued highly in India ([17]).

According to the multiplying model, if one attribute of a bus system is undesirable (i.e., closer to subjective value of zero), then it would completely nullify the impact of other positive attributes. On the contrary, a desirable attribute would compensate considerably for different attributes of low value. This has one practical implication for transportation planning. To make a system attractive, no salient attribute should be of zero value. As long as the system has all positive attributes, a strong attribute can always be expected to compensate for the weak ones. For example, a very expensive bus may not engender aversion if it is fairly comfortable and it can be available even after half an hour.

Measurement of Subjective Values

Findings of the two experiments show the utility of functional measurement of subjective values of bus attributes. Undoubtedly people vary in their value for different attributes, and so we must know how they perceive the various attributes. Results related to estimates of time, confort, and money clearly showed the utility of this approach. The finding that subjective values of the three stimuli did not exactly conform with their known objective values suggests that any good prediction about travel decision has to consider psychological values of the system users. Functional measurement allows such estimations.

It should be mentioned that much of the research performed on transportation planning has relied on the typical procedure to fit a linear function to the existing data and then extrapolate across changes in the predictors ([6]). This approach deals with correlations between variables and not with causal relationships. Furthermore, the often used technique of regression analyses assumes that values of the predictors are known and fixed contrary to what the present research shows.

Information integration theory emphasizes the causal determinants of transportation planning. It provides powerful tools for analysis and synthesis of problems in multiple causation. It may, therefore, be considered as much better approach to transportation planning than the traditional correlation-regression approach (e.g., [6], [11]).

3. Further Work

These experiments are only a beginning. Numerous stimulus variable remain to be studied. These include distance travelled, time required to complete journey, purpose of journey, and the various transportation modes available to the travellors. These and other variables can also be studied by applying the methods of information integration theory as illustrated here.

One finding of the present work deserves further work. While the three-characteristic bus systems were judged in accord with a multiplying rule, the two-characteristic systems were judged by an adding-type rule. This result was present in both Experiments 1 and 2; hence it can be adjudged as reliable. One simple interpretation of this discrepancy between two- and three-attribute systems would be that multiplying rule is employed in rating of only complex systems. Nevertheless, it is clear that integration rule changes as a function of task complexity. Psychologists interested in testing and developing integration theory have not paid attention to this aspect, and the present results call their attention to this aspect.

1.4. Concluding Comments

To the authors, information integration theory is impressive because it provides a useful framework for cross-sectional studies of perception of transportation systems. An important advantage with the integration rule is that it deal with patterns of responses, not with the numerical value of single responses. This aspect is vital for studying transportation choices of people of different sections, from school-going children to foreign tourists. No a priori knowledge of value of different attributes of the system or origin and unit of subjective scales is required. Different sections of riders can easily be compared with respect to the pattern in their preferences for transportation systems prepared according to factorial design.

Search for integration rule allows comparison between groups along two other criteria -- information utilization and information weighting. The former indicates how many attributes are used by the riders in making evaluation of a transportation system; the latter indicates how the used attributes are assigned importance. As information integration theory provides estimates for both information utilization and weighting at individual level as well as at group level of subjects, it can be of great use to transportation planners who have long been interested in the factors of mode choice in order to predict ridership (e.g., [9], [14]).

