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Research Area NegoTrans

08-2019

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Discussion Paper 06-2019

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Research Area "NegoTrans – Negotiation Research, Transformation, Technology, Media, and Costs"

ISSN 2364-2084

Data Quality and Information Loss in Standardised Interpolated Path Analysis – Quality Measures and Guidelines*

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Abstract. Standardised interpolated path analysis (SIPA) is a method to investigate negotiation processes making different negotiation histories comparable. Due to its interpolation approach, researchers employing SIPA must take data quality and potential information loss into account to maximise the method's explanatory power. This paper presents quality measures and applies them to two negotiation datasets for deriving meaningful boundaries. Using these quality measures enables researchers to compare SIPA across segmentations, variables, and datasets also providing outlier analysis.

Keywords: Electronic Negotiation, Negotiation process, Phase analysis

1 Introduction

Standardised interpolated path analysis (SIPA) has been proposed as a method to investigate negotiation processes enabling phase analysis and offer process analysis [1, 2]. For instance, SIPA can be employed to analyse concession patterns based on the individual utility of negotiators. In addition to substantive values, SIPA has also been applied to qualitative content analysis data [3–5].

To standardise negotiations with varying numbers of messages sent at different points in time, negotiations are divided into n equally large time periods using $n + 1$ measurement points. SIPA assumes the change of opinion (e.g. in terms of utility) of the negotiator as a continuous process [6], calculating a linear interpolation between the messages at each measurement point. Defining the correct number of measurement periods is vital to achieve sufficient data quality and meaningful results [3]. A theory-driven approach for defining the optimal number of periods is to use negotiation phase-models [7–9], while data-driven approaches refer to the average number of messages exchanged [1] respectively communicative acts [10]. In data-driven approaches, such as SIPA, a low number of periods enables accurate modelling of the negotiation process as a whole, albeit with potential information loss within the periods. On the contrary, a high number of periods minimises information loss within the periods, potentially

* This paper has been published and presented in the Local Proceedings of the 19th International Conference on Group Decision and Negotiation (GDN 2019), Loughborough, UK, June 11-15, 2019. Eds. Morais, D.C.; Carreras, A.; de Almeida, A.T.; Vetschera, R.

producing an inaccurate model of the negotiation process [1]. This paper, therefore, aims to propose quality measures for data quality and information loss. Both goals are implemented presenting a distance measure, a data record measure, and an overall measure. The presented measures are evaluated in two datasets showing their feasibility for concession analysis and suggesting lower and upper boundaries respectively. Researchers employing SIPA are encouraged to use these quality measures to characterise their analyses and enable objective comparison.

2 Theoretical Background

Negotiations represent an iterative communication and decision-making process between at least two parties who are unable to reach their goals through unilateral actions [11]. Nowadays, negotiations are being conducted by using electronic channels.

Negotiation Support Systems (NSSs), as one type of electronic negotiation support, leave the control over the negotiation process with the human negotiator and have the goal of supporting the negotiation process by providing communication support as well as decision support [12, 13]. In particular, the Negoisst system enables formal and informal message exchange [12]. For formal messages (e.g. offer, counteroffer) message texts as well as utility data is tracked, whilst informal messages (i.e. question, clarification) do not contain utility data [14]. Negoisst calculates utility values based on a linear multi-attribute utility function that considers the preferences of issues to be negotiated for each of the respective parties. These offers can be made at different points in time and may also vary w.r.t. their quantity, which hinders process-oriented comparisons [1]. SIPA aims to map the varying numbers of exchanged messages onto a common time scale as well as a standardised number of measurement points.

For this purpose, linear interpolation is used to approximate the messages according to measurement points of the same length $S = \{s_1, \dots, s_n\}$ with regard to the presented SIPA formula (1) according to Filzmoser et al. [3]. Assuming that one negotiation is divided into quarters, the measurement points s_1 to s_5 separate the quarters. Based on this segmentation, the time of the last message of negotiator j made before the respective measurement point $s_{i^-,j}$ and the time of the first message of negotiator j made after the respective measurement point $s_{i^+,j}$ are considered for the linear interpolation of the estimated value at measurement point s_i ($v(s_i)$) [1].

$$v(s_i) = \frac{s_{i^+,j} - s_i}{s_{i^+,j} - s_{i^-,j}} v(s_{i^-,j}) + \frac{s_i - s_{i^-,j}}{s_{i^+,j} - s_{i^-,j}} v(s_{i^+,j}) \quad (1)$$

This approximation process is performed for each of the measurement points, to achieve a consistent process representation over all negotiator records.

