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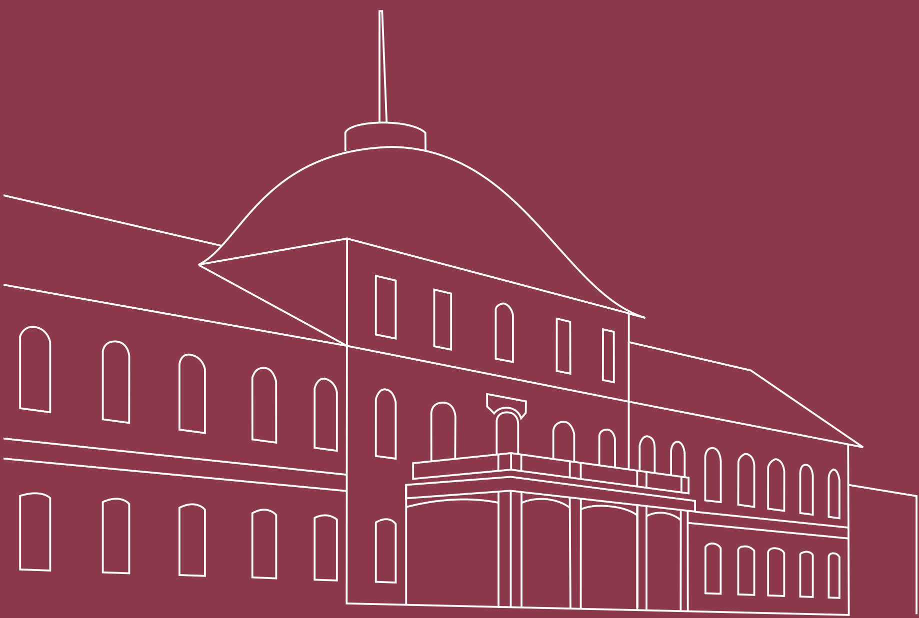

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Fostering Perspective-Taking in Social Interaction

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Abstract. Recent studies have repeatedly shown that interlocutors sometimes fail to (accurately) regard the perspective of their interaction partner, leading to (egocentric) errors in social interaction. However, it remains scarcely investigated how interlocutors can be stimulated to accurately engage in the process of perspective-taking during the interaction that requires perspective-taking to occur. The aim of this project is to fill this knowledge gap by focusing on how the perceptual and conceptual domains of perspective-taking can be facilitated by a stimulated attention to the other's perspective. Four studies are presented, each focusing on fostering different domains of perspective-taking.

Keywords: perspective-taking, egocentrism, circular questions, mediation

1 Introduction

The literature shows a puzzling picture with regard to interlocutors' ability and propensity to correctly engage in the process of perspective-taking. On the one hand, studies evidenced that people succeed at assessing and adapting their communication to their interlocutor's knowledge [1], [2], [3]. On the other hand, however, we find studies indicating that people do not always engage in an accurate audience design [4], [5], [6], and that they can even fall prone to their own egocentric perspective [7], [8], [9], [10]. According to these studies, language production and comprehension is not necessarily anchored to the interlocutor's informational need, but more to a person's own knowledge and attentional state, resulting in behavior that is based on information immediately accessible to persons themselves. Following this approach, another's knowledge state is only considered in a later, optional adjustment stage in which people can chose whether to adjust their behavior to the other's informational need or not. Scholars defending the latter view argue for an egocentricity bias [6], [11], [12]. According to this bias, peoples' own mental state is functioning as a representational default from which the other's knowledge state and/or perspective is derived [13], [14]. Engaging in perspective-taking is then considered to be a cognitive effortful process that can result in egocentric anchor mistakes when people do not correct for their automatic response. Failing to get beyond this default leads to egocentric errors in interactions [5], [8], [9], [10], [13], [15], [16], [17], [18].

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From a pragmatic point of view, it is interesting to investigate whether previously found egocentric errors [15], [17] can be countered by a mental activation of the others' (different) perspective. What if interlocutors in the abovementioned studies were made *explicitly* aware of the others' different perspective, would they still have fallen prone to their egocentric knowledge? This question is also interesting for social practices that try to enhance perspective-taking during social interaction. Being guided by the argument that accurate perspective-taking is at the core of the maintenance of interpersonal relationships [19], [20], therapeutic and/or conflict resolution practices employ various questioning techniques that are believed to elicit perspective-taking during the interaction [21]. One questioning-technique that is explicitly used to enhance perspective-taking processes during social interaction is the so-called 'circular-questioning' technique [21], [22], also described as 'circular' questions or 'mind-reading' questions [23], [24], [25], and 'other-awareness reflexive' questions [26]. Circular questions found their advent in the systemic family therapy [22] that treats families as a 'system' in which all members have certain roles and behavioral patterns. The behavioral patterns are circular in the sense that each (behavioral) change in the system asks for another (behavioral) change in return, resulting in circular patterns that keep the (malfunctioning) system sustained. Circular questions are used to elicit a change in addressees' thought or behavioral pattern, by asking members of the system to place themselves in another member's position while they provide an answer to a circular question (e.g., "How do you think member X feels when you behave in a Y way?"). Although the circular questioning approach is elaborately discussed and employed by therapeutic and conflict resolution settings [21], [27], [28], [29], empirical tests on the assumed relationship between the questioning-technique and the perspective-taking process are yet to be performed.

The empirical aim of this PhD project is to explore whether perspective-taking can be enhanced during the social interaction by employing the underlying mechanism of the circular questioning technique, namely by asking adults to regard their interlocutor's perspective during the perspective-taking tasks. This aim is currently being investigated in four experimental studies, each focusing on a different perspective domain. Results of these studies provide more insight in how perspective-taking processes are involved during language production and comprehension processes, and how egocentric anchoring mistakes can be accounted for. Practical implications can be sought in the field of therapeutic or conflict resolution settings, in which perspective-taking is considered to be an important factor contributing to the problem's resolution [30], and the restoration or maintenance of interpersonal relations [19], [20].

1.1 Study 1

Perspective-Taking in Referential Communication: Does Stimulated Attention to Addressee's Perspective Influence Speakers' Reference Production? The first study and follow-up study investigated the perceptual perspective-taking process (L1 visuospatial processes in [31]) during an interaction in which interlocutors referred to common-ground objects. We investigated whether speakers' referential communication benefits from an explicit focus on addressees' perspective. Dyads took part in a referential communication game and were allocated to one of three experimental settings. Each of these settings elicited a different perspective mindset (none, self-focus, other-focus). In the two perspective settings, speakers were explicitly instructed to regard their addressee's (other-focus) or their own (self-focus) perspective before construing their referential message.

Following [7], speakers were asked to describe mutually visible geometrical figures in such a way that the addressee could indicate the intended one out of a set of four. The four figures were physically presented on the table in front of both interlocutors. These same figures were depicted on speakers' private computer screen from which speakers were instructed to block one figure and, subsequently, to identify another figure on the table in front of them (Fig. 1). The occluded figure differed either in size or color from the three mutually visible figures. This occluded figure thus constituted speakers' privileged ground, whereas the other three (including the target object) were part of speakers' and addressees' common-ground. Speakers' privileged figure could act as a "curse of knowledge" [32], and influence speakers' tendency to leak information that could cue the identity of the hidden figure. Since all three common-ground figures had the same color and size, including color and size attributes would be redundant for addressees' selection process. However, since speakers were confronted with a privileged figure that always showed a contrast in either size or color to the target figure, their egocentric perspective could lead them to overspecify their target descriptions.

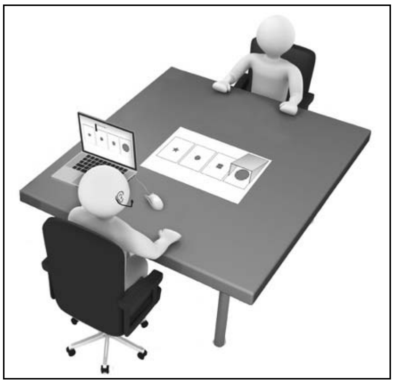

Fig. 1. The experimental setting in which the speaker (on the bottom) identified figures to the addressee (on the top).

Speakers' self- versus other-focus was manipulated by asking them explicitly to either regard their own (self-focus) or their addressee's (other-focus) perspective before they identified the target object. The self- versus other-focus was operationalized by asking speakers to answer a perspective question portrayed on the computer screen next to them. In the self-focus setting, speakers answered the question reinforcing their egocentric perspective: *"Which four figures are visible to you?"*. This in contrast to the speakers in the other-focus setting who were asked to regard the perspective of their addressee: *"Which three figures are visible to your addressee?"*. Speakers answered the question by selecting the figures on their private computer screen. To eliminate the possibility that the self-focused speakers would simply select all figures as a response to the question, a fifth figure was added to the four presented on the computer screen. The fifth figure's position and shape was balanced across all trials. To investigate the influence of our perspective manipulation, we allocated one third of the speakers to a baseline setting. In this setting, we did not reinforce speakers' self- versus other-focus. In this way, we were able to examine how speakers' reference production in the self- versus other-focused settings would diverge from a baseline situation. We measured the extent to which speakers were influenced by their privileged knowledge as a function of the perspective setting they participated in. For this, we counted the adjectives uttered that matched the contrast (in either size or color) between the target figure and speakers' privileged figure.

Results indicated that eliciting speakers' self- versus other-focus did not influence their reference production. We did find that speakers with an elicited egocentric perspective reported higher perspective-taking tendencies than speakers in the other two settings. These tendencies correlated with actual referring behavior during the game, indicating that speakers who reported a high perspective-taking tendency were less likely to make egocentric errors such as leaking information privileged to speakers themselves. These findings are explained using the objective self-awareness theory. A follow-up study addressed the limitations of the first study and measured speakers' objective self-awareness in relation to the perspectives elicited during the experiment. The results are currently being analyzed and will be available at the end of May 2017.

1.2 Study 2

Perspective-Taking in Spatial Communication: Elicited Allocentric Attention Increases Spontaneous Perspective-Taking. The second study investigated whether a stimulated attention to someone else's visual perspective can help speakers overcome their natural tendency to relate objects on the basis of their egocentric perspective. Speakers took part in a spatial perspective-taking task during which they indicated the location of an object in relation to another in a photographed scene [33], [34]. In this scene, objects were lying on either sides of the table with a man sitting in between these objects (Fig. 1). Before the start of the experiment, speakers were allocated to one of the three perspective settings (none, self-focus, other-focus). In the self- and other-focus settings, speakers were trained to either regard their own (self-focus) or someone else's' (other-focus) visual perspective (i.e., L2 visuospatial perspective-taking processes in [31]). That is, self-focused speakers indicated how the objects presented in the scene appeared to them, whereas other-focused speakers indicated how these objects appeared to the man depicted in the photograph (Fig. 2). Participants were exposed to four perspective-questions, and in all four questions they indicated their own or the man's perspective on the presented objects (i.e., mug, laptop, lamp, and picture frame). In the remaining setting, speakers' egocentric or allocentric attention was not elicited. This setting thus acted as a baseline setting.

After the training session and several filler questions, participants were again confronted with the photographed scene and asked to indicate on which side of the table the book in the picture was placed (Fig. 1). Participants could either take an egocentric perspective and describe the books' location using themselves as an anchor point, or they could take on an allocentric perspective and describe the books' location from the man's point of view. Findings revealed that a stimulated allocentric attention fostered spontaneous perspective-taking. Other-focused speakers were more likely to spontaneously describe the book's location from the visual perspective of the man in the picture (i.e., *"(the book is placed) on the left side of the table"*), than self-focused speakers.

Fig. 1. The photographed scene presented to participants. Participants were asked to indicate the location of the book lying on the table. They could either use themselves as spatial anchor point (i.e., "(the book is placed) on the right side of the table") or take on an allocentric perspective (i.e., "(the book is placed) on the left side of the table").

Fig. 2. An example of a perspective-training question. These training questions were only exposed to participants in the self- and other-focused settings. The self-focused participants answered the question: *"How do you see the mug?"*. Participants in the other-focused setting replied to the question: *"How does the man see the mug?"*. Participants answered the question by selecting the option that corresponded to the elicited perspective (left option, right option respectively).

1.3 Study 3

Inferential Perspective-Taking: Does Stimulated Attention to Addressee's Mental Representation Influence Speakers' Perspective-Taking? The previous study indicated that making people (constantly) aware of another person's visual perspective fosters spontaneous perspective-taking. The question remains, however, whether this effect also occurs when differences in perspectives are less tangible. While stepping in someone else's shoes allows us to literally look through this person's eyes, inferring what is going on inside this person's head is not so apparent. Since feelings, thoughts and mental states occur solely in the mind of interlocutors, stepping in someone else's mental shoe is a difficult process that is susceptible to inference errors. Previous research argues for an egocentric bias [11], claiming that people use their own mental state as a representational default to infer someone else's. This study investigates whether a stimulated attention to another's mental representation can help people overcome their egocentric bias while inferring this person's mental state.

A prestudy is currently being conducted (till July 2017) investigating whether we are able to replicate the "curse of knowledge" effect found by Keysar [32]. In Keysar's study, people fell prone to their egocentric perspective while inferring the perspective of another. Participants read a scenario in which the protagonist took his parents to a restaurant recommended by his colleague. Whereas one half of the participants learned that the protagonist and his parents had a remarkable dining experience there, the other half learned that the experience had been a miserable one. The following day, the protagonist replied by e-mail to his colleague: "You wanted to know about the restaurant: well, marvelous, just marvelous". When participants were asked to indicate how the colleague would interpret the comment, Keysar [32] found that the e-mail communicating a sarcastic intention (i.e., in the poor dining experience) caused participants to wrongly infer that the colleague would interpret the comment as a sarcastic one rather than as a sincere message. This in contrast to the e-mail communicating a sincere intention (i.e., in the remarkable dining experience). Please note that in the sarcastic condition, only the participants were privileged with the knowledge that the dining experience had been poor, and that the colleague of the protagonist had no other reason than to belief that the message had been a sincere one. Hence, participants reading the sarcastic message were cursed by their privileged knowledge: they wrongly inferred the colleague's mental state by making use of their egocentric perspective.

After the prestudy has been conducted, we will investigate whether stimulating people's attention to addressee's mental representation helps them to overcome this curse of knowledge and to correctly infer another's conceptual perspective (September – November 2017).

1.3 Study 4

Inferential Perspective-Taking: Changing Beliefs. This study will explore the extent to which interlocutors are able to change their (already) established beliefs by stimulating their attention to their interlocutor's mental state. This question is most relevant for social practices that try to enhance disputants mutual understanding (and change/correct previous established beliefs) by eliciting disputants' perspective-taking. This study will be conducted from January till March, 2018.

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Intended First Asking/Offer Prices and their Impact on Negotiation Behavior and Outcomes

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Abstract. 652 participants conducted a two-person negotiation involving the sale/purchase of a used car. The first price 272 (41.7%) participants actually asked/offered during their negotiation differed from their intended first asking/offer price. Participants whose intended and actual first prices remained the same ('maintainers') tended to obtain better outcomes. Intended first price 'changers' tended to obtain relatively worse outcomes regardless of whether their actual first price had created a 'stronger' or 'weaker' initial negotiation position than what would have been the case if they had announced their intended first price. Logistic regression tests (employing 21 independent/ 'predictor' variables) indicated that such 'changers', 'maintainers', 'strengtheners' and 'weakeners' had different identity profiles, pre-negotiation perceptions and expectations, and engaged in systematically different negotiation behavior. This juncture between a person's privately held intended first price and their publicly expressed actual first price has important implications for our understanding of the factors underlying successful bargaining, decision-making and 'mind-changing'.

Keywords: intended asking/offer prices, negotiation, uncertainty, mind-changing.

1 Introduction

This paper reports findings from a study of intended-actual first asking/offer price changing in a distributive negotiation exercise. The study shows that participants who announced a different first asking/offer price (hereafter 'first price') from their intended first price tended to compromise their negotiation outcome. More generally, those participants who maintained or changed and/or strengthened or weakened their intended first price comprise persons with significantly different identity profiles, pre-negotiation perceptions and expectations that engage in systematically different forms of initial and subsequent negotiation behavior.

Very few researchers have examined negotiators' intended first prices or have appeared to appreciate that negotiators' intended first prices may not always be the same as their actual first prices. For example, in three studies that employed 'intended

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first price' as an independent variable, the researchers actually or implicitly treated subjects' intended first prices as a proxy equivalent of their actual, first announced prices [1-3]. There appears to be only one study [4] that not only explicitly recognizes that a negotiator's first announced price may actually be different to his/her intended first price, but also reports findings that display evident, outcome-related consequences of any discrepancy between these two types of prices.

1.1 Study Conducted

The dataset examined for this study comprises 652 participants who took part in a two-person negotiation exercise involving the sale/purchase of a used car. The bulk of this data was collected—at three British universities and on eight separate occasions—from: i) six groups of postgraduate (MBA and MSc) business students; ii) one group of postgraduate law students; and: iii) one group of undergraduate business students. On two other occasions data was collected from groups of professional sales/purchasing negotiators (some of whom were now managers of such negotiators) employed at: i) a major European supplier of offshore oil and gas equipment; and: ii) a multi-national motor vehicle manufacturer and retailer. Collectively, these participants—though predominantly British, Chinese, Indian or Nigerian—were from 60 different countries, aged between 19-62 years (M = 25.1 years) and had a stated level of "negotiation-involving employment experience" that ranged from zero (68.9%) to 29 years (M = 0.94 years). 333 (51.1%) participants were male and 319 (48.9%) female.

