

Methodologies for Constraints Analysis

Sanjay Kumar Gupta¹, Sudeep Gorai², Manjeet Singh Nain³

^{1&2} Research Scholars, ³ Principal Scientist, Division of Agricultural Extension, ICAR- IARI, New Delhi-110012

ARTICLE INFO

Keywords: Constraint analysis, Garrett's ranking, Rank based quotient, Value based index, AHP, Delphi

ABSTRACT

Constraint analysis research pertains to identification and quantification of factors responsible for lack of technology adoption and performance. The most common methodologies for constraint analysis includes; Garrett's ranking technique, Rank Based Quotient (RBQ) Followed By Value Based Index (VBI), Weighted Mean, Delphi methodology, Pair wise Comparison, AHP, fuzzy analytic hierarchy, Kruskal-Wallis H Test, Friedman Test, Post Hoc Tests etc. The paper tries to discuss major data requirements, assumptions, formulae used, application of tests and interpretation of results of various methods so that the researchers can choose the best option available according to data set.

Introduction

Defining the right problems for research is crucial. This can be done in a number of ways, but an obvious approach is to involve the technology users and government officials. They are the ones who come across these problems in the course of their daily work, and often have developed very good diagnostic insights. It is far better to build on the judgments of the users than to rely solely on the judgments of the researchers themselves. Nevertheless, even where users have concrete ideas about the problems they are facing, various methodologies for constraint analysis may help to elucidate further problems, and may put problems in perspective. The developments of new agricultural technologies do not yield benefits by itself rather they are required to be transferred to the farmers' field for their effective adoption by the farmers. In the past, improved technologies were developed at a fast pace, but, the adoption of technologies occurred at desired pace only in case of some regions and crops. There have been some constraints in the adoption of technology in other regions and crops. A pressing need arises to probe into the factors responsible for lack of technology adoption and performance in one region, crop

and farmer than the others. An enquiry into these factors leads to constraint analysis research. For such research several methodologies can be used to find out the most important constraints. Constraint analysis research pertains to identification and quantification of factors responsible for lack of technology adoption and performance and removal of these bottlenecks including reference to technology refinement" (Reddy, 2017). The findings of such research have many implications for research to modify technology so as to reduce gaps. There are wide range of factors influencing adoption and performance of new technologies at the farmers' field (Kumar et al 2010). These have been already categorized and discussed in the field of agriculture by using several methodologies by many researchers.

According to business dictionary constraints means; element, factor, or subsystem that works as a bottleneck. It restricts an entity, project, or system (such as a manufacturing or decision making process) from achieving its potential (or higher level of output) with reference to its goal. Common Constraints seen in agriculture includes; Environmental constraints, Physical and biological constraints, Constraints in Diagnostic research,

^{*}Corresponding author.

E-mail address: sanjay.gupta526@gmail.com (Sanjay Kumar Gupta)

Received 20-10-2020; Accepted 19-11-2020

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Constraints due to Yield gap, Socio-organization constraints, Techno-economic constraints, Extension gap, Technology deficiencies, Whole-farm constraint, Non-transferable component of technology, Socio-political constraints, Socio-psychological constraints, Administrative and policy constraints, etc. (Soam, (2004), Ohnishi *et al* (2006), Kumar *et al* (2010), Omar *et al* (2012), John (2014),) Reddy & Reddy (2010), Radionovs & Užga-Rebrovs (2017), Rebollo *et al* (2018))

Methodologies For Constraints Analysis

The most common methodologies for constraint analysis are:

Garrett's ranking technique: To find out the most significant factor which influences the respondent, Garrett's ranking technique was used. As per this method, respondents have been asked to assign the rank for all factors and the outcome of such ranking have been converted into score value with the help of the following formula:

$$\text{Percent position} = \frac{100 (R_{ij} - 0.5)}{N_j}$$

Where

R_{ij} = Rank given for the i th variable by j th respondents,

N_j = Number of variable ranked by j th respondents

With the help of Garrett's table, the percent position estimated is converted into scores. Then for each factor, the scores of each individual are added and then total value of scores and mean values of score is calculated. The factors having highest mean value is considered to be the most important factor.