3 Measures for the Assessment of Data Quality and Information Loss in SIPA

To achieve meaningful results with SIPA, it is of paramount importance that the interpolated measurement points reflect the actual negotiation process as good as possible. By these means, SIPA quality can be assessed by (i) the distance between messages and measurement points and by (ii) the value difference of actual messages and interpolated values. Moreover, a combination of these two factors facilitates a combined quality measure, e.g. the slope in a measurement point. SIPA can be applied to varying content dimensions such as communication or emotion [e.g. 3]. Thus, the value difference can be used for any content dimension of interest, requiring linearity of the underlying processes. Developing such a uniform measure lies beyond the scope of this work. Thus, we focus on the temporal distances of measurement points to actual messages of a negotiator as the basis for quality measures of SIPA.

With the distance of actual messages to measurement points, SIPA quality on the one hand depends on when measurement points are set and thus in how many periods of equal length the negotiation is split into. On the other hand, the data quality is of importance, which may vary between negotiators depending on their individual offer process. Hence, the data of individual negotiators must be considered separately. However, this allows an assessment of SIPA quality for single data records.

3.1 Data Quality Measure

The proposed quality measures are based on the temporal distance of a measurement point and a negotiator's next closest message. Since the first and the last measurement point are set to the time of the first message and the last message in SIPA, this distance is per definition zero. Hence, quality measures only apply for a number of measurement points $S > 2$.

For all measurement points in between, two values apply, namely the absolute temporal distance of measurement point s_i to the last message of negotiator j before the measurement point s_i, i.e. $d_{i^-,j}$, and its counterpart, which describes the absolute temporal distance of measurement point s_i to the first message of negotiator j after the measurement point s_i, i.e. $d_{i^+,j}$. These measures can be calculated based on the difference of measurement point s_i and the next closest message of negotiator j before (i.e. $d_{i^-,j}$) or after s_i (i.e. $d_{i^+,j}$). In the following, we will illustrate the measures for $d_{i^-,j}$. The measures for $d_{i^+,j}$ apply analogously. Fig. 1 shows an example of one negotiator's absolute temporal distances to measurement point s_2.

$$d_{i^-,j} = |s_i - s_{i^-,j}| \tag{2}$$

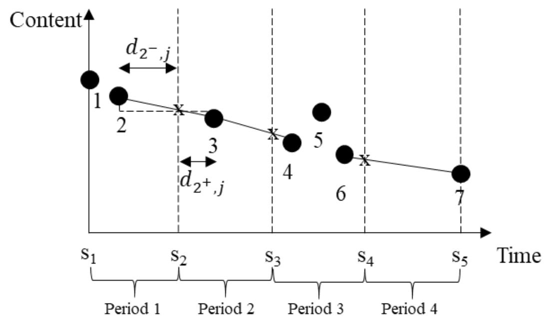

Fig. 1. Example negotiation messages divided into quarters using SIPA

Furthermore, the relative distance of the next closest messages of negotiator j to measurement point s_i, denoted as $d^r{}_{i^-,j}$ is required. It is calculated by the absolute distance $d_{i^-,j}$ divided by the individual period of negotiator j between two measurement points z_j, which provides normalisation by two means: a) the individual negotiation duration is normalised, and b) the influence of the number of measurement points of a certain SIPA is normalised.

$$d^r{}_{i^-,j} = \frac{d_{i^-,j}}{z_j} \tag{3}$$

The normalised distances $d^r{}_{i^-,j}$ and $d^r{}_{i^+,j}$ allow to calculate the relative interpolated distance of measurement point s_i of negotiator j, $mp^r{}_{i,j}$.