Before each of these ten classroom-based negotiation sessions, a 'General Information' handout was sent to the participants describing the car on offer, details of the sale (the potential buyer of the car in question was responding to an advertisement the seller had placed in a motor trader magazine that included a specific asking price for this car—"£8,500."), and the exercise objective (i.e., "Your task is to negotiate with the other person in your group and reach the best possible mutually agreed deal for the sale/purchase of this car.").

At the beginning of each negotiation session, participants were randomly allocated the role of the seller or buyer of the car in question, given a 'Confidential Information' handout to read (which included additional and private information pertinent to their particular buyer or seller role), and asked to make "final preparations" for their negotiation. Before commencing their negotiation (and, importantly, without yet knowing the identity of the person with whom they would be negotiating), each participant completed a single-page questionnaire that asked them to provide their aforementioned identity details and to specify (in the following order): i) their 'aspiration price' (i.e., the best possible price they believed they would actually be able to sell/purchase the car); ii) their intended first asking/offer price; iii) their 'walk-away price' (for the sellers, the lowest price they would be willing to accept and, for the buyers, the highest price they would be willing to pay for the car in question); and: iv) the price they thought would be the "fairest" sale/purchase price—"for both the buyer *and* the seller"—for the car. Participants were also asked to state (on a scale ranging from 0% to 100%) how confident they were that they actually would be able to sell/buy the car for their previously mentioned aspiration price.

Participants were then randomly placed into buyer-seller dyads and provided with a 'Negotiation Prices' form that was pre-formatted so as to enable them to easily keep a record, during their negotiation, of: i) every asking/offer-related price that was mentioned; ii) the order in which these prices were mentioned; iii) whether it was the buyer or seller who had mentioned each price; and: iv) the final, agreed 'outcome' price at which the car had been sold/purchased. To help standardize the conditions faced by all participants the same instructor delivered (from a script) the same exercise instructions to each cohort of participants, and the length of time participants were given to read their 'Confidential Information' handout (40 minutes) and to negotiate with each other (50 minutes) was also the same.

Embedded within the handouts each participant received was a variety of information designed to encourage an outcome settlement within a £1,500 positive and fully overlapping 'zone of *probable* agreement' (ZOPA) that ranged, for the buyers *and* the sellers, from £8,500 to £7,000. That is, £8,500 was the seller's optimum aspiration price *and* the buyer's walk-away price, and £7,000 was the seller's walk-away price *and* the initial boundary point of the buyer's optimum aspiration price. In this paper some of the tests reporting prices announced and all of the tests reporting outcomes obtained by the participants studied are expressed as percentages of this ZOPA. ($\alpha = 0.05$ for all reported significance tests.)

Of course, this exercise-generated £1,500 ZOPA often differed from the actual 'bargaining zone' established by each dyad as a result of the discrepancy between the seller's first *orally* announced asking price and the buyer's (invariably lower) first announced offer price. Nevertheless, confirmation that the instruction materials for this negotiation exercise had successfully influenced participants to orient to this ZOPA came from the findings that: i) 562 (86.2%) of the 652 participants' first prices fell within or on the £8,500–£7,000 boundary points of this zone; ii) the 90 (13.8%) exceptions to this tendency comprised buyers whose first offer price was <£7,000; iii) only 9 (2.8%) of the 326 final outcomes were outside this ZOPA; and: iv) all 9 of these outcomes were <£7,000, the lowest being £6,500.

2 Intended-Actual First Prices, Negotiation Outcomes and Negotiation Behavior

Intended first price changing was commonplace in this dataset: the first price 272 (41.7%) participants *actually* announced in their negotiation differed from the first price they stated they *intended* to announce. Such price changing took one of two possible forms: i) where a participant's actual first price created a weaker negotiating position than what would have been the case if they had announced their intended first price—that is, when a buyer's actual first price was higher than their intended first price or a seller's actual first price was lower than their intended first price (n = 162, 59.6%); or: ii) where a participant's actual first price created a stronger negotiating position than what would have been the case if they had announced their intended first price—that is, when a buyer's actual first price was lower than their intended first price or a seller's actual first price was higher than their intended first price) (n = 110, 40.4%).

These 272 instances of intended-actual first price changing are not likely to have been the result of the participants having forgotten the first price they intended to ask/offer in their negotiation. Each negotiation had commenced within (at most) ten minutes of participants having stated their intended first price and, after completing their pre-negotiation questionnaire, participants were not provided with any additional information from the exercise instructor that could have influenced their decision to change (or to maintain) their intended first price. (The only additional information participants *were* provided with before they commenced their negotiation was the identity of the person with whom they would be negotiating.) Furthermore, the size of the 272 intended-actual first price discrepancies tended to be quite substantial and, as such, they suggested that those participants who had changed their intended first price had done so for some perceived to be important, negotiation consequential reason(s). The 162 'weakeners' announced a first price that was M = £476.96 weaker than their intended first price and the 110 'strengtheners' announced a first price that was M = £464.48 stronger than their intended first price. By virtue of announcing a different first price to their intended first price, weakeners tended to contract what otherwise would otherwise have been (i.e., with their intended first price) the bargaining zone for their negotiation by M = 63.3% (*Mdn* = 33.3%) and strengtheners tended to expand their bargaining zone by M = 45.9% (*Mdn* = 34.1%).

Intended first price changing also had an impact on negotiation outcomes. Such changers tended to obtain a significantly lower percentage of the ZOPA (*Mdn* = 43.3%) than intended first price maintainers (*Mdn* = 56.7%): z = -3.70, p < .001, r = -.15. Maintainers tended to obtain an outcome that was M = 7.1% better than changers. Moreover: i) changers tended to obtain a worse outcome than maintainers regardless of whether their actual first price had been stronger (*Mdn* = 40.0%) or weaker (*Mdn* = 45.5%) than their intended first price; and: ii) there was no significant difference between the median (or mean) level of the ZOPA obtained by weakeners and strengtheners.

Furthermore, intended first price maintaining and changing was a common and differentiating feature of the highest and lowest negotiation performers: 70 (76.1%) of the highest achieving participants—who each obtained ⩾80% of the ZOPA in their negotiation (n = 92)—did *not* change their intended first price and only 11 (12.0%) weakened their intended first price. In contrast, 41 (44.6%) of the *opponents of* the 92 highest achieving participants changed their intended first price and 23 (25.0%) weakened their intended first price. In short, the very act of changing their intended first price tended to significantly compromise the outcome that participants obtained—and it did so irrespective of whether such changing involved strengthening or weakening their intended first negotiating position.

One reason for the aforementioned general discrepancies in negotiation outcomes is that the first announced prices of changers, maintainers, strengtheners and weakeners tended to differ from one another. Changers tended to announce a first price that asked for/offered a significantly smaller percentage of the ZOPA (*Mdn* = 97.2%) than maintainers (*Mdn* = 100.0%): z = -6.82, p < .001, r = -.27, and weakeners tended to announce a first price that asked for/offered the least of all (*Mdn* = 96.5%). Pairwise Mann-Whitney U tests indicated that the median first prices of these groups were all significantly different from one another.

Intended first price changers, maintainers, weakeners and strengtheners also differed in their negotiation behavior *after* their exchange of first prices. Here, the total sum conceded (i.e., the difference between each participant's first price and their final agreed sale/purchase outcome price) was analysed. This is because the level of concessions a person gives up during a negotiation commonly comprises the most economically consequential way in which first asking/offer prices are then transformed into negotiation outcomes [e.g., 5]. Contrary to expectations, changers tended to concede a significantly smaller percentage of the ZOPA (*Mdn* = 33.3%) than maintainers (*Mdn* = 33.3%), and weakeners tended to concede the least (*Mdn* = 26.7%), whereas strengtheners tended to concede the most (*Mdn* = 51.2%).

In discovering these findings our study then sought to determine, via a series of binary logistic regression tests, the following three things: i) which factors may have influenced participants to change, maintain, weaken or strengthen their intended first price; ii) when any such 'change of mind' may have taken place; and: iii) the relative level of influence of those factors that had a significant impact on participants' decisions to change, maintain, weaken or strengthen their intended first price.

3 Logistic Regression Tests

The first three binary logistic regression tests compared the following participant groups: i) 'Weakeners' vs. 'Others'; ii) 'Maintainers vs. 'Others'; and: iii) 'Strengtheners' vs. 'Others' (see Fig. 1, i-iii). In order to obtain final ('most efficient') models that captured the key predictive characteristics of the different participant groups studied, a series of preliminary univariate tests involving 21 independent variables and a total of 28 'predictors' were conducted between the different groups compared. Figure 1 presents the 21 predictor variables employed in these tests.

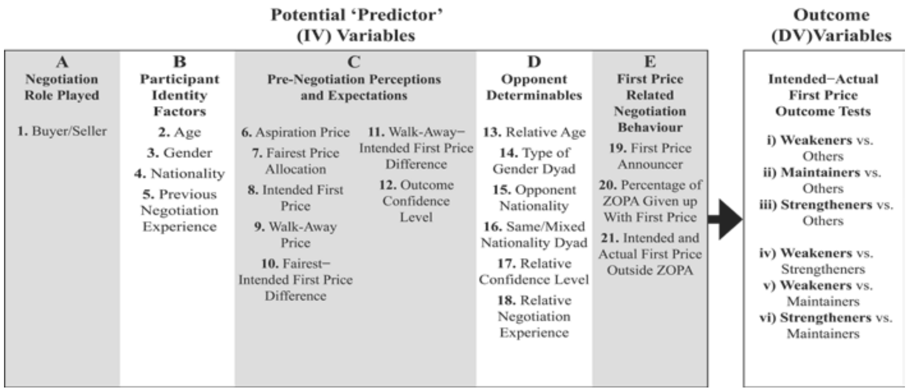

Fig. 1. Potential 'Predictor' Variables (*n* = 21) Employed in the Logistic Regression Tests

Those predictors that were not statistically significant in both the univariate (Mann-Whitney *U* and Chi-square) tests and the logistic regression 'baseline' models were taken out of the equation for each test via an iterative process of backward elimination. That is, the independent variable with the lowest Wald score and the highest non-significant *p* value had the highest priority to be removed from the model's equation [6]. Whilst doing this, any change in each model's overall accuracy rate as a result of the elimination of a particular non-significant variable was noted. If the model's overall prediction accuracy rate dropped by more than ten percent as a result of omitting such a variable it would be put back into the equation and treated as a confounder [6]. This process allows researchers to decide whether a particular, non-significant variable's effect is spurious or whether it has a unique predictive effect/influence on one or more of the other independent variables that remain in the final model, even though it may not be a significant predictor on its own. However, there were no such confounders in the final models; the highest level of influence of the non-significant predictors omitted from the final models compiled was 0.1%.

All three final models showed a significant improvement (at the $p < .001$ level) over the 'intercept only' for each model. Sensitivity ranged from 54.5% (with strengtheners as the reference group) to 81.6% (with maintainers as the reference group). The R^2_N of these models ranged from .49 to .55—indicating, for all three models—a 'medium' relationship between prediction and grouping. ROC tests revealed AUCs ranging from .86 (indicating the model was likely to have a 'good' ability to distinguish between the designated reference group and the other participants) to .92 (indicating the model was likely to have an 'excellent' distinguishing ability). All three final models had an EPV (Events Per Variable) >10. There were no collinearity, outlier or influential case issues in each final model.

Weakeners, when compared with the other participants, were significantly more likely to: i) be sellers (OR = 2.3); to have: ii) a weaker aspiration price (OR = 1.02); iii) a fairest price more favourable to themselves rather than to their opponent (OR = 1.002); iv) a stronger intended first price (OR = 1.03); v) a medium or high (rather than a low) level of difference between their fairest and intended first price (ORs = 2.7 and 2.7 respectively); vi) a high (rather than a medium) level of difference between their walk-away and intended first price (OR = 2.1); vii) to *not* be the first price announcer in their negotiation (OR = 2.4); viii) to have their intended and/or their actual first price inside the ZOPA (OR = 33.3); and: ix) to give up more of the ZOPA with their first price (OR = 1.05). All other predictor variables were not significant.

Maintainers, when compared with the other participants, were significantly more likely to: i) be sellers (OR = 3.2); ii) *not* be of Indian nationality (OR = 2.13); to have: iii) a medium (rather than a low) level of difference between their fairest and intended first price (OR = 1.9); iv) a medium (rather than a high) level of difference between their walk-away and intended first price (OR = 4.5); to be: v) the first price announcer in their negotiation (OR = 1.8); to have: vi) both their intended and actual first price outside the ZOPA (OR = 77.0); and: vii) to give up more of the ZOPA with their first price (OR = 1.04). All other predictor variables were not significant.

Strengtheners, when compared with the other participants, were significantly more likely to: i) be buyers (OR = 14.7); to have: ii) a stronger aspiration price (OR = 1.02); iii) a fairest price more favourable to their opponent (OR = 1.001); iv) a weaker intended first price (OR = 1.06); v) a low (rather than a medium) level of difference between their fairest and intended first price (OR = 6.2); vi) their intended and/or their actual first price inside the ZOPA (OR = 10.5); and: vii) to give up less of the ZOPA with their first price (OR = 1.12). All other predictor variables were not significant.

A further series of three binary logistic regression tests were then conducted. Here, weakeners, maintainers and strengtheners were compared with one another as individual groups (see Fig. 1, iv-vi). All three of these final models showed a significant improvement (at the *p* < .001 level) over the 'intercept only' for each model. Sensitivity ranged from 57.3% (in the strengtheners vs. maintainers test) to 95.1% (in the weakeners vs. strengtheners). The R^2_N of these models was .82 (weakeners vs. strengtheners test), .55 (weakeners vs. maintainers), and .51 (strengtheners vs. maintainers), indicating, respectively, a 'good, 'medium' and 'medium' relationship between prediction and grouping. ROC tests revealed AUCs of .97, .90, and .88 respectively, indicating that the models were likely to have an 'excellent', excellent and 'good' ability to distinguish between the designated reference group and the other, compared participant group. All three final models had an EPV >10. Again, there were no collinearity, outlier or influential case issues in each final model.

Weakeners, when compared with strengtheners, were significantly more likely to: i) be sellers (OR = 6.1); to have: ii) a weaker aspiration price (OR = 1.06); iii) a fairest price more favourable to themselves (OR = 1.01); iv) a stronger intended first price (OR = 1.15); v) a medium or high (rather than a low) difference between their fairest and intended first price (ORs = 7.5 and 11.5 respectively); vi) their intended and/or their actual first price inside the ZOPA (OR = 250); and: vii) to give up more of the ZOPA with their first price (OR = 1.21). All other predictor variables were not significant.

Weakeners, when compared with maintainers, were significantly more likely to have: i) a weaker aspiration price (OR = 1.02); ii) a fairest price more favourable to themselves (OR = 1.001); iii) a stronger intended first price (OR = 1.03); iv) a high (rather than a medium) level of difference between their walk-away and intended first price (OR = 3.9); to: v) *not* be the first price announcer in their negotiation (OR = 2.5); and: vi) to have their intended and/or their actual first price inside the ZOPA (OR = 83.3). All other predictor variables were not significant.

Strengtheners, when compared with maintainers, were significantly more likely to: i) be buyers (OR = 12.6); to have: ii) a stronger aspiration price (OR = 1.02); iii) a weaker intended first price (OR = 1.04); iv) a low (rather than a medium) level of difference between their fairest and intended first price (OR = 5.0); v) their intended and/or their actual first price inside the ZOPA (OR = 27.0); and: vi) to give up less of the ZOPA with their first price (OR = 1.10). All other predictor variables were not significant.

4 Discussion and Conclusion

This study found that negotiators who maintain, change, strengthen or weaken their intended first asking/offer price comprise persons who have significantly different identities and pre-negotiation perceptions who engage in systematically different forms of negotiation behavior and tend, as a consequence, to secure different negotiation outcomes. Almost all the evident outcome-compromising 'damage' that intended first price changers engaged in tended to occur at the very beginning of their negotiation and was the result of the relatively weaker or stronger first asking/offer price they tended to announce compared to intended first price maintainers. Generally, post-first asking/offer price behavior—in the form of the level of concessions the participants subsequently made during their negotiation—did not have the same level of influence on negotiation outcomes.

In addition, whilst a number of personal identity and ‘opponent determinable’ factors (such as buyer/seller role played, participant nationality, opponent nationality and relative age difference) occasionally were also significantly related to the type of first asking/offer price the participants announced, it was the pre-negotiation *price-related* variables (and their relationship with other price-related variables) that generally had the highest level of impact on: i) whether a participant’s first announced price was weaker, stronger or the same as their intended first price; and: ii) how strong or weak the intended first asking/offer price they announced tended to be.

But why did so many participants change their intended first price and announce a stronger or weaker first asking/offer price? The most plausible reason seems to be some form of uncertainty—for instance, that intended first price changers were, in some way, relatively less sure than maintainers about some aspect(s) of the task that lay ahead of them and/or their ability to perform successfully during their negotiation. This general uncertainty appears, primarily, to derive from a combination of misplaced participant perceptions that were allied to an even lower level of negotiation skill than what was typically the case for the higher performing participants in the dataset studied. Certainly, the type of intended first price changing that many of the participants engaged in tended to tell us more about the changers themselves than it did about their particular opponents.

These findings have a number of implications for negotiation researchers. In particular, by omitting to take intended first prices into account in the analysis of *any* form of price-related negotiation behavior, researchers are likely to seriously compromise their ability to accurately understand not only the particular type of negotiation conduct they are examining but also other directly and indirectly related negotiation processes more generally. For example, although many studies have shown that first announced asking/offer prices have a major ‘anchoring effect’ impact on negotiation outcomes [e.g., 5, 7-13], very little of this research appears to have recognized that the first asking/offer price a person actually does announce during their negotiation may have been different to and (even more importantly) significantly influenced by the first price they *intended* to announce.