Rank Based Quotient (RBQ) Followed by Value Based Index (VBI): The constraints based on the information obtained from the respondents can be ranked, the data can be quantified and the rank based quotient (RBQ) can be calculated. The order of merit assigned by the respondents was converted into scores using the formula:

$$\text{RBQ} = \frac{\sum f_i (n + 1 - i)}{N \times n} \times 100$$

Where,

f_i = Frequency of farmers for the i th rank of the attribute, N = No. of farmers contacted for factor identification, n = Maximum no. of ranks given for various factors, i = Rank of the attributes

To infer about the real needs of farming community in integrated agricultural system, Participatory Rural Appraisal (PRA) was conducted in Rampur village of Patna situated at southern Bihar in the sub humid region of eastern India (Mukharjee (2016). The Ranked Based Quotient (RBQ) was calculated followed by Value Based Indicator (VBI) to find out the ranking of the problems in that area. The problems based on the infor-

mation obtained from the farmers were ranked, the data were quantified and the rank based quotient (RBQ) was calculated. Preferential ranking technique, utilised in the present study, provides the scope of constraint analyses through participatory approach. Unlike simple ranking technique, this technique takes into consideration the average affected area as well as percentage of economic loss caused by the constraints as perceived by the farmers to prioritize the constraints on the basis of overall magnitude value (Sabarathnam, 1998). After interrogating selected farmers, several problems were identified and among them nine problems were selected based upon sensitivity and severity. Paired comparison technique was used to rank the problems as it is easy for the farmers to compare fairly between two problems at a time. The extent of damage (per acre/animal) and average monetary losses of the village were calculated for each problem. Frequencies of each rank for a problem were calculated and tabulated in rank frequency table after that RBQ was calculated. The magnitude of the problem associated with the village was estimated through Value Based Index (VBI) using following formulae:

$$\text{VBI} = \frac{\text{RBQ} \times \text{Av. loss experienced} \times \text{Area of crops}}{\text{No. of Animal}} \times 100$$

Pair wise Comparison And AHP: Pair wise comparison and the analytic hierarchy process (AHP) came out of Wharton business school in the 1970s. The AHP methodology was proposed by T.L. Saaty in 1977. It is a way to break down complex decisions into a series of small judgments – this helps eliminate bias and moves us from unreliable “intuition” towards more rational decisions. It elicits weights of criteria and alternatives through ratio judgments of relative importance. Finally the preference for each alternative can be derived. The steps to be followed will include; defining the problem, structuring the elements in criterion, alternative etc., making pair wise comparisons of elements in each group, calculating weight and consistency ration and evaluating the alternatives according to weights.

FAHP (fuzzy analytic hierarchy process) by using geometric mean: Continuing with same example: after the creation of pair wise matrix and scale of relative importance.

I) **Fuzzification:** Converting linguistic term into membership function (shown in the below fig. 1 in triangular form, it can be in other form).

II) **Scale of relative importance:** Pair wise comparison matrix is created with the help of scale of relative importance (Saaty scale, 1977) as below:

- 1-Equal importance
- 3-moderate importance
- 5-strong importance
- 7-very strong importance
- 9-extreme importance
- 2,4,6-intermediate value
- 1/3, 1/5, 1/7, 1/9- values for inverse comparison