$$mp^r{}_{i,j} = d^r{}_{i^-,j} + d^r{}_{i^+,j} \tag{4}$$

For **measurement point analysis**, the relative interpolated distances $d^r{}_{i^-,j}$ and $mp^r{}_{i,j}$ respectively are compared among the measurement points i. The analysis might include the relative mean $\overline{d}^r{}_{i^-}$ of all negotiators in measurement point s_i and the mean of the relative interpolated distance of measurement point s_i of all negotiators $\overline{mp}^r{}_i$. As a mean relative distance of 1 indicates a high possibility of periods without measurements, it presents a natural upper threshold. Besides that, lower values indicate an increase in data quality. For $\overline{mp}^r{}_i$, respectively a value of 2 represents an upper threshold. It is important, however, that in measurement point analysis, the measurement points are evaluated with respect to the underlying data enabling the investigators to spot unsuitable measurement points or irregularly distributed data between them. Moreover, the data quality of different measurement points can be compared by the standard deviation $\sigma_{d^r{}_{i^-}}$ of the relative distances of the negotiators to the messages before and after a measurement point s_i; and the standard deviation $\sigma_{mp^r{}_i}$ of the relative interpolated distance of all negotiators in measurement point s_i.

For **data record analysis**, the comparability of the negotiators' data quality is facilitated based on $mp^r{}_{i,j}$, i.e. the mean of the absolute distance of negotiator j to all measurement points $\overline{mp}^r{}_j$, to allow an analysis of the SIPA quality of an individual data record.

For **SIPA data quality analysis**, the concept of $\overline{mp}^r{}_j$ can be utilised to observe the mean relative distance of all negotiators j to all measurement points i, described by $\overline{mp}^r$. The SIPA quality measure $\overline{mp}^r$ allows an overall assessment by means of temporal interpolation accuracy, which facilitates an assessment of SIPA quality for different data sets or time dependant interpolation of different content dimensions. The smaller $\overline{mp}^r$ is, the less relative time is interpolated. A value of 0 means that no values are interpolated at all, while 1 means that on average, one period is interpolated in each measurement point for each negotiator. Thus, $\overline{mp}^r$ should not be greater than 2, since this would mean that the SIPA value is in the mean interpolated over more than two individual relative distances. The smaller $\overline{mp}^r$ is, the better the SIPA data quality. Its standard deviation $\sigma_{\overline{mp}^r}$ provides insights into the amount of dispersion of the relative interpolated distances.

3.2 Information Loss Measure

As SIPA only considers interpolated values at given points in time, information of observed messages in between two measurement points may be lost, which results in a false interpretation of the negotiation process. In the example in Fig. 1, messages 4 and 6 are considered in the respective measurement points s_3 and s_4. However, message 5, which provides additional information about the content dimension, is not considered.

In order to estimate how well the observed messages are considered in the SIPA, we develop a measure to relate to the message frequency in between two measurement points. By the number of messages n_{ij} for negotiator j in period i, i.e. $\bar{n}_i$, the mean number of messages in period i can be utilised for **measurement period analysis.** $\bar{n}$ values should be between a lower threshold of 1 and an upper threshold of 2. A value below 1 would lead to low interpolation accuracy, while a value above 2 would mean excess information. The mean number $\bar{n}_j$ of messages of negotiator j can also be calculated, which may be used for **data record analysis**. In data record analysis $\bar{n}_j$ should be equally distributed over all measurement periods fulfilling the thresholds explained above. These two measures will eventually build the **SIPA data quality measure** $\bar{n}$, the mean number of messages in all periods of all negotiators.

For further analysis, the standard deviation $\sigma_{\bar{n}}$ may be used to assess the distribution of exchanged messages amongst negotiators. The more messages a negotiator has exchanged; the more measurement points are necessary to prevent information loss.

4 Comparative Application of Quality Measures in Two Datasets

In the following, the described quality measures are applied to two datasets showing the measures' feasibility and providing insights for their interpretation and boundaries.

4.1 Data Collection and Descriptive Statistics

Both datasets have been collected in negotiation simulations lasting for five days using the NSS Negoisst [12, 13] with student negotiators attending a negotiation course at universities in Austria, the Netherlands, and Germany. The students received credit points as an incentive for participation. In the simulations, master students negotiated identical bilateral multi-issue case studies including five issues with pre-defined preferences enabling competitive as well as compromising strategies [15].

After cleaning dataset 1 (D1), which was collected in the winter term 2016/17, includes 145 individuals who sent 5.64 messages on average; dataset 2 (D2) was collected in the winter term 2017/18 and includes 130 individuals who exchanged 6.59 messages on average.