Finally, this paper has explored a ‘hidden’ process that has an evident and significant impact on both the course that a negotiation takes as well as its outcome. Whether a negotiator changes his or her intended first price and/or announces a first price that is stronger than, weaker than or the same as his/her intended price is not something that ordinarily is publicly expressed by a negotiator; nor is it something a negotiator can readily determine from their opponent’s first announced price. Nevertheless, this study has indicated that such important yet hitherto under-researched and privately held factors can actually be located and formally examined by researchers and, moreover, that their impact on negotiation behavior and outcomes can be determined and explicated in some detail.

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Structuring Objectives for Public Wastewater Infrastructure Decisions as Evolutionary Process

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Abstract. Sound decision making rests on a thorough understanding of the objectives that should be achieved. The process of generating or identifying and then selecting and agreeing on a set of decision objectives is shaped by individual capacities and social interaction. The structuring process is decisive in framing the decision and discussion. This is critical in decisions around public infrastructure where decision makers, stakeholders, and implementing organizations coincide only partially. With this research we aim at investigating the structuring of objectives for real-world decisions on wastewater infrastructure. We explore breadth and depth of objectives' generation, procedures and criteria for selection and reduction of a set of objectives, and how both can be related to an explanatory model of such a process.

Keywords: multicriteria decision making, decision objectives, structuring process, multi-organization, public infrastructure, wastewater

1 Introduction and theoretical background

Rational decision making is based on objectives that should be achieved [e.g., 1]. These decision objectives are generated, formulated, structured, and refined in a process that is often iterative. As the objectives define the content of the evaluation, analysis, and also discussion around decision alternatives, different sets of objectives potentially lead to different decision outcomes [2].

The process of eliciting and structuring objectives, while often considered "more of an art than a science" [3], will influence the set of objectives the decision makers will end up with. In group decisions, this process is inherently a social process, subject to interpretation and negotiation [e.g., 4]. Both, the decision analyst or facilitator and the participants will shape this process to varying degrees, depending, e.g., on roles and personalities of those involved, institutional boundaries, and case characteristics.

Several approaches and methods have been developed to bring some rigor and clarity to this "art" [e.g., 5]. Particularly in problem structuring methods decision objectives are often identified at some point in the process [6, 7]. Bond et al. [8, 9] have found empirical evidence that decision makers are unable to specify all objectives they consider relevant for their decision and provide some

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recommendations for supporting objectives' generation. However, guidance on the process of structuring objectives is still limited [e.g., 10, 11].

Every objectives structuring process will be unique. However, there are common characteristics, which can be abstracted to a model or a more general theory of this process. The process of starting with a unclear collection of concerns to arriving at a concise objectives hierarchy, can be described as consisting of a phase of "opening up" and "closing down" [cf. 12], or a diverging and a converging phase [13]. This description can also be useful from a prescriptive standpoint, as the opening up phase calls for consideration of a range of objectives and alternatives while the closing down phase brings the decision problem into a form that can be solved by decision analysis procedures. While valuable as a high-level description of the structuring process, this model is quite limited for explaining the process and patterns that occur within.

In the process research literature more general archetypes or models of processes are discussed [14]. Transferring these ideas to the objectives structuring process, a compelling proposition for an explanatory model could lie in an evolutionary theory of process [15]. It is based on an analogy of biological evolution to an evolution of ideas [16]. This theory explains process as interplay between mechanisms of variation, selection, and retention. In objectives structuring we may consider variation of objectives as starting point, followed by a selection through different mechanisms, and a retention of those objectives that prove fit or useful in some sense. This process explanation adds detail to the two-phase model introduced above.

Where water and wastewater services are provided by a public provider, decisions in urban water management are public decisions, as they affect the whole population. These decisions are traditionally technocratic and solved by engineering companies by optimizing cost under constraints of thresholds given by law. However, there is growing interest in breaking up this technocratic paradigm and promoting more holistic and also multi-criteria approaches to decision making [e.g., 17, 18].

Such public infrastructure decisions are an interesting study case to investigate the topic of objectives structuring. Here, the group of stakeholders or problem owners may be much larger than the group of decision makers and not necessarily overlap. This requires an even more careful structuring process, as decision makers not only need to consider their personal or organizational objectives, but also those of third parties (e.g., citizens, future generations).

2 Research topic

The aim of this research is to explore the objectives structuring phase for public wastewater infrastructure decisions with the purpose of contributing to better practices in this field. The research will investigate five propositions that were derived from previous work and theory. In the following the propositions are first listed and then briefly motivated.

1.) When unaided, decision makers will identify decision objectives that are variations of the same few themes or categories, thereby neglecting less salient decision dimensions. They are unable to generate all decision objectives they consider to be of relevance.

2.) Intervention by the decision analyst can lead to a more comprehensive and deliberate objectives set.

3.) When faced with the need to reduce this set to the most relevant objectives, decision makers revert to objectives they had in mind first, not considering less common problem dimensions.

4.) Intervention by the decision analyst can lead to a more deliberate selection process which favors a broader perspective on the decision.

5.) Considering objectives structuring in terms of an evolutionary process, can be helpful in explaining propositions 1-4.

Propositions 1 and 2 have been investigated in similar form by Bond et al. [8, 9] who found that decision makers indeed have trouble articulating all objectives they consider important when unaided, but can improve with aid [8]. We will explore whether this pattern also can be seen in real-world cases of public decision-making. Here, it is of special interest, in how far objectives of less salient decision dimensions and objectives of the wider public are taken into account by their representatives.

Propositions 3 and 4 are based on the ideas of "anchoring" [19] on a psychological side as well as "lock-in" [e.g., 20] or "crisis of innovation" [21] on a socio-technological side. While acknowledging that transition processes in infrastructure systems are a highly complex interplay of factors and forces, a narrow consideration of objectives in decision making contributes to perpetuate "business as usual", even though other solutions may outperform traditional approaches [22].

The proposition of an evolutionary process model is based on previous studies on objectives structuring in this context [17] and first observations in the case studies. Objectives that are initially brought forward in these cases are for the most part small variations of common themes (e.g. economic feasibility). The decision analyst may try to increase this variation by introducing other themes (e.g. resource recovery). The subsequent selection process may sort out those objectives that do not "fit" to the decision problem. This can be for practical reasons, e.g. they do not help distinguish between alternatives, but also other reasons, such as political ones. Objectives that are in some sense useful will be retained. In an iterative structuring process several such evolutionary cycles can occur. It will be determined how far this model is suitable for explaining the empirical findings, or if they lend themselves to a different explanation.

Independent of the empirical evidence turning out to be consistent or inconsistent with these propositions, they serve as guideposts for a better understanding of the objectives structuring process. On the empirical side, we gain insight into the capabilities of decision makers to generating and selecting objectives for public decisions with and without support. On the practical side, we hope the findings will support consultants to build useful and valid objectives hierarchies for wastewater infrastructure decisions. The experiences can result in recommendations on how such a process may be designed for decisions of similar nature. On the theoretical side, empirically grounding a model of an evolutionary process of objectives structuring may enrich the common model of a two-phase structuring process and thus allow new questions and insights in the objective structuring phase in the future.

3 Research approach and methods

The research is conducted in the context of three real-world decision cases concerning mergers of wastewater treatment plants in Switzerland (i.e. instead of operating several wastewater treatment plants in a region, all wastewater would be routed to one, possibly newly built, treatment plant). Mergers of technical infrastructure usually involve several organizational bodies which create a planning committee, leading to multi-organizational group decision processes. If the planning committee finds agreement, in Switzerland these decisions have to be approved by the citizens of the involved municipalities, typically by public vote. Usually, an engineering consultant leads the decision process and provides technical expertise and predictions on the performance of different alternatives. The research team is involved in the cases to different degrees. It is present at meetings, can ask stakeholders for participation in research, and can provide input, but has little control over the decision process itself.

3.2 Case study research

All decision cases concern the same decision topic, but differ considerably in decision processes, type and number of involved actors, institutional arrangements, local challenges, and thus in the concrete decision problem.

The unit of analysis for some of the research questions are the individual actors. For these, the case studies represent different contexts that allow differentiation of context-dependent and independent patterns. A second layer of analysis is a cross-case comparison where we can compare outcomes (e.g. objectives hierarchies) and processes between the three cases. This allows exploring differences and similarities between cases.

3.3 Data collection and analysis

Due to external constraints in the cases the data collection will differ slightly. However, the main data collection activities are similar.

One stream of data concerns the set of objectives of each individual participant. Participants are individually asked to come up with objectives and, subsequently, to reconsider and complement their objectives for example with the help of a “master list” [see 9]. In addition, they are asked to sort and rank objectives (e.g., assigning categories of perceived importance). Elicitation of objectives is planned twice. First, early in the problem structuring phase, and then after a decision model has been formulated, i.e., when preference elicitation interviews take place. For the first elicitation we will employ an online survey. The second elicitation would take place in personal interviews, where survey information can be enriched by reasoning and explanation of the participants. For confidentiality reasons we are likely restricted to members in the planning committees, which are about 10–15 per case study.

The second stream of data is gathered in group meetings. Group meetings are recorded where possible. Depending on the case, decision objectives are also collected, discussed, and selected in group meetings under the lead of the engineering consultants with input by the research team. This results in a second collection of sets of objectives at different time points in the decision. In addition the discussions around the objectives provide a qualitative account of positions, views, and concerns of the different parties.

The most important unit of data are the sets of objectives provided by different actors at different time points, as well as ordinal data on rankings and perceived importance of objectives. Partly, these will need to be interpreted by the researcher team to homogenize phrasing, but can be regarded as quantitative data sources. Accordingly, they can be examined by descriptive statistics and, depending on sample size, inferential statistics can be applied to test hypotheses derived from the aforementioned propositions. In addition to a generalization via statistics, one line of reasoning will be to generalize the findings to existing theory. We have not decided on a way to investigate and integrate the qualitative data, yet.

4 Overview over schedule and state

The three real world cases we have negotiated access to are all in early phases of the decision-making process. We have been present at several committee meetings and data on a group brainstorming of objectives has been collected in one case (recording of discussion and collected objectives). The first individual survey of actors' objectives is planned for July to September 2017. Discussion of objectives in the planning committee is scheduled for August in one case but not clear for the others, yet. The second round of objectives' elicitation would be coupled to preference elicitation interviews for a multi-criteria decision model. This requires an agreed upon model structure and predictions about alternatives' impacts and will be scheduled contingent on this.

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Industry 4.0 - Towards Automated Supply Chain Formation

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Abstract. In the vision of Industry 4.0, most enterprise processes must become more digitized. A critical element will be the evolution of traditional supply chains toward a connected, smart, and highly efficient supply chain ecosystem. This ecosystem will enable companies to react to disruptions in the supply chain and adjust the supply chain in real time as conditions change. Algorithms will enable machines to make autonomous decisions in the digitized supply chain of the future. The current research focuses on contract negotiation in a digital supply chain formation environment by mapping the problem in terms of a directed acyclic graph where the nodes are represented by the suppliers/consumers acted by agents. Communication between agents along the supply chain is done by message exchange and provides support for negotiation of contract constraints along the network.

Keywords: Supply Chain Formation, Agent-based negotiation, Digital Manufacturing, Contract Negotiation, Decision Support

1 Motivation

The dynamic of supply networks that Industry 4.0 promises requires new mechanisms for negotiation of contracts with upstream and contracted suppliers. The supply chain formation process will undergo an organizational change mainly with respect to the connecting production facilities across geographies and company boundaries and will create new business models and disrupt current supply chain designs.

The current work considers the problem of supply chain formation as a form of coordinated commercial interaction. The considered supply chain scenario represents a network of production and exchange relationships that spans multiple levels of production or task decomposition. This supply chain model is typically used in manufacturing industries that produce complex goods (planes, cars etc.) but any service or contracting relationship that spans multiple levels can be mapped to this supply chain scenario. The current work translates the Supply Chain Formation problem in terms of a directed acyclic graph where the nodes are represented by the agents.

The agents are characterized in terms of their capabilities to perform tasks, and their interests in having tasks accomplished. A central feature in the considered scenario is hierarchical task decomposition: in order to perform a particular task, an agent may need to achieve some subtasks, which may be delegated to other agents. These may in

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turn have subtasks that may be delegated, forming a supply chain through a decomposition of task achievement. Constraints on the task assignment arise from the underling suppliers' network as exemplified in Figure 1

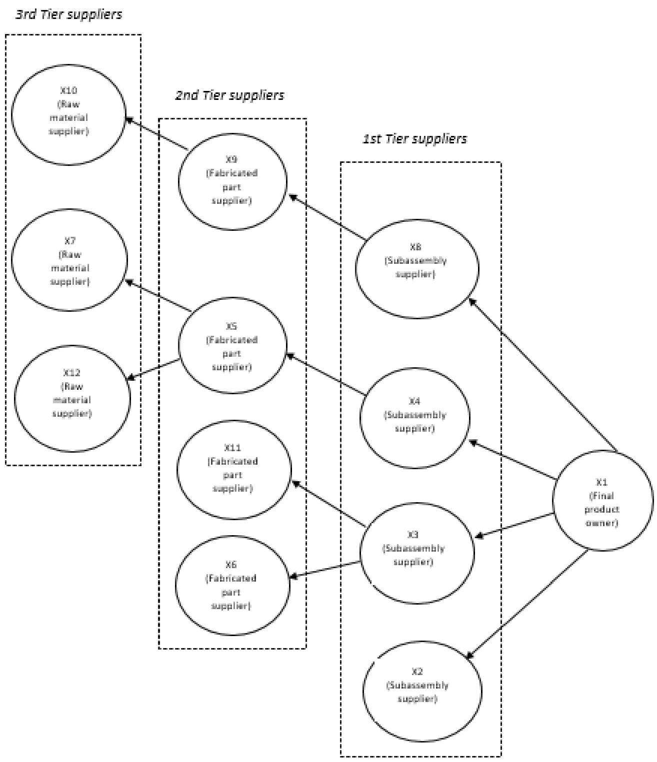

Fig. 1 Example of supply chain with hierarchical task decomposition

The final product owner X_1 at the root of the supply chain can chose among X_2, X_3, X_4 and X_8 sub-assembly suppliers. The length of the four possible supply chains is different because there may be 1st tier suppliers that are able to produce the sub assembly without further task decomposition. At lower levels a certain subassembly supplier or a certain part supplier has the option of choosing among multiple possible descendant suppliers. For example X_3 may chose X_6 or X_{11} as his fabricated part supplier and X_5 may choose between X_7 and X_{12} as raw material suppliers.

Research aims: providing support for negotiation and for linking end-consumer requirements to underlying suppliers to conjointly guarantee end-to-end agreed contract parameters.

Research challenges:

1. The contracts between partners in the supply chain involve multiple issues (cost, time of delivery, quality constraints, penalties etc.), that the involved entities are negotiating on. These give raise to different utility values for a contract of the participating agents, according to their preferences.

2. In a SCF process, an entity can be both a supplier and a consumer in different negotiation contexts at the same time. The dual role of a participant in the SCF complicates the negotiation scenarios. In particular, a participant has to confirm that its own suppliers can support the issues it negotiates with its consumer, before it commits to his own contract as a supplier.

2 Theoretical Foundations

The Supply Chain Formation (SCF) problem has been widely studied by the multi-agent systems community. Numerous contributions can be found in the literature where participants are represented by computational agents [2],[6],[3],[7]. These computational agents act in behalf of the participants during the SCF process. By employing computational agents it is possible to form SCs in a fraction of the time required by the manual approach [8]. The existing literature on SCF uses two approaches: the first one is modeling the supply chain as a network of auctions, with first and second-price sealed bid auctions, double auctions and combinatorial auctions among the most frequently-used methods [1],[2]. In the past years another type of approaches were proposed. These approaches make use of graphical models and inference algorithms to tackle SCF and related problems [4],[6],[7],[8].

2.1 Max-sum

Max-sum [9] is a message passing algorithm that provides approximate solutions for the problem of maximizing a function that decomposes additively in three steps. First, it maps the problem into a structure called local term graph. Then it iteratively changes messages between vertexes of that graph. Each vertex of the local term graph is in charge of receiving messages from its neighbors, composing new messages and sending them to its neighbors. Finally, it determines the states of the variables.

2.2 Loopy Belief Propagation(LBP)

LBP is the first peer to peer approach that has been used to solve the SCF problem in a decentralized manner[4],[5],[7],[10]. In [5], an LBP-based approach was applied to the SCF problem, noting that the passing of messages in LBP is comparable to the placing of bids in standard auction-based approaches. The work in [4] shows that the SCF problem can be cast as an optimization problem that can be efficiently approximated using max-sum algorithm [9] presented in the section above. Thus, the authors offer the means of converting a SCF problem into a local term graph, on which max-sum can operate.

3.3 Reduced Binarized Loopy Belief Propagation (RB-LBP)

As LBP suffers from scalability issues in [6] the authors introduce the Reduced Binarized Loopy Belief Propagation algorithm (RB-LBP). RB-LBP is based on the max-sum algorithm and simplifies the calculation of max-sum messages through careful analysis of its local terms. The variables are binary which simplifies the supply chain formation process and each buy and sell decision is decoupled, encoded in a different variable, from the rest of buy and sell decisions. By decoupling these decisions the algorithm is able to reduce the number of combinations to take into account.