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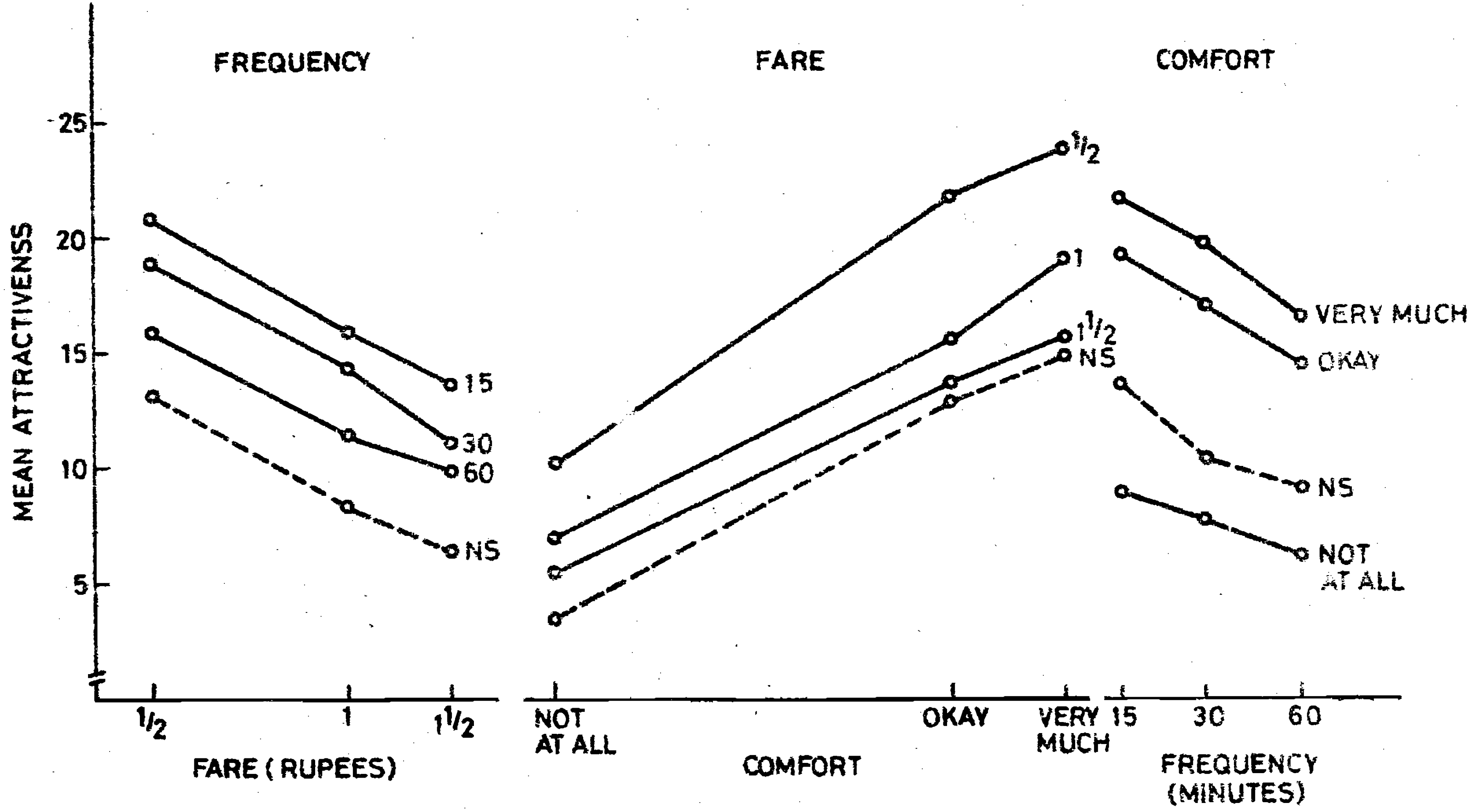
Figure Captions

Figure 1. Two-way plots of Frequency of Service x Fare, Fare x Comfort, and Comfort x Frequency of Service effects from the main three-characteristic, Frequency of Service x Fare x Comfort factorial design, Experiment 1. The three factors listed on the horizontal axis are spaced according to their functional scale values. The dashed curve is based on only the factor listed on the horizontal axis; the curve factor was not specified (NS).