4.2 Application of Quality Measures

For measurement point analysis, measurement period analysis, and SIPA data quality analysis, comparisons between both datasets are performed. Record analysis is performed with D2 as an example. Values are marked in bold if they are within the boundaries providing valid SIPA as defined in section 3.

Measurement point analysis. Table 1 presents the relative interpolated distances for both datasets. To enable further comparisons (e.g. to [1, 3]) we employ SIPA dividing the negotiations in quarters. In general, the relative interpolated distances are near the upper threshold of 1 showing that only few negotiation data is available in between the measurement points. Most negotiation data is available at the start respectively end of the negotiations producing the lowest values before s1 respectively after s4. While this finding is identical for both datasets, D2 exhibits slightly higher data quality than D1 over all measurement points. Nevertheless, both datasets present acceptable for all measurement points.

Table 1. Measurement point analysis

Variable	D1-s2	D1-s3	D1-s4	D2-s2	D2-s3	D2-s4
${d^r}_{i^-,j}$	0.7289	0.9036	0.9132	0.7466	0.9047	0.8559
${d^r}_{i^+,j}$	0.9343	0.7807	0.5841	0.8326	0.7533	0.5134
${\overline{mp}^r}_i$	**1.6633**	**1.6843**	**1.4973**	**1.5792**	**1.6580**	**1.3692**

Measurement period analysis. Table 2 shows the mean number of messages sent for each period. In line with measurement point analysis, we can observe peaks in the first and last period in both datasets. In period 4 of D2 $\boldsymbol{\bar{n}_i}$ exceeds the threshold of 2 indicating a loss of information. In period 2 both datasets exhibit values slightly below the threshold of 1, indicating low interpolation accuracy. Again D2 exhibits slightly higher numbers of messages exchanged.

Table 2. Measurement period analysis

Variable $\bar{n}_i$	Period 1	Period 2	Period 3	Period 4
D1	**1.58**	0.90	**1.04**	2.12
D2	**1.65**	0.91	**1.04**	2.99

Record analysis. We conducted a record analysis to identify individual negotiators with an exceptional mean relative distance. The boxplot diagram in Fig. 2 shows that negotiator-IDs 4, 26, 56, 57, 58, 61, 82 and 90 are potential outliers, as their mean relative distance differs from the mean (M=1.54) indicating lower interpolation accuracy. Fig. 2 furthermore shows the mean number of messages per period (M=1.64). The boxplot again indicates potential outliers being subject to information loss.

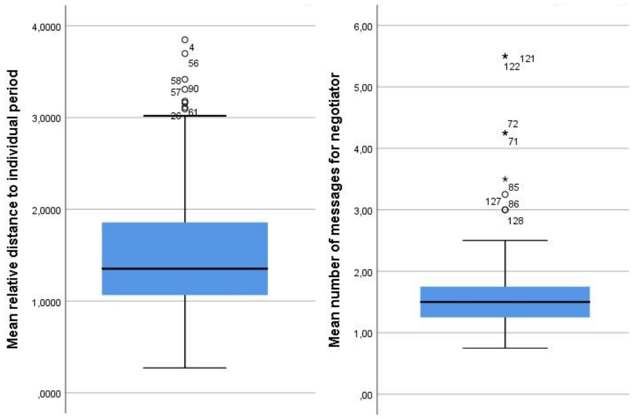

Fig. 2. Boxplot of the mean relative distance and mean number of messages per negotiator and period

SIPA data quality analysis. For the overall quality analysis of the SIPA, we perform a sensitivity analysis as suggested by [1] to compare the proposed quality measures across segmentations, datasets, outcome variables, and negotiators. Table 3 presents the quality measures for D1 with five measurement points (D1-S5) and D2 with three up to seven measurement points (D2-S3 to D2-S7). Whilst the previously described SIPAs are based on formal and informal messages exchanged, D2-S5-U varies the content dimension and only includes formal messages having utility values available. Finally, the quality measures are also presented for a cleaned version of D2 (D2-S5-Cleaned) excluding those records outside the upper whisker in Fig. 2 (left). Table 3 relates the newly developed quality criteria to the number of messages available in each dataset.