3 Research approach and preliminary results

Multi-agent systems enable the modelling of supply chain formation (SCF) using self-interested agents for decentralized decision making and the process of information propagation across the whole network. The current paper uses the max-sum algorithm mechanism of passing messages for the values of the issues that the agents are negotiating on, the agents having an exact way to estimate the utility they get, by making use of utility functions. The agreed values of the negotiated issues are reflected in a contract which has a certain utility value for every agent. By using utility functions, they can assess the benefits they would gain from a given contract, and compare them with their own expectations in order to make decisions. During the SCF process the messages are passed between a consumer and its suppliers. Agents send messages regarding multiple contract issues: cost, time of delivery, quality indicators, delay penalties etc.

The following paragraph provides a formal description of the supply chain formation problem in terms of a directed, acyclic graph (X, E) where $X = \{X_1, X_2, ..., X_n\}$ denote set of participants in the supply chain represented by agents and a set of edges E connecting agents that might buy or sell from another.

The agents negotiate on multiple contract parameters and negotiation finishes with a contract that is composed of the actual values of the issues that they have agreed on. Notation v_i represents the expectation of a participant in the supply chain on issue *i* of the contract and U(v) the utility that a participant obtains by receiving the actual value $v = (v_{i1}, v_{i2}, ..., v_{ik})$.When a supplier (seller) negotiates with a consumer (buyer), both parties are interested in obtaining those contract values $v = (v_{i1}, v_{i2}, ..., v_{ik})$ that maximize their utility functions U(v) . This means that during the negotiation, the agent sends a messages to its neighbors regarding the states of his variables that is maximizing its utility function.

The utility functions U(v) will be calculated by means of weighted sum as follows:

$$U(v) = \sum_{i=1}^{k} w_i * v_i \ , \ with \ \sum_{i=1}^{k} w_i = 1 \qquad \textbf{(1)}$$

where $0 <= w_i <= 1$ represent the weights measuring the importance of a given issue *i* for a certain agent in the chain.

The agents don't know each other utility functions, they are aware only of the values of the discrete states variables they share. Each agent interacts with its neighbors agents such that the utility of an individual agent U(v), is dependent on its own state and the states of these other agents.

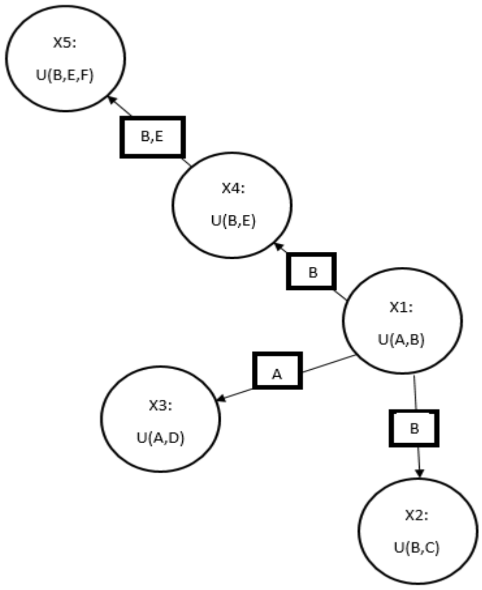

Fig. 2 Example of supply chain with agents sharing state variables

Solving the problem stated above provides means for finding an allocation that maximize each agent utility in the supply chain within the underlying partners' constraints.

An allocation is a sub-graph (X',E') ⊆ (X, E). For Xi, Xj ∈ V ', an edge between X_i, X_j means that agent X_j provides goods to agent X_i. An agent is in an allocation graph if it acquires or provides goods.

In the graph in Figure 2 each node represents a participant in the supply chain. Each two nodes share at least one issue that they must agree on, and the value that they have agreed on, must be propagated from the underlying suppliers to the upper level of the supply chain. Figure 3 shows how the message is send between node X_1 and X_2 and back, when the agents have to agree on the issue B of a potential contract.

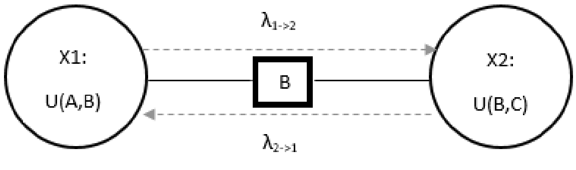

Fig. 3 Messages sent from X_1 to X_2 and back when they negotiate on issue B

By sending the message in equation (2), X_1 says to X_2 which is his preferred value from the set of values for issue B.

$$\lambda_{1\to 2}(B) = max_B(U(b_j, c_k) + max_A\left(U(a_i, b_j)\right)) \qquad \textbf{(2)}$$

X_1 sends the max-marginalization of B over A ($max_A(U(a_i,b_j))$) and then adds the computed utility of agent X_2 and then computes the max marginalization of B over the above terms.

Agent at node X_2 evaluates using his utility function, the utility that he gets for each combination of values from the set of values for issues B and C. X_2 send to X_1 the message in equation (3), which is his preferred value from the set of values for issue B.

X_2 sends the max-marginalization of B over C (max_C $(U(b_j ,c_k))$) and then adds the computed value for utility of agent X_1 and then computes the max marginalization of B over the above terms.

$$\lambda_{2\to 1}(B) = max_B(U(a_i, b_j) + max_C\left(U(b_j, c_k)\right)) \qquad \textbf{(3)}$$

The messages are scheduled starting from leaves and then are propagated upward towards the root.

4 Experimental Evaluation

In order to validate the proposed model in section 2, PeerSim simulator was selected. The reasons for making this choice are the PeerSim performance regarding scalability and because it is based on components that allows prototyping a new protocol, combining different pluggable building blocks. [11].

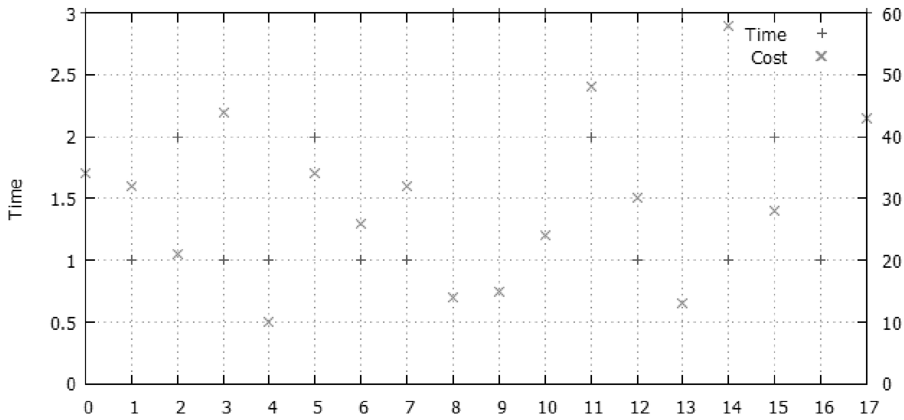

Fig. 4 Initial random states for variables time and cost

The network used for the current simulation has 18 nodes and each node has three possible partners that he can trade with. The initial random states for variable time and cost are presented in Figure 4. Each node *v* has a vector of numeric values that are the preferred states of the negotiated issues. The considered issues for negotiation over the supply chain are: delivery time and cost. The delivery time is measured in months and the cost is measured in the amount of money spent and it has been divided by 100 for the simplicity of the illustration of the values obtained. Also each node owns a utility function which is computed as a weighted sum from each of the issues that the agents in the supply chain are discussing on.

At the beginning of the simulation all the agents in the network are being initialized with random preferred values for the states variables and also for the weights used at computing every agent utility. Each node that is not a leaf is receiving messages from its neighbors, composing new messages and sending them upward to its neighbors.

Each node will assess messages received from the corresponding neighbor according to his own utility function and will chose among all the possible partners the one that maximizes his utility function. Note that there are agents whose utility remain 0 after running the protocol because they remain inactive during the supply chain formation process. The final states of the variables and utility obtained by each agent are illustrated in Figure 5.

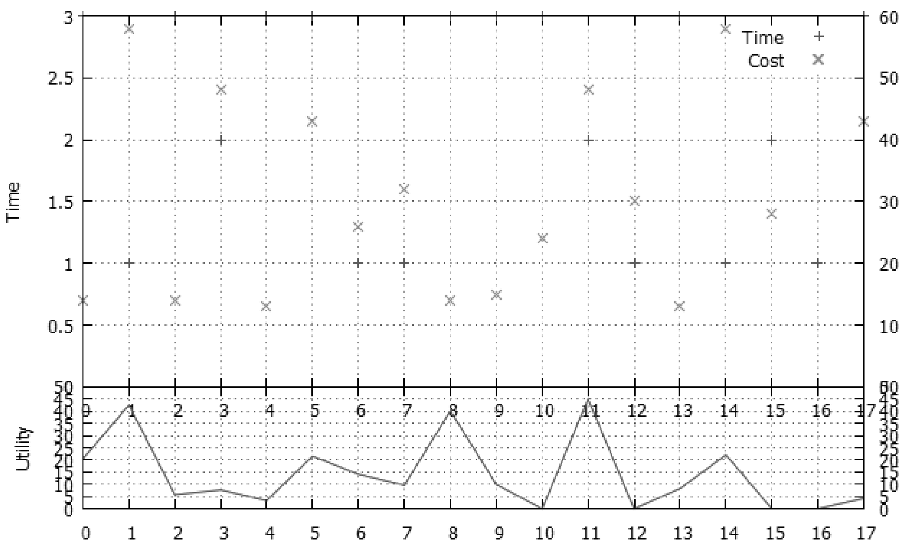

Fig. 5 Final states for variables time and cost and utility obtained by each agent

There are three possible allocation sub-graphs, illustrated in Figure 6. The first solution that the implemented protocol finds is the allocation sub-graph being formed of the following nodes {X_{11},X_3,X_0}and the utility that the end-consumer gets is 16.64 with the states of the variables being propagated to the root (t=2;c=48)

The second solution that the implemented protocol finds is the allocation sub-graph being formed of the following nodes {X_6,X_1,X_0} and the utility that the end-consumer gets is 19.14 with the states of the variables being propagated to the root (t=1;c=58).

The propagation of the states of the variables for agent X_2 has two phases: in phase

1 the agent X_2 chooses X_9 as a partner as it finds that the utility that he gets is higher than the previous one but in phase 2 the agent chooses agent X_8 as he gets an even higher utility that the one provided be agent X_9. The delivery time is shorter and the cost is higher than the ones at the allocation in solution 1 and according to the utility function of the agent at node X_0 it provides a higher utility. The agent gets a higher utility if the required component is provided in shorter time event it costs more.

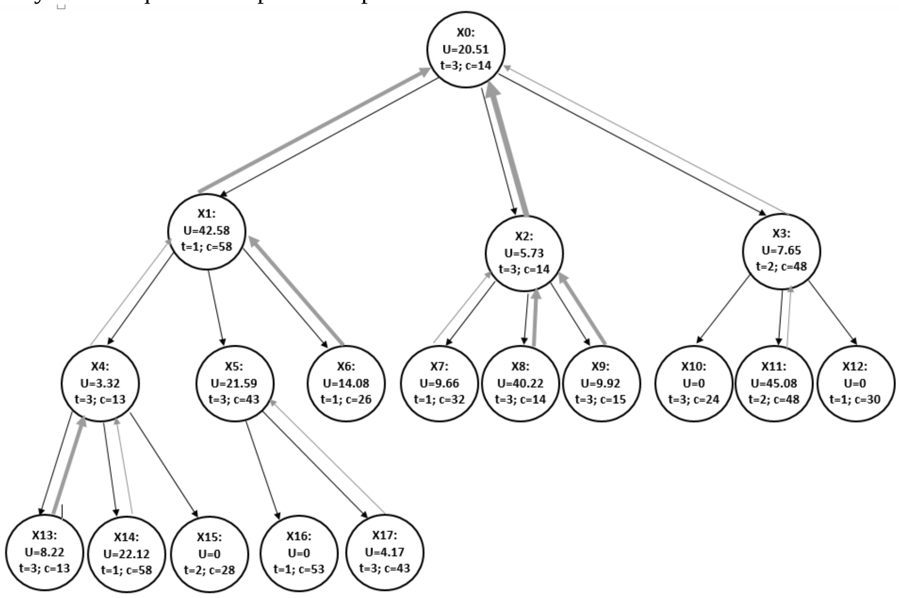

Fig. 6 Possible allocations

The third solution that the implemented protocol finds is the allocation sub-graph is being formed of the following nodes {X_8, X_2, X_0} using the propagation at the previous solution it propagates further the states of agent X_2 to the root and the utility that the end-consumer gets is 20.15 with the values states of the variables (t=3; c=14). The delivery time is longer but the cost is much lower that the allocation at solution 2 and according to the utility function of the agent at node X_0 it provides the maximum utility.

5 Reflections

As opposed to the previous decentralized approaches, the current approach incorporates multiple negotiated issues and uses utility functions in order to compute and maximize utility in the supply chain. The current approach that this work presents uses message passing between agents during the supply chain formation process and is closer to real life scenarios than the previous approaches that were using only cost as a mean for pairwise agents.

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Insight Oriented Intuition as a New Negotiation Strategy

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Abstract. The problem of negotiation in ill structured group decision problems is considered. An approach to solve such problems is proposed for the cases with the lack of measurable information related to a problem. The approach recommends insight-oriented intuition to apply. The proposal presents a research frame which allows to tackle issue of identification of reliable intuition occurrence and the problem of measurability of potential of intuition of a negotiation player. The proposal addresses the issue of implementation of intuition into negotiation process. The preliminary research results indicate that reliable intuition can be identified and the measurement of potential of intuition is feasible, at least in laboratory conditions. Further studies within this concept are discussed.

Keywords: negotiation strategy, intuition, leap of faith, insight, experts, decision-making, problem-solving

1 Introduction

The technological breakthrough in the processing of information on the one hand and the globalization of transactions as well as the integration of economic systems on the other hand, has led to groundbreaking complications in the negotiations aimed at agreeing contracts. New features of current and future negotiation situations include: changing complexity of the surrounding environment, changing scale of intercultural interactions, and changing pace of the environment. The market must presently function in conditions where the number of factors and complexity increase and the process of modeling decision problems and correcting procedures do not the keep up with the flow of incoming information [1]. In effect of this civilization breakthrough, ill structured negotiation situations are increasingly occurring requiring decision-making based on intuition. Thus, there exist a necessity to rethink the classical methods of carrying out business transactions for ill structured negotiation problems.

Works dealing with the methodology of this field of science, underline a need to conduct basic research devoted to including unmeasurable, subjective factors and information gaps in decision-making analysis. Druckman [2] indicates this area as an important research development direction. He states the moment to undertake the issues happening “at *the negotiating table, around the table, and away from the table*” in situations when missing data preclude explicit analysis.

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Negotiation is a strategy that is utilized when different or even contradicting interests of two parties occur. Both parties are interdependent to the extent an agreement would be mutually beneficial [3]. Negotiation situation in characterized with incomplete information parties possess on themselves [4]. That is why progressing the process of negotiation might be very difficult.

Intuition is found to be a helpful mechanism to support decision-making in ill structured situations and lack of measurable information related to the problem [5]. However, there are studies that show intuition could be misleading [6]. A frequent lack of ability to justify the source of intuition makes intuition a problematic element of decision-making process [7]. However, what if unsupported intuition could lead to explicitly supported insight?

Intuition is defined as *"affectively charged judgments that arise through rapid non-conscious and holistic associations"* [8] whereas *insight* is perceived to be "*sudden unexpected thoughts that solve problems*" [9]. In the paper, this definition is clarified and made more precise: *insight results from knowledge, experience and the right judgment about problem and its causes, it occurs in form of sudden unexpected thoughts that solve problems due to enabling deliberate justification of solution.* In other words, intuition may provide solution but not necessarily justification for this solution, while insight allows to explain why a recommendation solves the problem. Both processes appear unexpectedly but, contrary to intuition, insight could be justified with previously collected information. Moreover, as intuition communicates its results only in form of feelings [10], insight provides solutions that are fully understandable [11]. The above mentioned characteristics indicate insight to outperform intuition in the process of problem-solving. However, there is no theory that explains what triggers its occurrence.

While we don't know what initiates the process of gaining insight, we can't reliably support its occurrence in decision-making process.

There are no studies indicating that intuition leads to insight. However, there are some hypotheses that assume this possibility [12]. One of the reasons that intuition and insight were not considered to be interdependent is caused by different scientific fields studying those processes [13]. If it will occur that intuition can lead to insight, this insight oriented intuition could become a reliable negotiation support in situations where missing data preclude explicit analysis.

Another issue concerns individual differences in accuracy of their intuition [14]. Among different factors, experience [15] and individual abilities [16] are found to determine accuracy of intuition. That is why, the negotiation process should be supported with intuition from participants with its highest potential. Results of previous studies provided by the author of the paper, indicated that it is not the preference for intuitive over analytical thinking that make people utilize intuition accurately.

It's rather the potential of intuition[1] that allows prediction of its reliability in future judgments [17]. The problem here concerns the method that would enable intuition potential measurement. As there are questionnaires to assess preference for intuitive decision-making [18], there are no tools that will allow to predict accuracy of one's intuition.

2 Research Plans/Methodology

The project aims at a new approach to solve ill structured problems in situations of missing measurable information. This approach recommends implementation of intuition providing a subject with insight. This goal of the project splits in two parts. The first part concerns verification of a significance and interrelation between intuition and insight in ill structured decision-making problems. The second part is devoted to a construction of a negotiation support procedure which will expand classic methods with the concept of intuition. These goals require verification of the following research hypothesis:

Hypothesis 1: There exist ill structured negotiation situations when intuition influences negotiation process.