$$\mu_{\tilde{A}}(x) = \tilde{A} = (1, 2, 3)$$

↑
Fuzzy Number

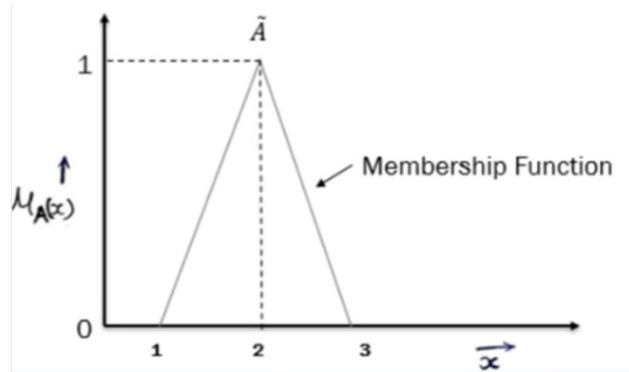


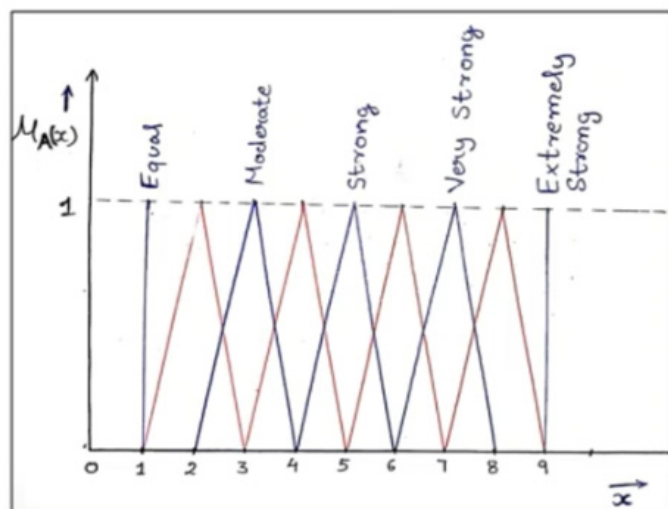
Figure 1. Fuzification process

Converted into fuzzy scale of relative importance by using membership function:

Fuzzy Scale of relative importance

Equal	(1, 1, 1)
Moderate	(2, 3, 4)
Strong	(4, 5, 6)
Very strong	(6, 7, 8)
Extremely strong	(9, 9, 9)
Intermediate values	(1, 2, 3)
	(3, 4, 5)
	(5, 6, 7)
	(7, 8, 9)

Membership function of fuzzy number:



Moderate	Intermediate of moderate and strong
(3)	(4)

Example: Buckley (1985): Geometric mean is used to calculate the weights:

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n)^{-1}$$

$$\begin{aligned} \tilde{A}_1 \oplus \tilde{A}_2 &= (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) \\ &= (l_1 + l_2, m_1 + m_2, u_1 + u_2) \end{aligned}$$

$$\tilde{A}^{-1} = (l, m, u)^{-1} = \left(\frac{1}{l}, \frac{1}{m}, \frac{1}{u} \right)$$

$$(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4)^{-1} = \left(\frac{1}{6.80}, \frac{1}{5.64}, \frac{1}{4.58} \right)$$

Calculation of fuzzy weights: The weights are generally normalized to get the weight as one that can be done by dividing each value with total as follows:

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 * l_2, m_1 * m_2, u_1 * u_2)$$

Defuzzification method-Center of Area (COA):

$$\left| \text{Centre of Area(COA)} \quad w_i = \left(\frac{l + m + u}{3} \right) \right|$$

Delphi methodology: The Delphi procedure consists of a series of steps undertaken to elicit and refine the perspectives of a group of people who are either experts in the area of focus or representative of the target group (Rothwell and Kazanus, 1997). The first step is to select the panel or participants. The second step is developing structured questionnaire based on the problems to be investigated, or unstructured, in which an open-ended invitation to comment on the issues of interest is distributed individually to the participants. The information generated is processed and used by the investigating team to develop a subsequent more focused questionnaire, which is distributed together with the results of the previous round to participants in the thirdstep of the procedure. This process of synthesizing data and refining the

questionnaire continues until there is a convergence of perspectives among participants (Lang, 1998).

The questionnaire for the first round of Delphi can be developed by the experts, scientist and extension functionaries after reviewing the existing literature, job description of the experts, scientist and extension functionaries and discussing with the Research Advisory Committee members. Questionnaires for second round can be developed from the responses of first round of Delphi using constant comparative method. Subsequently, the questionnaire for round III (developed using the responses from the round II) can administered in the same manner as in previous two rounds. The data were collected from the experts through questionnaire and electronic mail method. Furthermore, consensus is said to be high when quartile deviation was less than or equal to 0.5 and IQR less than or equal to 1, medium when quartile deviation was in between 0.5 and 1 and IQR greater than 1 but less than 2 and low consensus if quartile deviation is more than 1 and IQR more than 2. The important levels were: high in which the median value is 4 and above, while medium in which the median value is 3 and low when medium value is less than 3.