Table 3. SIPA data quality analysis

Variable	**D1-S5**	D2-S3	D2-S4	**D2-S5**	**D2-S6**	D2-S7	**D2-S5-U**	**D2-S5-Cleaned**
$\overline{mp}^r$	**1.6150**	**0.8290**	**1.1628**	**1.5355**	**1.8796**	2.2467	**1.8704**	**1.4164**
$\sigma_{\overline{mp}^r}$	0.8644	0.3977	0.5287	0.6763	0.8041	0.9234	0.7645	0.5006
$\bar{n}$	**1.4103**	3.2962	2.1974	**1.6481**	**1.3185**	**1.0987**	**1.2904**	**1.6783**
$\sigma_{\bar{n}}$	0,5824	1,5448	1,0299	0,7724	0,6179	0,5149	0,5216	0,7863
$M_{messages}$	**5.64**	6.59	6.59	6.59	**6.59**	**6.59**	**5.16**	6.71

In the following, we provide a two-step rationale for evaluating SIPA quality measures balancing interpolation accuracy and information loss. (1) While interpolation accuracy $\overline{mp}^r$ should be below an upper threshold of 2, the average number of messages per period $\bar{n}$ should be between 1 and 2 to balance data quality and information loss. Fig. depicts valid SIPA segmentations lying within the shaded area. To be even more precise, the optimal segmentation of a given dataset can be found at the intersection of both lines, exhibiting the optimal trade-off between interpolation accuracy and information loss. (2) In addition to these absolute guidelines, $\sigma_{\overline{mp}^r}$ and $\sigma_{\bar{n}}$ characterise the distribution of records to enable outlier analysis. In general, the lower these values, the better the fit. Compared to the rule-of-thumb introduced by Vetschera and Filzmoser [1], which would recommend segmentation D2-S6 or D2-S7, the quality measures developed in this paper suggests D2-S5. Performing data cleaning according to record analysis can improve data quality. D2-S5-Cleaned improved the mean relative interpolated distance by 7.76 % while increasing the mean number of messages in all periods by only 1.83 %.

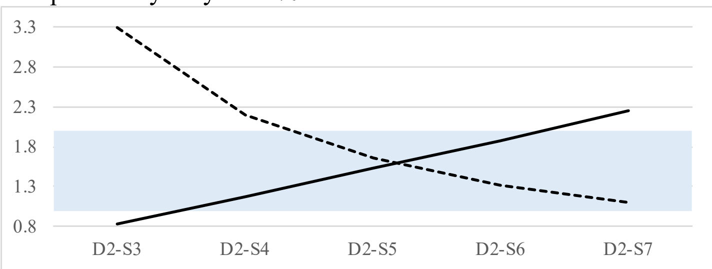

Fig. 3 Interpolation accuracy $\overline{\boldsymbol{mp}}^{\boldsymbol{r}}$ (solid) depicted against information loss $\overline{\boldsymbol{n}}$ (dotted).

5 Discussion and Outlook

The quality measures presented in this paper enable negotiation researchers to conduct SIPA investigating negotiation processes in a more structured manner. We developed several measures to assess interpolation accuracy and information loss on measurement periods/points, data records, and on an overall level. Based on these measures, guidelines and thresholds are derived to evaluate the quality of SIPA in the form of sensitivity analysis over segmentations, datasets, variables, and outlier analysis. A two-step process enables researchers to select the best SIPA having the highest explanatory power. Our findings show external validity as they provide similar results as previous rules-of-thumb. However, our quality measures enable detailed assessment of SIPA quality. Limitations of this work are based on the datasets used for evaluation. As indicated in section 3, both datasets share numerous properties. Further validation of the defined quality measures should use datasets varying regarding NSSs, negotiation protocols, participants, or case studies. Furthermore, the question of data cleaning discussed in this paper, has to be handled with care. Deletion of outliers has been shown to improve data quality. However, valid negotiation data might be deleted, which could deter the observed data. The developed quality measures to characterise SIPA data contribute to the research on data-driven phase analysis in e-negotiations as a means to optimise explanatory power. Combinations with other data-driven [10] and theory-driven approaches are heavily recommended to make sense of the data and results. Finally, selection of suitable SIPA segmentations based on the presented guidelines could be (semi-)automated using Machine Learning approaches to create unequal segmentations, increasing data-fit and theory-fit.

Acknowledgements. We gratefully acknowledge the support of the research area "Negotiation Research - Transformation, Technology, Media, and Costs", of the Faculty of Business, Economics, and Social Sciences at the University of Hohenheim.

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