Hypothesis 2: There exist ill structured negotiation situations when intuition leads to insight.

Hypothesis 3: There exists a measure of players in terms of intuition potential in a class of ill structured negotiation situations.

Hypothesis 4: For a class of ill-structured negotiation problems, there exist a procedure of negotiation support which increases effectiveness of negotiation due to an increase of potential of intuition.

In order to verify previously stated hypotheses, a series of experiments within three different studies are planned to be conducted. The studies assume use of a mix of methods which enable researcher to confirm her claims on intuitive behaviors. These methods involve analysis of results of experiments with (mostly student) subjects. Experiments are prepared as negotiation games with real pay-offs. The analysis is to take into account changes during the game and games' process. These changes are revealed in descriptions of positions in games (e.g. numbers, written statements of position in each round of the game etc.). Also, measurement of unconscious physiological reactions during the process reflects changes resulted from solving behavior. Consequently, players behaviors will be described twofold. Firstly, the natural (words) or formal language (numbers etc.) describes subject of negotiation. Secondly, as far as internal players' reaction is concerned, the process of solving is reflected also in register of measurable physiological reactions – changes in skin conductance.

[1] In this paper intuition potential is perceived as an ability to utilize intuition when it leads to correct decisions.

2.1 Study 1 – Intuition leading to insight

Preliminary studies provided by the author of the paper were conducted on experienced police criminal intelligence analysts. Results indicated that, in the absence of clear facts, experts use intuition to find an anchoring point for data analysis. Subsequently, they take leap of faith to interpret their intuition and to define direction for further data collection and analysis. While explicit and probably unconscious data analysis, analysts gain insight with a solution to a given problem [19]. This strategy seems to be very helpful in situations when missing data preclude analysis decision-maker is fully aware of (see description of the process in Fig. 1).

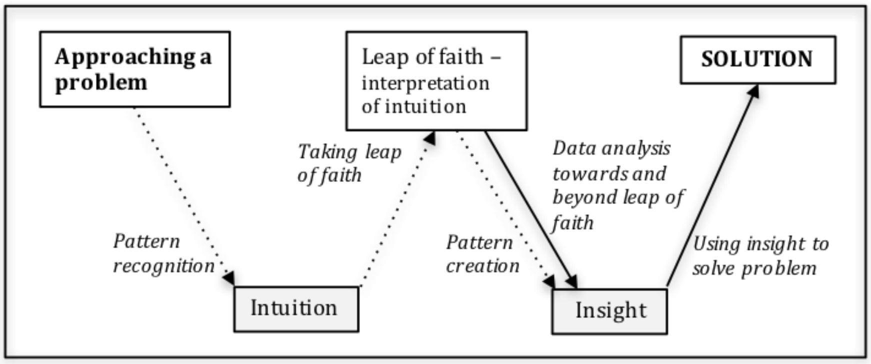

Fig. 1. A mix of conscious and unconscious processes in situations of missing data employs expert intuition to find an anchoring point and a leap of faith to direct the search for solution to a problem. Data analysis allows to gain insight that provides a solution to a given problem.

Study 1 will be a continuation of the preliminary studies. The author of the paper proposes an experimental procedure to identify an ill structured situation where intuition leads to insight during negotiation process. More precisely, a hypothesis will be verified that intuition is a triggering factor for searching information leading to insight.

In the study 1, according to the procedure provided in Iowa Gambling Task (IGT) [20], negotiation games in form of human-computer interaction will be designed. The games will contain a dominating strategy that leads to consensus and they will take into account different negotiation styles (according to the Mastenborek's classification [3]). The study anticipates two phases. Phase 1 heads to detect intuition occurrence and phase 2 – manifestation of insight. The scenarios will base on case studies and the games will anticipate real payoffs. The experiment will allow to verify the subsequent partial hypotheses:

A. Intuition co-exists with a specific skin conductance,
B. Intuition could be ignored,
C. Inclusion of intuition leads to better negotiation strategies,
D. Inclusion of intuition improves negotiating process.

2.2 Study 2 – Intuition potential measurement

Study 2 will be a continuation of previous research provided by the author of the paper. Results of the study allowed to detect individual differences in ability to implement intuition while solving problems among entrepreneurs [17]. A tool created for this research will be further developed and implemented in the context of group decision making. The aim of this study is to confirm a hypothesis about existence of individual differences in ability to implement intuition while problem solving as well as a feasibility of measuring those differences.

2.3 Study 3 – Implementation of intuition into negotiation process

Study 3 uses results from Study 1 and Study 2 in order to verify hypothesis that there exist a procedure of negotiation support which increases effectiveness of negotiation due to an increase of potential of intuition. According to the hypothesis, increasing group intuition potential (by adding to the negotiation team people with a high intuition potential), will lead to better results. Subsequent partial hypotheses will be considered:

A. Introducing negotiation participants with high intuition potential will increase frequency of utilizing intuition,

B. Negotiation teams with higher group intuition potential will gain more insights,

C. Negotiation teams with higher group intuition potential will achieve better results (more consensus) than teams with lower potential.

3 Scientific/practical merit

Based on results of the research project, a new dimension into negotiation process may be introduced – insight oriented intuition. Intuition could be implemented by providing additional experts to the process of negotiation in situations when missing data preclude explicit analysis. Experts with task relevant experience and high intuition potential could support negotiation process. In situations when negotiation participants can't progress a certain moment, experts' intuition could be helpful. Experts would use their intuition to find a starting point for searching solution to a given problem. Afterwards, they will take a leap of faith to interpret their intuition and to indicate direction for data collection and analysis. While receiving and analyzing collected data, experts or negotiation participants would gain insight with a right solution to be implemented. Moreover, results of the study could be intoduced in the process of creating a profile of a negotiation team where team members could be selected with respect to a need for a more or less intuitive strategy.

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Living the Brand in Negotiations – Internal and External Brand Management in Negotiation Context

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Abstract. Previous research in consumer marketing has identified branding as a powerful marketing tool. Only recently, research could acknowledge that branding is also suitable for business-to-business (B2B) relationships and capable for creating an emotional bonding with the brand. In B2B interactions, which are highly dependent on the personal exchange, the human acts as a personification of the brand. As products become interchangeable, in a growing competitive environment, there is an increasing need to differentiate the brand. One of the most relevant brand touch points in an B2B environment are negotiations. In negotiations, one can have a direct experience with the brand. Consequently, an accurate brand representation is required. While prior research has proven, that branding is a crucial part of the overall company success, it is rather surprising that no research exists, that analyzes the applicability of brand management in negotiations. This dissertation is aiming to close this research gap.

Keywords: negotiations, brand management, corporate branding, brand strategy, business-to-business marketing, brand personification, brand representative

1 Motivation, research aims and research questions

From a historical perspective, branding developed out of the consumer marketing. In business-to-consumer (B2C) marketing, branding is seen as a technique to enhance the value of a product [12]. Because products are mainly bought in order to serve a functional purpose, branding offers an opportunity to increase the emotional value [12]. Consequently, the functional and emotional brand attributes are one of the most important indicators for B2C buying decisions [11], [13].

For the application of branding into the business context, the brand concept has to be adjusted [19]. In B2B transactions, buying decision made by the company, are quite different, not only in monetary terms but also in the collective manner of deciding [4]. This decision making process can be described as highly rational [13], [31]. Furthermore, the success of B2B interactions is highly dependent on personal exchange [4]. Nevertheless, for a long period, the concept of B2B branding has not attracted a lot of attention from the marketing science, due to the limited practical relevance [4]. Recent changes in the marketplace have led to a new perspective on branding in B2B interactions [4]. Due to the growing global competition, the need for differentiation, higher prices and the complexity of products and increasing commoditization,

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industrial companies are now becoming more and more aware of the use of branding [4], [25], [26]. Furthermore, from an internal branding perspective, the use of the employee in his role as a personification of the brand is highly important in markets, where personal relationships are needed [17]. Therefore, personal communication remains a significant opportunity for creating brand value [21]. Thus, in the B2B environment the sales force is one of the most capable ways of delivering the brand promises and holds a major role in communicating the emotional brand values [22], [30]. So far, the benefits of humanizing the brand by the employee as a brand representative in B2B setting are under researched [6], [14], [15].

The concept of the human as a brand representative originates out of the B2C marketing and has been applied in the service context [3], [18], [30]. The idea of the brand as a person can be realized in many different ways [3]. One method is to humanize the brand through the employee and therefore make the brand come alive and perceivable for the customer. Due to the lately changed perspective on B2B branding in the practice, the marketing science has become attentive to brand management in business relationships. Only recently, studies have been conducted which indicate the relevance of the affective component of the brand in business relationships [22]. Additional studies could acknowledge that the perceived brand experience is highly dependent on the personal employee interaction [5]. Moreover, it could be observed that brand congruent employee behavior in personal face-to-face situations, has an impact on customer satisfaction [7], [16], [28], [34], [35].

From the perspective of brand management, branding is necessary, when it is highly effective and efficient to communicate the brand message. Therefore, brand managers have to identify the relevant brand touch points. Brand touch points are situations in the interaction between a company and a business customer, where the business customer can directly perceive the brand [8]. Thus, in a B2B interaction, brand consistent employee behavior is of crucial importance. A very common brand touch point in B2B relationships are negotiations. In these conflicting situations, one can examine the brand directly and very intensely through the negotiator in his role as a personification of the brand. Consequently, the negotiator is acting as a brand representative. Hence, negotiations are a highly relevant application area for brand management.

Although, negotiations are an essential part of everyday business life, they can occur in many different forms. These different forms have to be distinguished from each other. The reason for the appearance of the diversity of negotiations is the high individuality and situational dependence of negotiations in a business context. Even though, one can classify different forms of business negotiations (e.g. sales negotiations or M&A negotiations), they are all characterized by a high degree of complexity. Some characteristics for distinguishing negotiations are the frequency, the organizational affiliation and the form of the settlement [32]. In general, a negotiation is defined as an interaction between at least two parties with conflicting interest's respectively partially different preferences that concludes with a certain negotiation outcome [20]. Furthermore, the parties are aiming to find an agreement about one or more objectives, whereby all parties are trying to influence the general solution to their benefit [32]. Therefore, one can understand a negotiation also as a joint decision making process between at least two parties [32]. Constitutive features of a negotiation are for example the participation of more than one organization, the congruency of goals, the conflicting preferences, the possibility of reaching a solution and the interactive process [32].

While prior research has proved that negotiations and the brand depict a significant part of the overall company success and value, it is rather surprising, that no research exists which provides comprehensive knowledge regarding the potential usage of branding in negotiations. The aim of this dissertation is to close this research gap. Thus, the objective of this dissertation is to examine a possible application of branding and the implementation of the concept of humanizing the brand through the negotiator in a negotiation context.

To fulfill this intention, different questions have to be considered. First, one could argue, that when the brand is humanized through the negotiator as a representative of the brand in a negotiation, a better negotiation outcome can be reached (research question 1). This negotiation outcome refers to the individual negotiation outcome and the satisfaction with the relationship. Another perspective on the objective of this dissertation can be given by examining the benefits of humanizing the brand during negotiations in general, not only for the specific negotiation but also for the brand as a whole (research question 2). For example, one could have a positive experience with the brand when personified through the negotiator during the negotiation, which could lead to a positive brand perception, a better brand attitude and a better understanding of the brand. All of these brand indicators could lastly lead to an increase in the brand value. Finally, it is necessary, in order to give a holistic view on the topic, to take an internal branding perspective and therefore to indicate the requirements for turning employees into brand representatives (research question 3). Insights into the necessity for an effective brand personification in negotiations are highly needed. For example, the internal brand management has to ensure a sufficient brand knowledge and therefore a high brand commitment of the negotiators in order to guarantee an optimal brand representation.

2 Theoretical foundations

Due to the globalization of the markets and the increasing competition, it has become necessary for companies to differentiate themselves [8]. Especially in B2B interactions, it is important to generate a relationship with the business customer. In markets where the actual product becomes a commodity, the emotional factors are gaining relevance. Therefore, in order to retain a competitive advantage, an increasing number of B2B companies have started to initialize brand management. This emotional bounding can be reached through the creation of a relationships with the brand, which in the case of business settings, is mostly the corporate brand [4], [8]. Brands are therefore a highly relevant part of the company value [8]. In literature, this specific value created by the brand is defined as brand equity [2]. Brand equity can be understood as a psychographic or economic value [23]. The psychographic value of a brand, also defined as brand strength, is related to the perception of the customer as well as the behavioral relevance [9]. Whereas the economic value of a brand is related to a monetary meaning [9]. Due to the fact, that branding is an investment for a company, the benefits of this capital spending have to be precise and clear [19], [1]. Recent research on B2B relationships demonstrates a strong impact of branding on the product and service quality perceived by the business customer [10]. This indicates that having a strong brand can lead to a competitive advantage [1], [27].

A conceptual approach, that describes how a company can capture the value of the brand, is given by the theory of the identity based brand management, which originates mainly out of the approach of Aaker, who takes a value-based view on the brand management [2], [8]. This value-based perspective respectively the approach of the identity based brand management will be the theoretical foundation for the dissertation [8], [29]. In the theory of the identity based brand management, a brand is “a bundle of benefits with specific features” [8]. These features ensure that one bundle of benefits, compared to another bundle of benefits that meets the same basic needs, is sustainably differentiated from the viewpoint of the relevant target group [8]. The benefits of a brand can be physical or symbolic [8]. The sum of all of these benefits sends external signals that are perceived by the target group and lastly reflected in the brand image [8]. The brand image is therefore the external image of the brand [8]. In literature, the brand image is defined by the psyche of the relevant external target group strongly anchored, condensed and judgmental perception of the brand [8].

To the contrary, the brand identity is related to the internal target group and consists of the self-image of the brand [8]. The brand identity is essential for perceiving the brand as authentic and different from competing brands [8]. The brand identity or brand message is defined as a unique set of brand associations for defending and establishing a brand [17]. The brand identity is necessary in giving a company and the employees “direction, purpose and meaning for a brand” [2]. Furthermore, the brand image is the spatial-temporally homogeneous features of a brand, which, from the perspective of the internal target group, has a lasting influence on the character of the brand [8]. Therefore, the brand identity is a result of a management process [9]. One element of the brand identity is the brand personality, which is reflected in the way a brand is communicated to the target group [8]. This brand communication is influenced by the origin of the brand and the brand representatives, which in the case of a company, are mainly the employees [3], [24].

An explanation of the origins of brand consistent employee behavior is given by the approach of the behavioral branding [33]. According to this approach, the employee has a significant influence on the brand perception of the external target group [33]. Furthermore, a brand inconsistent behavior of the employee in a selling situation can lead to dissatisfaction of the customer [33]. The employees are therefore seen as the internal target group [33]. Employee behavior, which is representative for the brand and according to the brand image, is only possible, if the employee has sufficient brand knowledge, a strong brand commitment and the ability to represent the brand in the interaction with the customer [33]. In addition, the approach of the behavioral branding can be distinguished between the interaction of the employee and the customer and the interaction of the company and the employee [33]. The exchange between the employee and the customer in a selling situation is defined as a touch point with the brand [8]. An insight into the interaction between the brand image and the brand identity and an application of the described approaches into the negotiation context is shown in figure 1.

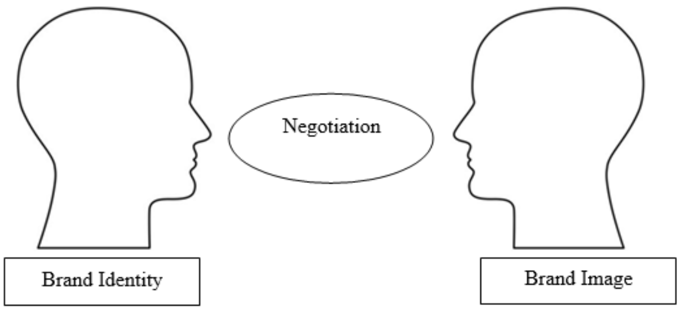

Fig. 1. In a negotiation, the identity of the brand is personified by the negotiator and perceived by the counterpart. This perception of the brand is defined as brand image. Therefore, a negotiation can be seen as a brand touch point [8].

3 Research approach, overview of the schedule and indication of the current state

The dissertation will follow a deductive research approach. In the first stage, a holistic literature review will be conducted. The relevant literature on negotiations and branding, with a special consideration of the literature on brand personification, will be identified, reviewed, analyzed and evaluated. Throughout this process, the current state of marketing science on negotiations and branding respectively brand personification as well as the most important theories, for examine the research questions, will be determined. Based on constantly reviewing of the relevant literature, hypotheses will be developed, in order to assess the applicability of brand management in negotiations and to analyze the personification of a brand by a human as a brand representative in a negotiation. These propositions will be tested empirically through qualitative interviews, observations and questioners. These methods will allow answering the research questions.

To give an insight into the preliminary results, a major part of the relevant literature is already reviewed. Nevertheless, the literature review has turned out to be a permanent process, due to number of on-going studies conducted in the research field of branding. However, a first study is about to be initialized. This study is mainly concerned with the brand personality, the personality of the negotiator and the negotiation behavior. Furthermore, the study will include the internal branding perspective as well. For this study, a questioner has been conceptualized. Besides this questioner, the study contains also an observation of the negotiation behavior and the personality of the negotiators. Moreover, the questioner has been pretested. The main part of the data generated will take place during this summer.