Delphi have certain advantages like; Anonymity can be guaranteed, anonymity for participants make contributions of ideas a safe activity, conducted in writing and does not require face-to-face meetings, responses can be made at the convenience of the participant, opportunities for large number of experts to participate, opportunities for participants to reconsider their opinions, gives access to groups of widely dispersed experts, Time for reflection, improving the strength of opinion, participants have an equal say, Greater acceptance of Delphi results than other consensus methods, Learning and motivating experience for participants, Highly cost-effective, when conducted by experts and relatively free of social pressure, personality influence, and individual dominance and is, therefore, conducive to independent thinking and gradual formulation of reliable judgments or forecasting of results. The disadvantages of Delphi includes; large amount of time to conduct several rounds, complexity of data analysis, difficulty of maintaining participant enthusiasm throughout process, potential of low response rates due to the multiple feedback processes, the power of persuasion or prestigious individuals to shape group opinion and the vulnerability of group dynamics to manipulation.

Weighted Mean: Weighted mean is the mean of each value when it is multiplied by some weight w_i .

which means:

$$\bar{x} = \frac{w_1x_1 + w_2x_2 + \dots + w_nx_n}{w_1 + w_2 + \dots + w_n}$$

$$\bar{x} = \frac{\sum_{i=1}^n w_i x_i}{\sum_{i=1}^n w_i},$$

Therefore, data elements with a high weight contribute more to the weighted mean than do elements with a low weight. The weights cannot be negative. Some may be zero, but not all of them (since division by zero is not allowed).

$$\text{Mean percent score} = \frac{\text{Total score obtained}}{\text{Maximum obtainable score}} \times 100$$

Kruskal-Wallis H Test using SPSS Statistics: The Kruskal-Wallis H test (sometimes also called the “one-way ANOVA on ranks”) is a rank-based nonparametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. It is considered the nonparametric alternative to the one-way ANOVA, and an extension of the Mann-Whitney U test to allow the comparison of more than two independent groups. For example, we could use a Kruskal-Wallis H test to understand whether exam performance, measured on a continuous scale from 0-100, differed based on test anxiety levels (i.e., your dependent variable would be “exam performance” and your independent variable would be “test anxiety level”, which has three independent groups: students with “low”, “medium” and “high” test anxiety levels). Alternately, we could use the Kruskal-Wallis H test to understand whether attitudes towards pay discrimination, where attitudes are measured on an ordinal scale, differed based on job position (i.e., your dependent variable would be “attitudes towards pay discrimination”, measured on a 5-point scale from “strongly agree” to “strongly disagree”, and your independent variable would be “job description”, which has three independent groups: “shop floor”, “middle management” and “boardroom”). If you wish to take into account the ordinal nature of an independent variable and have an ordered alternative hypothesis, you could run a Jonckheere-Terpstra test instead of the Kruskal-Wallis H test.

It is important to realize that the Kruskal-Wallis H test is an *omnibus* test statistic and cannot tell you which specific groups of your independent variable are statistically significantly different from each other; it only tells you that at least two groups were different. Since you may have three, four, five or more groups in your study design, determining which of these groups differ from each other is important. You can do this using a post hoc. The “quick start” guide shows you how to carry out a Kruskal-Wallis H test using SPSS Statistics, as well as interpret and report the results from this test. However, before we introduce you to this procedure, you need to understand the different assumptions that your data must meet in order for a Kruskal-Wallis H test to give you a valid result. We discuss these as assumptions.