Figure 2. Two-way plots of Frequency of Service x Fare, Fare x Comfort, and Comfort x Frequency of Service effects from the main three-characteristic design, Experiment 2.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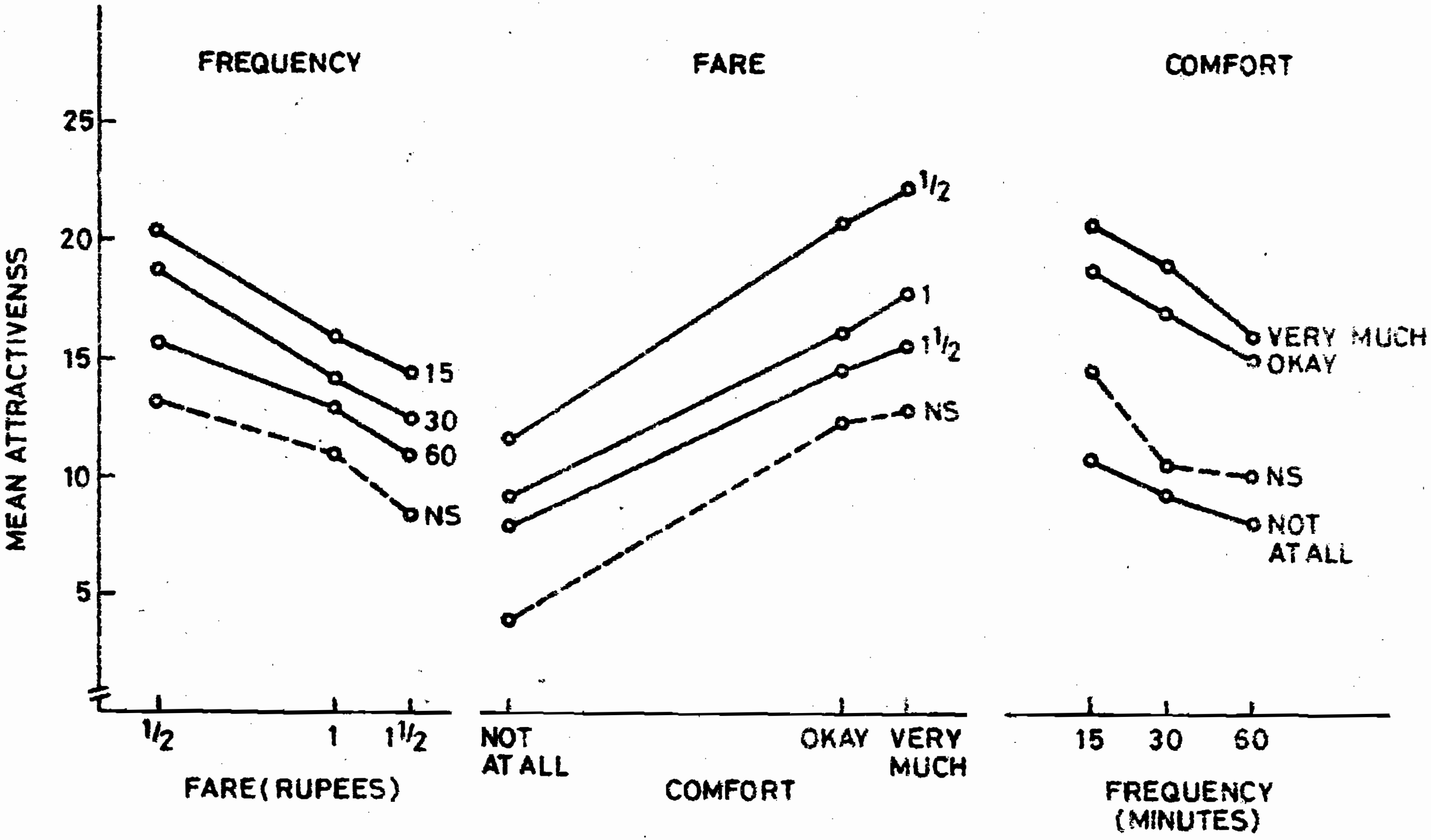
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