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Combinatorial Auction Mechanism for Allocation of Transportation in Collaborative Networks

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Abstract. In this work, a combinatorial auction-based mechanism is applied to a collaborative transportation network, in which carriers interchange requests in order to increase efficiency. All carriers operate in a hub-and-spoke network consisting of two clusters, where short-haul vehicles cover intra-cluster routes and larger capacity long-haul vehicles are used for the inter-cluster routes. Transport requests are reallocated between carriers via an auction organized by a central, neutral institution. The mechanism is composed by four major processes: Request Selection, Bundle Generation, Bid Generation and Winner Determination. Bidders select which requests to send to the auctioneer. The auctioneer groups complementary requests into attractive bundles to be offered to all the carriers in the network. Carriers then bid on each of these bundles, and finally, the auctioneer solves the Winner Determination problem by assigning bundles to carriers minimizing the total cost to be paid. Calculating exact costs for each bundle would involve prohibitive computational costs of solving a large number of vehicle routing problems (VRP's). We therefore propose a regression-based approximation for bundle evaluation. It is shown, that by using the proposed methods for every process, it is possible to run combinatorial auctions of a real-world size. Moreover, this mechanism allows the network to improve efficiency by reducing total distance traveled by up to about 25% , in relatively small computing times.

Keywords: Combinatorial auctions, Bundle Generation, Bid Generation, Collaboration, Approximation.

1 Introduction

The competition found nowadays in the shipping and transportation industry keeps companies aiming to operate more efficiently. To achieve this efficiency, two main considerations are brought up for research and discussion. First, solution methods to optimize time and resources are continuously being tested and improved, in [14] and [18], we are able to find some of the latest developments for these methods. Second, as mentioned in [8], [2] and [10], there is a growing interest in collaboration networks motivated by the connectivity provided by the existing information technologies, in which suppliers, customers and even competitors can be potential partners. For our research, we will focus in this second point, specifically on the competitors collaboration.
Carriers have to transport a parcel or package from one customer's location, known as the pick-up node, to the destination customer's location, known as the delivery node. A request is the transportation of a package between these two nodes. The parcel, its pick-up and delivery nodes, as well as other characteristics from the customers, like time-windows for example, are all part of the information needed to define a request. Carriers may perform their own set of requests with the resources they have available, or they may look for collaboration opportunities with other carriers and shippers.
Companies might collaborate in different ways, depending on their size and similarities. For example, a big carrier might sometimes hire smaller shippers to perform part of their requests. Resources sharing , such as depots, vehicles and human resources also presents an improvement opportunity based on collaboration. Requests interchange is an attractive collaboration mechanism that allows carriers, usually from similar sizes, to improve their sets of customers, reducing operational costs by saving time and resources. Moreover, requests interchange might turn a disadvantageous scenario for one or more

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carriers, into a very attractive one for the collaboration network as a whole, in which the total profit might greatly increase.

To perform requests interchange, carriers start by selecting which requests they are willing to give away, evaluating them one by one. Then, an interchange mechanism has to be used to allocate these selected requests to the carrier that value them the most. In order to do so, we resort to the use of auctions. The whole mechanism aims to minimize system wide costs, this means it should provide a successful reallocation of requests, which, in a worst case scenario, corresponds to the initial allocation, getting zero improvement but guaranteeing that the system is not worse off.

By participating in this collaboration approach, a carrier is willing to share some information about their customers and requests. This amount of information differs when dealing with two types of auctions:

– Centralized auctions: This setting presents a central neutral institution as an auctioneer, to which each carrier transfers requests that they want to be performed by other carriers. The auctioneer generates bundles and solves an allocation problem based on the bids submitted by the carriers.
– Individual auctions: This approach is very similar to the Centralized Auction. The main difference is that in this case, each carrier is allowed to run its own auction. The bundles contain requests exclusively from the carrier running the auction. The winner determination is then solved as an allocation problem based on the bids submitted by the carriers.

The core of this research lays on proposing solution methods for sub-processes for these auctions-based mechanisms. From the obtained results, we will be able to consider maximum costs for a central institution needed for centralized auctions, the main differences between individual and centralized auctions in terms of obtained improvements. Finally, results will be compared with those obtained from a centralized planning approach, which assumes a central authority with perfect information from all carriers.

In section 2, the collaboration mechanism is described with its sub-processes. Section 3 presents a proposed solution method to estimate routing costs and develop solution methods for the mechanism's sub-processes. Section 4 provides a description and results of an initial application of the mechanism. Section 5 presents conclusions and in section 6 a research overview for the dissertation project is proposed.

2 Combinatorial Auctions-based Collaboration Mechanism

In this work, we include a complete mechanism, starting with the selection of requests that carriers are willing to give away and finishing with the assignment of the final sets of requests back to carriers. In figure 1, the four main processes of the mechanism are shown. Arrows show the logic order they should follow, this means, a process has to be completed for the next one to start.

2.1 Request Selection

A carrier should determine which requests to give away, based on the set of requests they have initially. In Berger and Bierwirth [2], the marginal profit of a request is taken as the only indicator of its attractiveness, i.e. how good or bad a request is to the carrier. A way to get this indicator, is solving routing problems for the set of requests taking one out at a time. So, if we have a set N, with n requests, we should solve n routing problems. One important aspect about the marginal value of a request is that it is not an additive property. The marginal value of two requests is not the sum of their marginal values. This can be easily observed in any routing problem.

Gansterer and Hartl, in [10], propose 18 different selection methods, including a random choice. These methods are geographical-based, profit-based or combined. Based on their results, the authors conclude that geographical-based methods dominate pure marginal profit-based methods. An extra remark we can state about the geographical-based methods is that they take smaller computing times.

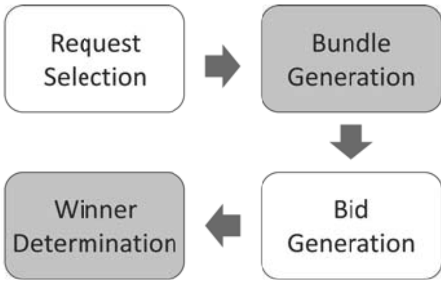


Fig. 1: Mechanism Main Processes
Gray colored frames indicate the central institution is the decision maker for these processes. As for white colored frames, each carrier is the decision maker.

2.2 Bundle Generation

Once every carrier has sent requests to the central institution, they have to be grouped into bundles to conduct combinatorial auctions. Previous work like in Berger and Bierwirth's [2] and Gansterer and Hartl's [10] has considered all possible combinations of requests, which means getting $2^m - 1$ bundles, where m is the number of requests to be traded. This approach, of course, contains the best combination of bundles to be assigned, however, a large number of requests, generating a very large number of bundles, could make the winner determination solution very difficult to obtain, therefore, new methods on how to generate an attractive and limited set of bundles would be recommended to deal with large problems.

2.3 Bid Generation

Every carrier participating in the collaboration network acts as a bidder in the auction mechanism. The bid they make for a bundle, should be its marginal cost when it is added to the remaining set of requests each carrier has. Here, we call remaining set, to the set of requests a carrier has kept from their original assignment, after sending some requests to the central institution to be exchanged.
The way to get this marginal cost in works like Berger and Bierwirth's [2] and Gansterer and Hartl's [10], is getting the difference between the solution of the remaining set routing problem and the solution of the set containing the remaining set and the bundle routing problem.

2.4 Winner Determination

The central institution, based on the received bids, solves the Winner Determination Problem (WDP), which provides a final assignment solution. This solution must assign all submitted requests back to carriers, if no improvement is found, requests should be sent back to their original carriers and no interchange should be conducted.If both, bundle and bid generation solutions are performed in such a way that only a relatively small set of attractive bundles is generated with truthful bids, the (WDP) could be solved as an exact assignment problem.

3 Regression Based Approximation

A critical aspect in the collaboration mechanism mentioned in section 2, is determining the cost that a request or group of requests represents for a carrier. In practice, this cost can be determined by solving logistics problems such as the Traveling Salesman Problem (TSP) or the Vehicle Routing Problem (VRP). For both, algorithms have been developed over the last years, being able to get a solution in a few seconds [18]. However, when dealing with a large number n of requests and their combinations $(2^n - 1)$[2], we could end up facing thousands of different bundles of requests, which means thousands of logistics problems to be solved, taking thousands of seconds.

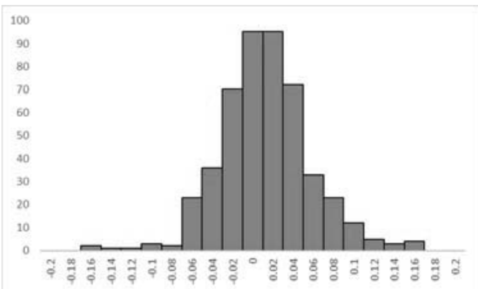
A proposed method being developed in this research is using Regression-based Approximation to estimate the costs that a bundle will have when it is assigned to a carrier. Approximate costs are obtained by estimating them from geographical and non-geographical properties that are easy to obtain from a bundle. The main benefit from this method is an enormous decrease in computing times, allowing us to generate thousands of bids in a few seconds, which of course, allows the collaboration network to deal with a larger amount of collaboration.

These methods use the TSP or VRP total distances as dependent variable, and geographical and non-geographical properties as independent variables. For instance, working with a TSP, we are able to estimate the total distance of a single tour, using parameters obtained from a multi-variate regression, using distances as independent variables. Specifically, minimum and maximum distances between nodes, variances for every coordinate, the total sum of distances to the middle point and their variance were used as independent variables. In the regression, an $R^2 = 99,6677\%$ is obtained from 480 observations. In figure 2a, we can observe the errors when the predicted and observed values are compared.

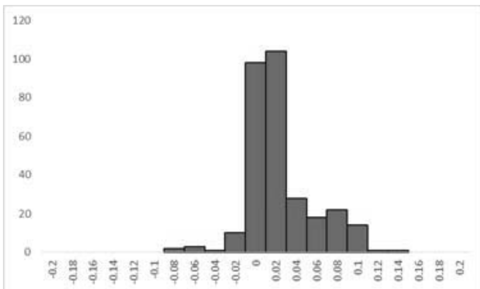
As for the VRP'S, the same process is performed, this time estimating the total distance for several tours on two regions joint by a long-haul connection, using distances to the depots, a binary indicating the type of time windows (tight or broad), a binary indicating if the long-haul is flexible or fixed, quantities and interactions between variables as independent variables. This regression yields an $R^2 = 99,9602\%$ with 443 observations. In figure 2b, the errors for the comparison between observed and predicted values are shown, having differences close to 0% on average.

The regressions are first ran with generated data similar to the actual data we are working with. The obtained parameters can then be used to estimate the costs for every bundle as if they were part of the set of requests each carrier has.

The regression-based approximation methods are mainly useful for bids generation. Nevertheless, their results should be taken into account for requests selection and bundle generation, suggesting which properties influence total costs the most.



(a) Distribution of approximation errors for TSP Application



(b) Distribution of approximation errors for VRP Application

Fig. 2: Distributions of approximation errors.

4 Double Traveling Salesman Problem Application

The complete mechanism has been tested with regression based solution methods in a double TSP scenario. The solution methods for every process shown in figure 1 are described in the following lines.

Request Selection: Nine different selection strategies were proposed and tested; these are:

- OwnDepot1: Requests far from the carrier's depot in cluster 1 were selected.
- OwnDepot2: Requests far from the carrier's depot in cluster 2 were selected.
- OwnDepotC: Requests far from the carrier's depot in both clusters combined were selected. The sum of the distances on both clusters is considered.
- OtherDepots1: Requests close from other carriers' depots in cluster 1 were selected.
- OtherDepots2: Requests close from other carriers' depots in cluster 2 were selected.
- OtherDepotsC: Requests close from other carriers' depots in both clusters combined were selected. The sum of the distances on both clusters is considered.
- SelectiveOwn: The carrier selects which cluster is worse for her, depending on that then uses OwnDepot1 or OwnDepot2.
- SelectiveOther: The carrier selects which cluster is worse for her, depending on that then uses OtherDepots1 or OtherDepots2.
- Random Choice: A random number of randomly selected requests are selected.

Bundle Generation: In order to have a manageable number of bundles, requests are grouped with the closest requests to them. A minimum and maximum sizes are set based on the number of requests each carrier sent to the central institution. Taking one request as a seed point at a time, requests are grouped with the closest requests (on each cluster and combined). Every original set of requests sent by every carrier is also a bundle, this guarantees a feasible solution that is not worse than the original allocation.

Bid Generation: Every carrier bids on all bundles. The bids are generated using the regression based approach described in section 3. The bid corresponds to the difference between the estimated costs of performing the whole set of requests including the bundle and the estimated costs of performing the set of requests excluding the bundle.

Winner Determination: To get the final allocation, a mixed integer program is used.

C set of carriers
R set of requests
B set of bundles
p_{bc} bid for bundle b offered by carrier c
q_{rb} binary parameter indicating if request r is in bundle b
x_{bc} binary variable indicating if bundle b is assigned to carrier c

$$min \sum_c \sum_b p_{bc} x_{bc} \quad s.t. \tag{1}$$

$$\sum_b x_{bc} \leq 1 \ \forall c \in C \tag{2}$$

$$\sum_c x_{bc} \leq 1 \ \forall b \in B \tag{3}$$

$$\sum_c \sum_b x_{bc} q_{rb} = 1 \ \forall r \in R \tag{4}$$

Equation 1 is the objective function, which minimizes the total allocation cost. Constraint 2 ensures that a bundle is allocated to one carrier. Constraint 3 ensures that a carrier obtains at most 1 bundle. Constraint 4 ensures that each request is allocated to one carrier.

4.1 Experimental Data

Experimental instances were generated. Every instance corresponds to a network in which a set of carriers exchange requests in two regions which are connected by a long-haul vehicle. A carrier has one depot on each region and customers are paired, i.e. one customer in region 1 represents a pick-up/delivery node while a customer in region 2 represents its corresponding delivery/pick-up node. Two groups of instances were created in a 200x200 distance units space.

- Random Positioned Depots: Depots were randomly generated in both regions. Instances correspond to a 4 carrier network, each serving 25 customers with similar demands. The long-haul trip is assumed to have enough capacity for all the requests together, so they all could be transported in one single trip. Results for these instances are shown in table 1 in the appendix.
- Sector Positioned Depots: Both regions were divided first into sectors. A depot then, is randomly positioned within a sector in every region. These instances also correspond to a 4 carrier network, with 25 randomly positioned customers with similar demands. In this case, the long-haul is also assumed to have enough capacity for all requests to be transported in one single trip. Results for these instances are shown in table 2 in the appendix.

5 Conclusions

- Geographical based evaluation strategies, bidding generation, bundle generation and winner determination shown in this research represent a relatively low computational effort, solving the whole process in acceptable times, up to three magnitudes lower than when solved with other methods (e.g. routing algorithms for bidding generation, all possible combinations for bundle generation, etc).
- Approximation methods can be successfully used to estimate total distances(& costs) in the shown scenarios. Computational calculations for this process are simple and practically immediate.
- Evaluation strategies, as well as bidding and bundle generation methods, should be generated based on the approximation methods used to estimate distances in this two-cluster scenario.

6 Research Overview

As part of the FEAT[1] (Fair & Efficient Allocation of Transportation) Project), which goal is to improve the system-wide efficiency in a transportation network, our research deals with the development of a collaboration model based on combinatorial auctions.

In the first part of the dissertation project, we are looking for efficient solution methods for the Request Selection, Bundle Generation, Bid Generation and Winner Determination sub-processes. The findings obtained from this, allow us to determine the degree of collaboration we are able to support, in terms of the amount of requests that can be interchanged in acceptable computing times.

For the second part, we are planning to apply these solution methods in auctions-based collaboration mechanisms. Moreover, we are interested in finding how much improvement can be done by having carriers that collaborate with each other under this request interchange approach. One aspect that calls for our interest, is the comparison between centralized and individual auctions, mainly because this can set a limit for a central institution costs.

In the third part, the auctions-based collaboration mechanisms will be compared with a centralized planning approach [2], which assumes that all requests information is known by a central authority that performs the best expected request allocation to a set of carriers with the objective of minimizing costs. Here, we would observe how efficient the collaboration mechanisms are when compared to a benchmark that must be better in terms of this objective. Our main interest would be to determine how much collaboration should be performed in order to get a desired level of improvement, keeping in mind that it depends on how good the initial allocation is; the worse it is at a beginning, the larger the improvement that can be made.

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[2] Research from a joint project

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Appendix

Results

In both tables, column 1 lists the strategies used for requests selection. Column 2 shows the average improvement made by the mechanism, while column 3 shows the maximum improvement obtained in a single instance. Column 4 and 5 show the number of requests sent to auctions and interchanged. Column 6 shows the percentage of requests that have been interchanged. Columns 7 and 8 contain an improvement ratio, i.e. the average improvement made by a single requests being sent and interchanged respectively. Column 9 shows the computing time needed by the mechanism, starting with the requests selection and ending with the new allocation.