When you choose to analyse your data using a Kruskal-Wallis H test, part of the process involves checking to make sure that the data you want to analyse can actually be analysed using a Kruskal-Wallis H test. You need to do this because it is only appropriate to use a Kruskal-Wallis H test if your data “passes” four assumptions that are required for a Kruskal-Wallis H test to give you a valid result. In practice, checking for these four assumptions just adds a little bit more time to your analysis,

requiring you to click a few more buttons in SPSS Statistics when performing your analysis, as well as think a little bit more about your data, but it is not a difficult task. Before these four assumptions, do not be surprised if, when analysing your own data using SPSS Statistics, one or more of these assumptions is violated (i.e., is not met). This is not uncommon when working with real-world data rather than textbook examples, which often only show you how to carry out a Kruskal-Wallis H test when everything goes well. Even when your data fails certain assumptions, there is often a solution to overcome this. First, let's take a look at these four assumptions:

Assumption #1: Your dependent variable should be measured at the ordinal or continuous level (i.e., interval or ratio). Examples of ordinal variables include Likert scales (e.g., a 7-point scale from “strongly agree” through to “strongly disagree”), amongst other ways of ranking categories (e.g., a 3-point scale explaining how much a customer liked a product, ranging from “Not very much”, to “It is OK”, to “Yes, a lot”). Examples of continuous variables include revision time (measured in hours), intelligence (measured using IQ score), exam performance (measured from 0 to 100), weight (measured in kg), and so forth.

Assumption #2: Your independent variable should consist of two or more categorical, independent groups. Typically, a Kruskal-Wallis H test is used when you have three or more categorical, independent groups, but it can be used for just two groups (Mann-Whitney U test **is more commonly used for two groups**). Example independent variables that meet this criterion include ethnicity (e.g., three groups: Caucasian, African American and Hispanic), physical activity level (e.g., four groups: sedentary, low, moderate and high), profession (e.g., five groups: surgeon, doctor, nurse, dentist, therapist), and so forth.

Assumption #3: You should have independence of observations, which means that there is no relationship between the observations in each group or between the groups themselves. For example, there must be different participants in each group with no participant being in more than one group. This is more of a study design issue than something you can test for, but it is an important assumption of the Kruskal-Wallis H test. If your study fails this assumption, you will need to use another statistical test instead of the Kruskal-Wallis H test (may be a Friedman test). As the Kruskal-Wallis H test does not assume normality in the data and is much less sensitive to outliers, it can be used when these assumptions have been violated and the use of a one-way ANOVA is inappropriate. In addition, if your data is ordinal, a one-way ANOVA is inappropriate, but the Kruskal-Wallis H test is not. However, the Kruskal-Wallis H test does come with an additional data consideration.

Assumption #4: In order to know how to interpret the results from a Kruskal-Wallis H test, you have to determine whether the distributions in each group (i.e., the distribution of scores for each group of the independent variable) have the same shape (which also means the same variability). If your distributions have the same shape, you can use SPSS Statistics to carry

out a Kruskal-Wallis H test to compare the medians of your dependent variable (e.g., “engagement score”) for the different groups of the independent variable you are interested in (e.g., the groups, Caucasian, African American and Hispanic, for the independent variable, “ethnicity”). However, if your distributions have a different shape, you can only use the Kruskal-Wallis H test to compare mean ranks. Having similar distributions simply allows you to use medians to represent a shift in location between the groups. As such, it is very important to check this assumption or you can end up interpreting your results incorrectly. You can check assumption #4 using SPSS Statistics. You should also check that your data meets assumptions #1, #2 and #3, which you can do without using SPSS Statistics. Just remember that if you do not check assumption #4, you will not know whether you are able to compare medians or just mean ranks, meaning that you might incorrectly interpret and report the result of the Kruskal-Wallis H test.