Strategy	% Imp	Max Imp	Requests		Int %	Ratios		Time
			Sent	Inter		Sent	Inter	[s]
OwnDepot1	**10.40**	26.58	38.03	32.45	85%	0.29	**0.34**	31.92
OwnDepot2	**10.39**	**27.50**	36.31	31.39	86%	0.31	**0.36**	42.35
OwnDepotC	6.61	19.45	33.44	25.76	65%	0.19	0.24	36.89
OtherDepots1	3.58	17.12	45.76	28.16	65%	0.08	0.11	38.15
OtherDepots2	3.63	15.04	47.07	27.14	61%	0.08	0.12	34.81
OtherDepotsC	1.39	8.55	26.60	14.95	49%	0.04	0.05	26.89
SelectiveOwn	8.66	22.69	37.66	30.21	81%	0.27	**0.33**	27.93
SelectiveOther	3.18	13.26	44.76	24.75	60%	0.08	0.11	32.14
Random	3.57	13.23	36.90	24.93	68%	0.10	0.14	40.96

Table 1: Results Sector Positioned Depots

Strategy	% Imp	Max Imp	Requests		Int %	Ratios		Time
			Sent	Inter		Sent	Inter	[s]
OwnDepot1	5.88	15.53	35.88	22.15	61%	0.17	**0.25**	53.44
OwnDepot2	**6.21**	18.02	38.32	21.87	55%	0.17	**0.28**	46.59
OwnDepotC	5.35	**20.80**	35.79	22.57	58%	0.15	0.24	59.36
OtherDepots1	3.38	17.20	40.15	24.08	61%	0.09	0.13	50.33
OtherDepots2	3.28	13.63	38.65	22.68	64%	0.10	0.13	59.79
OtherDepotsC	1.39	9.27	15.94	10.23	51%	0.07	0.10	44.83
SelectiveOwn	**6.79**	18.45	48.92	29.68	60%	0.14	**0.21**	59.89
SelectiveOthers	3.27	10.51	35.60	19.87	62%	0.11	0.16	43.87
Random	3.47	9.97	35.84	24.69	67%	0.10	0.15	64.64

Table 2: Results Random Positioned Depots

IAHP-based approach to select Solar Station Location

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Abstract: The reasonable position of solar power station has a direct effect on the utilization of resources and the interests of the access. And in a case that if the decision makers give a pair-wise comparison matrix (PCM) which is not consistent in teams of the location choice algorithm of solar power station in the Interval Analytic Hierarchy Process (IAHP), the derived priority vector should be as similar to each column vector of the PCM as possible. Therefore, a cosine maximization method (CM) for interval positive complementary matrix is proposed in this paper, which combines the transformation formulate, cosine similarity measure and the interval numbers possibility degree matrix. It is not necessary to consider the acceptably consistent of the PCM. And then a new interval cosine consistency index is defined. Finally, using the method to deal with a siting case of solar power station.

Keywords: Interval Analytic Hierarchy Process, Priority weights, Cosine similarity measure, Solar Power Station.

1. Introduction

China is the largest country in the production of electricity with 24.1% of the global share. The unpredicted growth in the China economy leads to increase in the usage of electricity. In China, according to 2015 statistics, 76.6% of the electricity is produced from non-renewable sources: 4% - nuclear, 73.5%-power-fossil and the grid solar generated 421.8 million kilowatts, an increase of 69.66 percent over the previous year. It is forecasted that in China, non-fossil energy of primary energy consumption ratio reached 15% by 2020, reached 20% by 2030. China has a large population, resulting in a low per-capita average of energy resources in the world. This problem is particularly acute for solar power. Compared with conventional source of energy, solar energy has some unique advantages. They include: inexhaustible, inexhaustible, clean, safe and reliable, low operation cost. From the function and necessity views, solar power can solve the problem of supplying electricity in some areas.

The national energy administration issued a "Solar energy development 13th five-year plan". By the end of 2020, solar power generation capacity reach 110 million kw or more, among them, the photovoltaic power generation capacity of 105 million KW or more, on the basis of "twelfth five-year" every year to keep stable development scale; Solar thermal power generation installed 5 million kw.Solar thermal utilization heating area of 800 million square meters. By 2020, the solar year reached

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more than 140 million tons of standard coal. In the research of these areas, it is an important and interesting issue to select the location of solar power station in China. Considering the resources in the economy and social benefits, the location of solar power should concern the total investment cost, generating revenue, climate and meteorological conditions, the operation and maintenance cost. In addition, the utilization of power also needs to refer to the transportation, geology, conditions such as network transmission and construction factors [26]. So solar power station site selection is a comprehensive evaluation problem involving multi-factor. Due to the influence degree of each factor is determined by people's subjective judgment, inevitably, the evaluation conclusion is fuzziness. Therefore, in order to improve the accuracy of location and reliability, a method handling multiple factors and fuzzy evaluation[19] and the subjective judgment problem have to be obtained.

When experts put forward the influence information with a pair-wise comparison matrix (PCM) of point value, the Analytic Hierarchy Process(AHP)[17,1]is useful to help decision maker(DM) to choose the reasonable position of solar power station. But in practical application, a point value is not easy to get, and in classical AHP, a point value is obviously unreasonable to indicate the importance of the difference between two more factors, for lacking of effective information of intrinsic link, or because of different experts do not have the same understanding of the importance with subjective differences. Interval Analytic Hierarchy Process(IAHP)[17]changes the description of factors from point value to interval number, this shift makes the understanding of things more objective, and decrease the subjective judgment in order to make it more accuracy. IAHP is one of the important methods for multiple criteria decision making (MCDM) problems [13]. MCDM mainly focuses on the ranking, sorting and choice types of decision making problems [2, 12, 14]. This paper only discusses the ranking problem, which consists in rank ordering of all alternatives with respect to the considered criteria [6,9,18]. In IAHP, the decision maker (DM) determine a PCM by analyzing collected information, and then derive a reliable priority weight from PCM.

It is a key issue to design the prioritization methods [5] and the calculation methods for the derivation. Kou et al. [7,8] maximized the sum of the cosine of the angel between the priority weight and each column vector of a PCM and proposed the cosine maximization method (CM) [3]. In the prior AHP theory, DM used the real number to estimate the MCDM problems. However, sometimes it is very difficult to gain a precise numerical value for DM’s judgment as the uncertainty and complexity of the decision-making problems in reality. Naturally, it is better to choose the fuzzy or interval ratios to illustrate the MCDM problems. Based on this, Van Laarhoven et al. [20] extended the Saaty’s priority in which they considered their opinion as fuzzy numbers. Liu [13] defined the consistency of a interval positive reciprocal matrix. In [21], Wang et al. gave another definition of it. Besides, the transformation formulate between interval positive reciprocal and complementary matrix were given by Liu [10,11]. And many researchers have paid more attention on the methods of deriving the priority weights from a interval positive complementary matrix [4, 6, 22,23].

In this paper, a new method of generating priority weights from an interval positive complementary matrix is proposed, which is based on cosine similarity measure. The similarity measure between the priority vector and each column vector of the PCM is denoted by the cosine similarity measure between them due to its simplicity. This paper will combine the transformation formulate, cosine similarity measure and the interval numbers possibility degree matrix to deal with the priority weights derivation from interval positive complementary matrix. The rest of this paper is organized as follows. In section 2, the related concepts of interval positive complementary matrix and cosine maximization method are given, a new interval cosine consistency index is defined. Section 3 gives a example which about siting a place of four options for building a solar power station to test our method. In section 4, the main conclusions are shown.

2. Preliminaries and methodology

In this part, we give some related concepts of interval positive complementary matrix and cosine maximization method, and then develop a new consistency index related with the CM to measure the inconsistency level of an interval positive complementary matrix. At last, we discuss the interval cosine consistency index.

2.1. Interval positive complementary matrix

Considering a set of alternatives $U = \{x_1, x_2, \cdots, x_n\}$ in a MCDM problem, we can get a interval positive complementary matrix *A* through pairwise comparison of each criterion, several definitions and theorems are introduced as follows:

Definition 2.1 ([16]). A matrix $A = (a_{ij})_{n\times n}$ is said to be positive reciprocal, if for all $i, j \in \{1,2,\cdots,n\}$, which exists that $a_{ij} > 0$, $a_{ii} = 1$, $a_{ij}a_{ji} = 1$ with $1/9 \le a_{ij} \le 9$.

Definition 2.2 ([16]). A positive reciprocal matrix $A = (a_{ij})_{n\times n}$ is said to be consistent if $a_{ij} = a_{ik}a_{kj}$ for all $i, j \in \{1,2,\cdots,n\}$.

Definition 2.3 ([16]). PRM $A = (a_{ij})_{n\times n}$ is said to be acceptably consistent, if the consistency ratio(C.R.) is 0.1 or less, where $C.R. = C.I./R.I.$, $C.I. = \lambda_{\max} - n/n - 1$.

n is the dimension of matrix *A, and* $\lambda_{\max}$ *is the principal eigenvalue of* matrix *A.* $R.I.$ *is the average* $C.I.$ *of a large number of randomly generated* positive reciprocal matrix and depends on the orders of the matrices.

Definition 2.4 ([19]). $B = (b_{ij})_{n\times n}$ is called a positive complementary matrix if $b_{ij} > 0$; $b_{ii} = 0.5$; $b_{ij} + b_{ji} = 1$ with $0 \le b_{ij} \le 1$, for all $i, j \in \{1,2,\cdots,n\}$.

Where the element b_{ij} represents a fuzzy preference degree of alternative x_i over x_j.

Definition 2.5 ([19]). A positive complementary matrix $B = (b_{ij})_{n\times n}$ is said to be consistent if $b_{ij} = b_{ik} - b_{kj} + 0.5$ for all $i, j \in \{1,2,\cdots,n\}$.

Now, let us consider that a decision maker compares each pair of alternatives on $X = \{x_1, x_2, \cdots, x_n\}$ and expresses the opinions as an interval positive reciprocal/complementary matrix. The expression interval positive reciprocal matrix was firstly given by Saaty [15] as:

$$U = (u_{ij})_{n\times n} = \begin{pmatrix} [1,1] & [u_{12}^-, u_{12}^+] & \cdots & [u_{1n}^-, u_{1n}^+] \\ [u_{21}^-, u_{21}^+] & [1,1] & \cdots & [u_{2n}^-, u_{2n}^+] \\ \vdots & \vdots & \vdots & \vdots \\ [u_{n1}^-, u_{n1}^+] & [u_{n2}^-, u_{n2}^+] & \cdots & [1,1] \end{pmatrix}$$

where u_{ij} indicates that x_i is between u_{ij}^- and u_{ij}^+ times as important as x_j. u_{ij}^- and u_{ij}^+ are real numbers, $1/9 \le u_{ij}^- \le u_{ij}^+$, $u_{ij}^- = 1/u_{ji}^+$ and $u_{ij}^+ = 1/u_{ji}^-$.

By using Definitions 1 and 2, if let we $C = (c_{ij})_{n\times n}$ and $D = (d_{ij})_{n\times n}$ with:

$$c_{ij} = \begin{cases} u_{ij}^+, & i < j \\ 1, & i = j \\ u_{ij}^-, & i > j \end{cases} \qquad d_{ij} = \begin{cases} u_{ij}^-, & i < j \\ 1, & i = j \\ u_{ij}^+, & i > j \end{cases} \qquad (1)$$

There are the following definitions:

Definition 2.5 ([10]). Let U be an interval positive reciprocal matrix. If the positive reciprocal matrix C and D determined by using formula (1) are all of consistency, the U is said to be consistent.

Definition 2.6 ([10]). If the positive reciprocal matrix C and D, which are determined by using formula (1) from an interval positive reciprocal matrix U, are acceptably consist, then U is called an acceptably consist interval positive reciprocal matrix.

Moreover, when the DMs estimate the judgments on $X=\{x_1,x_2,\cdots,x_n\}$ in terms of an interval positive complementary matrix it follows[23]:

$$V=(v_{ij})_{n\times n}=\begin{pmatrix} [0.5,0.5] & [v_{12}^-,v_{12}^+] & \cdots & [v_{1n}^-,v_{1n}^+] \\ [v_{21}^-,v_{21}^+] & [0.5,0.5] & \cdots & [v_{2n}^-,v_{2n}^+] \\ \vdots & \vdots & \vdots & \vdots \\ [v_{n1}^-,v_{n1}^+] & [v_{n2}^-,v_{n2}^+] & \cdots & [0.5,0.5] \end{pmatrix}$$

where v_{ij} indicates that x_i is between v_{ij}^- and v_{ij}^+ times as important as x_j . v_{ij}^- and v_{ij}^+ are real numbers, $0\le v_{ij}^-\le v_{ji}^+$, $v_{ij}^-+v_{ji}^+=1$ and $v_{ij}^+ + v_{ji}^- = 1$.

Theorem 2.1 ([10]). *Let $V=(v_{ij})_{n\times n}$ be an interval positive complementary matrix. If each element of $U=(u_{ij})_{n\times n}$ satisfies: $u_{ij}=9^{2v_{ij}-1}$, then U is an interval positive reciprocal matrix.*

Theorem 2.2 ([10]). *Let V be a consistent interval positive complementary matrix. The interval positive reciprocal matrix U derived from V through Theorem 2.1 is consistent.*

Definition 2.7 ([10]). Let V be an interval positive complementary matrix. If the interval positive reciprocal matrix U derived from V through Theorem 2.1 is acceptable consistent, then V is called an acceptable consistent interval positive complementary matrix.

2.2. Cosine maximization method (CM)

In order to develop the CM of interval positive complementary matrix for the priority vector derivation, we need to know the process of CM.

Theorem 2.3 ([11]). *Let two vectors be $t_i=(t_{i1},t_{i2},\cdots,t_{in})^T$ and $t_j=(t_{j1},t_{j2},\cdots,t_{jn})^T$, then the cosine similarity measure between two vectors t_i and t_j is denoted as*

$$CSM(t_i,t_j)=\frac{\sum_{k=1}^{n} t_{ik}t_{jk}}{\sqrt{\sum_{k=1}^{n} t_{ik}^2}\sqrt{\sum_{k=1}^{n} t_{jk}^2}}$$

Let V be an interval positive complementary matrix, the interval positive reciprocal matrix U could be derived from V through Theorem 2.1. Then the positive reciprocal matrices C and D could be derived by using formula (1) from the matrix U. We assume that the priority weights from C and D based on the cosine similarity measure of Theorem 2.3 have been derived. Let $w=(x_1,x_2,\cdots,x_n)$ with $\sum_{i=1}^{n} w_i=1$ and $w_i\ge 0,(i=1,2,\cdots,n)$ be a priority vector derived from C using some prioritization method. In AHP, we know that, if C is consistent [15], $c_{ij}=\frac{w_i}{w_j}\ (i,j=1,2,\cdots,n)$. From above formula, C can be precisely characterized by

$$C = \begin{pmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \cdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{pmatrix}$$

And then, C can be viewed as consisting of the following n column vectors:

$$(w_1, w_2, \cdots, w_n)^T / w_i,\ i = \{1,2,\cdots,n\}.$$

Let S_j be the cosine similarity measure between the priority vector w and the jth column vector c_j of C. Where $w = (w_1, w_2, \cdots, w_n)^T$ and $c_j = (c_{1j}, c_{2j}, \cdots, c_{nj})^T$. By Theorem 2., it follows that:

$$S_j = CSM(w, c_j) = \sum_{k=1}^{n} w_k c_{kj} \Big/ \left(\sqrt{\sum_{k=1}^{n} w_k^2}\sqrt{\sum_{k=1}^{n} c_k^2}\right),\quad j \in \{1,2,\cdots,n\}.$$

Since $c_{ij} = w_i / w_j$, $i, j \in \{1,2,\cdots,n\}$, we have

$$S_j = \left(\sum_{k=1}^{n} w_k^2 / w_j\right) \Big/ \left(\sqrt{\sum_{k=1}^{n} w_k^2}\sqrt{\sum_{k=1}^{n} (w_k / w_j)^2}\right) = 1,\quad j \in \{1,2,\cdots,n\}.$$

It is obvious that

$$CSM(w, c_j) = \begin{cases} 1, & C \text{ is consistent;} \\ [0,1) & C \text{ is not consistent.} \end{cases} \tag{3}$$

In order to derive a reliable priority vector, the $CSM(w, c_j)$ of a PCM should be equal to 1 as highly as possible. Inspired by this idea, Kou [7] constructed an optimization model as follows:

Maximize $S = \sum_{j=1}^{n} S_j = \sum_{j=1}^{n}\sum_{k=1}^{n} (w_k a_{kj}) \Big/ \left(\sqrt{\sum_{k=1}^{n} w_k^2}\sqrt{\sum_{k=1}^{n} a_{kj}^2}\right)$

Subject to

$$\begin{cases} \sum_{i=1}^{n} w_i = 1 \\ w_i \geq 0,\ i = 1,2,\cdots,n \end{cases} \tag{4}$$

We set $\tilde{w}_i = w_i \Big/ \sqrt{\sum_{k=1}^{n} w_k^2} \geq 0,\ i = 1,2,\cdots,n,$

And $b_{ij} = c_{ij} \Big/ \sqrt{\sum_{k=1}^{n} c_{kj}^2} > 0.\ i, j = 1,2,\cdots,n.$ (a)

Then we have $\sum_{i=1}^{n} \tilde{w}_i^2 = 1$, and $\sum_{i=1}^{n} b_{ij}^2 = 1$.

The optimization model (4) can be equivalently transformed into the following form:

Maximize $S = \sum_{j=1}^{n} S_j = \sum_{j=1}^{n}\sum_{i=1}^{n} b_{ij}\tilde{w}_i = \sum_{j=1}^{n} \left(\sum_{i=1}^{n} b_{ij}\right)\tilde{w}_i$

Subject to

$$\begin{cases} \sum_{i=1}^{n} w_i = 1 \\ w_i \geq 0,\ i = 1,2,\cdots,n \end{cases} \tag{5}$$

With regard to the above model (5), There are the following theorems.