Friedman Test in SPSS Statistics: The Friedman test is the non-parametric alternative to the one-way ANOVA with repeated measures. It is used to test for differences between groups when the dependent variable being measured is ordinal. It can also be used for continuous data that has violated the assumptions necessary to run the one-way ANOVA with repeated measures (e.g., data that has marked deviations from normality). When you choose to analyse your data using a Friedman test, part of the process involves checking to make sure that the data you want to analyse can actually be analysed using a Friedman test. You need to do this because it is only appropriate to use a Friedman test if your data “passes” the following four assumptions:

- **Assumption #1:** One group that is measured on three or more different occasions.
- **Assumption #2:** Group is a random sample from the population.
- **Assumption #3:** Your dependent variable should be measured at the ordinal or continuous level. Examples of ordinal variables include Likert scales (e.g., a 7-point scale from strongly agree through to strongly disagree), amongst other ways of ranking categories (e.g., a 5-point scale explaining how much a customer liked a product, ranging from “Not very much” to “Yes, a lot”). Examples of continuous variables include revision time (measured in hours), intelligence (measured using IQ score), exam performance (measured from 0 to 100), weight (measured in kg), and so forth.
- **Assumption #4:** Samples do NOT need to be normally distributed.

The Friedman test procedure in SPSS Statistics will not test any of the assumptions that are required for this test. In most cases, this is because the assumptions are a methodological or study design issue, and not what SPSS Statistics is designed for. In the case of assessing the types of variable you are using, SPSS Statistics will not provide you with any errors if you incorrectly label your variables as nominal. For example; A researcher wants to examine whether music has an effect on the perceived psychological effort

required to perform an exercise session. The dependent variable is “perceived effort to perform exercise” and the independent variable is “music type”, which consists of three groups: “no music”, “classical music” and “dance music”. To test whether music has an effect on the perceived psychological effort required performing an exercise session, the researcher recruited 12 runners who each ran three times on a treadmill for 30 minutes. For consistency, the treadmill speed was the same for all three runs. In a random order, each subject ran: (a) listening to no music at all; (b) listening to classical music; and (c) listening to dance music. At the end of each run, subjects were asked to record how hard the running session felt on a scale of 1 to 10, with 1 being easy and 10 extremely hard. A Friedman test was then carried out to see if there were differences in perceived effort based on music type.

Post Hoc Tests: To examine where the differences actually occur, you need to run separate Wilcoxon signed-rank tests on the different combinations of related groups. So, in this example, you would compare the following combinations:

- None to Classical.
- None to Dance.
- Classical to Dance.

You need to use a Bonferroni adjustment on the results you get from the Wilcoxon tests because you are making multiple comparisons, which makes it more likely that you will declare a result significant when you should not (a Type I error). Luckily, the Bonferroni adjustment is very easy to calculate; simply take the significance level you were initially using (in this case, 0.05) and divide it by the number of tests you are running. So in this example, we have a new significance level of $0.05/3 = 0.017$. This means that if the p value is larger than 0.017, we do not have a statistically significant result. It is important to note that the significance values have not been adjusted in SPSS Statistics to compensate for multiple comparisons – you must manually compare the significance values produced by SPSS Statistics to the Bonferroni-adjusted significance level you have calculated. We can see that at the $p < 0.017$ significance level, only perceived effort between no music and dance (dance-none, $p = 0.008$) was statistically significantly different.

You can report the Friedman test with post hoc tests results as that tF here was a statistically significant difference in perceived effort depending on which type of music was listened to whilst running, $\chi^2(2) = 7.600$, $p = 0.022$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Median (IQR) perceived effort levels for the no music, classical and dance music running trial were 7.5 (7 to 8), 7.5 (6.25 to 8) and 6.5 (6 to 7), respectively. There were no significant differences between the no music and classical music running trials ($Z = -0.061$, $p = 0.952$) or between the classical and dance music running trials ($Z = -1.811$, $p = 0.070$), despite an overall reduction in perceived effort in the dance vs classical running trials. However, there was a statistically significant reduction in perceived effort in the dance music vs no music trial ($Z = -2.636$, $p = 0.008$).

Conclusion

There are many options for deciding upon the methodologies for constraint analysis in agricultural situations, but each one is limited by certain assumptions and required type of data set. The assumptions are a methodological or study design issue, and not what analytical programme like SPSS Statistics is designed for. In the case of assessing the types of variable you are using, SPSS Statistics will not provide with any errors if you incorrectly label your variables as nominal. Hence, the suitably designed methodology is the best guide to choose amongst the alternatives.

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