Theorem 2.4. Let $\tilde{w}^* = (\tilde{w}_1^*, \tilde{w}_2^*, \cdots, \tilde{w}_n^*)^T$ be the optimal solution to optimization model (5) and C∗ be the optimal objective function value of it. Then

$$\tilde{w}_i^* = \sum_{j=1}^{n} b_{ij} \Big/ \sqrt{\sum_{k=1}^{n} \left(\sum_{j=1}^{n} b_{kj}\right)^2},\ i \in \{1,2,\cdots,n\} \tag{b}$$

$$S^* = \sqrt{\sum_{i=1}^{n}(\sum_{j=1}^{n} b_{ij})^2} \quad \text{(c)}$$

Proof of Theorem 2.4. Refer to [6].

Furthermore, we write $\Omega = \{w = (w_1, w_2, \cdots, w_n)^T \mid \sum_{j=1}^{n} w_i = 1, w_i > 0, i = 1,2,\cdots,n\}$. Then the objective function C of optimization model (4) has a unique maximize point $\tilde{w}^* = (\tilde{w}_1^*, \tilde{w}_2^*, \cdots, \tilde{w}_n^*)^T \in \Omega$.

That is to say, optimization model (4) can produce a unique solution, avoiding the inconvenience of how to choose one solution from a set of solution. The unique solution can be indirectly determined by optimization model (5). We have $w_i^* = \tilde{w}_i^* \sqrt{\sum_{k=1}^{n} w_k^2}, \quad i = 1,2,\cdots,n.$

Let $\sqrt{\sum_{k=1}^{n} w_k^2} \geq 0$, then $w_i^* = \tilde{w}_i^* \beta, \ i = 1,2,\cdots,n.$

where β is called weight assignment coefficient. Solving the following system of equation

$$\begin{cases} \sum_{i=1}^{n} w_i^* = \sum_{i=1}^{n} \tilde{w}_i^* \beta \\ \sum_{i=1}^{n} w_i^* = 1, \ i = 1,2,\cdots,n \end{cases} \quad (6)$$

We have

$$\beta^* = 1 \Big/ \sum_{j=1}^{n} \tilde{w}_j^*. \quad \text{(d)}$$

Then

$$w_i^* = \tilde{w}_i^* \beta = \tilde{w}_i^* \Big/ \sum_{j=1}^{n} \tilde{w}_j^*, \ i = 1,2,\cdots,n. \quad \text{(e)}$$

Theorem 2.5. *Let PCM $C = (c_{ij})_{n\times n}$ be perfectly consistent, the CM method can precisely derive the optimal objective function value $S^* = n$ and the priorities $w_j^* = 1 \Big/ \sum_{i=1}^{n} c_{ij} \ (j = 1,2,\cdots,n)$.*

Proof of Theorem 2.5. Refer to [6].

In the process above, the priority vector of positive reciprocal matrices *C* have been derived. Similarly, the priority vector of positive reciprocal matrices *D* could been derived. It is obvious that the combined weight of *C and D* is the interval weights of positive reciprocal matrices *V* with Cosine maximization method. But the interval weights is uncertain, and they can not present the clear result for DMs.

2.3. The possibility degree

In order to get the final ranking, we should draw support from the possibility degree.

Definition 2.8 [10]. Let $W_1 = [l_1, r_1]$ and $W_2 = [l_2, r_2]$ be two interval weights, $l_1 \neq r_1$ and $l_2 \neq r_2$,then the possibility degree of $W_1 \geq W_2$ is defined as:

$$p(W_1 \geq W_2) = s' / s,$$

with $s = (r_1 - l_1)(r_2 - l_2)$ .And the possibility degree of $W_2 \geq W_1$ is defined as:

$$p(W_2 \geq W_1) = s'' / s.$$

Where s' and s'' are defined as those given in[10].

A simple row-column elimination method is utilized to generate the ranking vector from the possibility degree matrix. That is, one first finds a row in the matrix where all elements except for the diagonal ones are larger than 0.5. If this row corresponds to x_i, then x_i is the most (likely) preferred alternative. Then eliminating the *i*th row and *i*th column in the matrix, one finds the second preferred alternative among the remaining alternatives such as x_j One has $x_i \succ x_j$ for $p_{ij} > 0.5$ or $x_i \sim x_j$ for $p_{ij} = p_{ji} = 0.5$ hereafter the notion " $\succ$ " indicates that one alternative is preferred to another. Repeating the above processes, we can rank all the alternatives.

2.4 Priority weights derivation

Many method of deriving priority weights from interval positive reciprocal matrix have been proposed, including various mathematical programming models. Moreover, it is reasonable and natural to express the DM's judgments as interval positive complementary matrix, and there is a transformation formula between interval positive complementary matrix and interval positive reciprocal matrix, also with the aid of the possibility degree, we can rely on combing pre-existing methods to deal with the priority weights derivation issue of interval positive complementary matrix.

In order to facilitate the solution process of the new method, the involved steps are briefly described as follows:

Step 1. Consider a decision making problem with an interval positive complementary matrix $V = (v_{ij})_{n\times n}$.

Step 2. Transform the interval positive complementary matrix $V = (v_{ij})_{n\times n}$ to an interval positive reciprocal matrix U by Theorem 2.1.

Step 3. Normalize the interval positive reciprocal matrix U to the transformation matrix $B_c = (b_{c_{ij}})_{n\times n}$ and $B_d = (b_{d_{ij}})_{n\times n}$ through formula (a).

Step 4. Calculate the transformed weights $\tilde{w}^*_{c_{ij}}$, $\tilde{w}^*_{d_{ij}}$, $i = 1, 2, \cdots, n$ through formula (b).

Step 5. Calculate the optimal objective function value C^*_c , C^*_d through formula (c).

Step 6. Calculate the weight assignment coefficient β^*_c , β^*_d through formula (d).

Step 7. Calculate the final priority vector $w^*_c = (w^*_{c1}, w^*_{c2}, \cdots, w^*_{cn})^T$ and $w^*_d = (w^*_{d1}, w^*_{d2}, \cdots, w^*_{dn})^T$ through formula (e).

Sept 8. Utilizing $w_i = [\min\{w^*_{ci}, w^*_{di}\}, \max\{w^*_{ci}, w^*_{di}\}]$, for $i = 1, 2, \cdots, n$, one obtains the interval weight vector.

Step 9. Construct the possibility degree matrix and rank all the alternatives by utilizing the simple row-column elimination method through Definition 2.8.

2.4. Interval cosine consistency index (ICCI)

It is well known that several consistency index and methods have been proposed. Analyzing above process, C^* is the optimal objective function value of model (4). If a PCM is consistent, we have $C^* = n$, otherwise, $0 < C^* < n$: So Kou et al. defined the cosine consistency index of PCM, which is write $CCI = C^* = n$, it is values in the interval $(0,1]$. If the PCM is consistent, it follows that $CCI = 1$, otherwise, $0 < CCI < 1$:

When we consider a interval positive complementary matrix, we can obtain two C^* , one is for positive complementary matrix *C*, the other one is for positive complementary matrix *D*. In order to make eliminate the influence of the size of a PCM, we should divide the objective function value C^*_c and C^*_d by 2, resulting in $ICCI = (C^*_c + C^*_d)/2n$. As a general rule, one would expert *ICCI* to be at least 90%.

3. Case Study

Case. Thirty percent of territory of China is desert and Gobi, where there is plenty of solar radiation. The potential power of solar energy of China is 50 times that of the Grand Three Gouges Hydraulic Power Station, or two times the total amount of electricity used in the year 2006, which would meet the expected total demand for electricity of the whole country in 2020. Where are the profitable candidate sites for the plants and the technique-economic properties of the sites is the serious problem. So we give an experiment to select the optimal place from Anhui, Jilin, Sichuan, Shanghai (Figure 1)to locate more necessary solar power station.

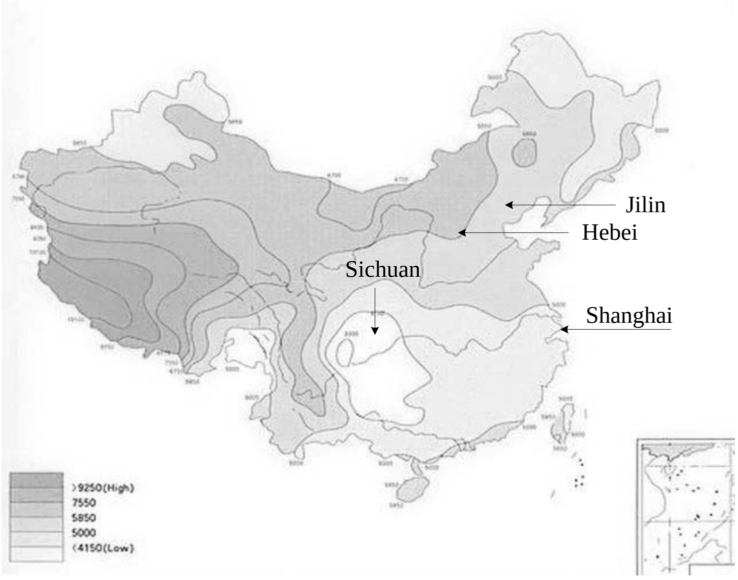

Figure 1. Distribution of solar energy in China(MJ/m^2)

A committee comprised of three experts $e_k (k = 1,2,3)$ has been set up to select a place from four candidate places $(Y_i, i = 1,2,3,4)$ to build solar power station, experts consider the distribution of land cover and the state of art techniques of power plant, then they give an initial estimate of the cost of the solar heat electricity generation, and make an estimation of the cost and benefit with these factors: total solar radiation, landuse and technology, maintenance expense and environmental and ecological influence , which are marked as $x_i (i = 1,2,3,4)$ to provide assessment information on $Y_i (i = 1,2,3,4)$, and the weight vector of three experts is $\lambda = (1/3,1/3,1/3)^T$.

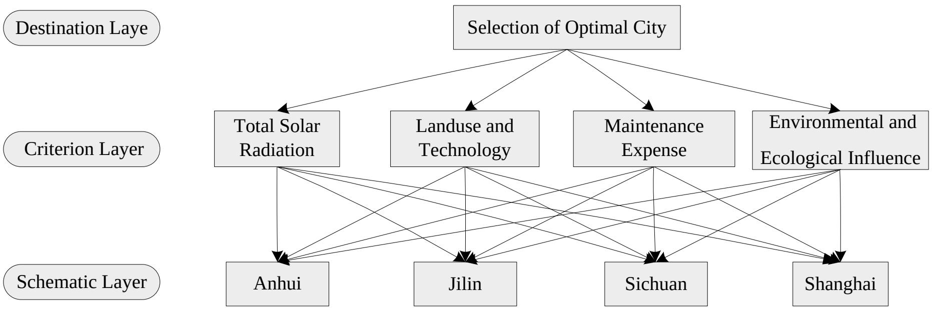

Figure2. IAHP hierarchy of the solar power plant location problem

At first layer in Figure 2, experts compare these four places with respect to their comprehensive functions and construct, respectively, the interval positive complementary matrices $R^{(k)} = (r_{ij}^{(k)})_{4\times4} (k = 1,2,3)$.

$$R^{(1)} = \begin{pmatrix} [0.5,0.5] & [0.2,0.4] & [0.5,0.6] & [0.5,0.7] \\ [0.6,0.8] & [0.5,0.5] & [0.7,0.9] & [0.6,0.8] \\ [0.4,0.5] & [0.1,0.3] & [0.5,0.5] & [0.7,0.8] \\ [0.3,0.5] & [0.2,0.4] & [0.2,0.3] & [0.5,0.5] \end{pmatrix} \quad R^{(2)} = \begin{pmatrix} [0.5,0.5] & [0.3,0.6] & [0.2,0.5] & [0.7,0.9] \\ [0.4,0.7] & [0.5,0.5] & [0.8,0.9] & [0.5,0.7] \\ [0.5,0.8] & [0.1,0.2] & [0.5,0.5] & [0.6,0.8] \\ [0.1,0.3] & [0.3,0.5] & [0.2,0.4] & [0.5,0.5] \end{pmatrix}$$

$$R^{(3)} = \begin{pmatrix} [0.5,0.5] & [0.6,0.7] & [0.7,0.9] & [0.6,0.8] \\ [0.3,0.4] & [0.5,0.5] & [0.3,0.6] & [0.6,0.7] \\ [0.1,0.3] & [0.4,0.7] & [0.5,0.5] & [0.8,0.9] \\ [0.2,0.4] & [0.3,0.4] & [0.1,0.2] & [0.5,0.5] \end{pmatrix}$$

Step 1. Utilize the fuzzy weighted averaging operator [30].

$$R = \lambda_1 R^{(1)} \oplus \lambda_2 R^{(2)} \oplus \lambda_3 R^{(3)} = \begin{pmatrix} [0.5,0.5] & [0.37,0.57] & [0.47,0.67] & [0.6,0.8] \\ [0.43,0.63] & [0.5,0.5] & [0.6,0.8] & [0.57,0.73] \\ [0.33,0.53] & [0.2,0.4] & [0.5,0.5] & [0.7,0.83] \\ [0.2,0.4] & [0.27,0.43] & [0.17,0.3] & [0.5,0.5] \end{pmatrix}$$

Step 2. Transform matrix R to an interval positive reciprocal matrix by Theorem 2.9:

$$U = \begin{pmatrix} [1.0000,1.0000] & [0.5648,1.3602] & [0.8765,2.1108] & [1.5518,3.7372] \\ [0.7352,1.7705] & [1.0000,1.0000] & [1.5518,3.7372] & [1.3602,2.7476] \\ [0.4738,1.1409] & [0.2676,0.6444] & [1.0000,1.0000] & [2.4082,4.2638] \\ [0.2676,0.6444] & [0.3640,0.7352] & [0.2345,0.4152] & [1.0000,1.0000] \end{pmatrix}$$

We write U in the form by formula (1):

$$C = \begin{pmatrix} 1 & 1.3602 & 2.1108 & 3.7372 \\ 0.7352 & 1 & 3.7372 & 2.7476 \\ 0.4738 & 0.2676 & 1 & 4.2638 \\ 0.2676 & 0.3640 & 0.2345 & 1 \end{pmatrix} \quad D = \begin{pmatrix} 1 & 0.5648 & 0.8765 & 1.5518 \\ 1.7705 & 1 & 1.5518 & 1.3602 \\ 1.1409 & 0.6444 & 1 & 2.4082 \\ 0.6444 & 0.7352 & 0.4152 & 1 \end{pmatrix}$$

Step 3. Normalize the PCM to the transformation matrix by (a), we get

$$B_c = \begin{pmatrix} 0.7379 & 0.7783 & 0.4783 & 0.5858 \\ 0.5425 & 0.5722 & 0.8468 & 0.4307 \\ 0.3496 & 0.1531 & 0.2266 & 0.6684 \\ 0.1975 & 0.2083 & 0.0531 & 0.1568 \end{pmatrix} \quad B_D = \begin{pmatrix} 0.4134 & 0.3745 & 0.4203 & 0.4667 \\ 0.7319 & 0.6630 & 0.7441 & 0.4090 \\ 0.4716 & 0.4273 & 0.4795 & 0.7242 \\ 0.2664 & 0.4875 & 0.1991 & 0.3007 \end{pmatrix}$$

Step 4. Calculate the transformed weights by (b), we can get

$$\tilde{w}_C^* = (0.6727, 0.6237, 0.3644, 0.1605)^T, \quad \tilde{w}_D^* = (0.4283, 0.6516, 0.5377, 0.3206)^T$$

Step 5. Calculate the optimal objective function value by (c), we get $C_C^* = 3.8358, C_D^* = 3.9103$.

$$ICCI = (C_c^* + C_d^*)/2n = (3.8358 + 3.9103)/(2 \times 4) = 96.83\%.$$

Step 7. Calculate the final priority vector by (e),we get

$$w_C^* = (0.3694, 0.3424, 0.2001, 0.0881)^T, \quad w_D^* = (0.2210, 0.3362, 0.2774, 0.1654)^T$$

Step 8. We obtain the interval weight vector:

$$w = ([0.2210, 0.3694], [0.3362, 0.3424], [0.2001, 0.2774], [0.0881, 0.1654])^T$$

At second layer in Figure 2, experts provide four interval positive reciprocal (consistency) matrices of project $Y_i (i = 1,2,3,4)$ under factor $x_i (i = 1,2,3,4)$.

$$X_1^{(y)} = \begin{pmatrix} [1,1] & [2,3] & [5,7] & [7,9] \\ [1/3,1/2] & [1,1] & [2,3] & [3,4] \\ [1/7,1/5] & [1/3,1/2] & [1,1] & [1,3/2] \\ [1/9,1/7] & [1/4,1/3] & [2/3,1] & [1,1] \end{pmatrix}, \quad X_2^{(y)} = \begin{pmatrix} [1,1] & [1,2] & [4,5] & [6,8] \\ [1/2,1] & [1,1] & [5/2,4] & [4,6] \\ [1/5,1/4] & [1/4,2/5] & [1,1] & [3/2,2] \\ [1/8,1/6] & [1/6,1/4] & [1/2,2/3] & [1,1] \end{pmatrix}$$

$$X_3^{(y)} = \begin{pmatrix} [1,1] & [1/7,1/5] & [1/3,2/3] & [1/2,1] \\ [5,7] & [1,1] & [2,4] & [3,5] \\ [3/2,3] & [1/4,1/2] & [1,1] & [1,2] \\ [1,2] & [1/5,1/3] & [1/2,1] & [1,1] \end{pmatrix}, \quad X_4^{(y)} = \begin{pmatrix} [1,1] & [5/2,9/2] & [3/2,5/2] & [1,5/4] \\ [2/9,2/5] & [1,1] & [2/5,9/10] & [2/9,1/2] \\ [2/5,2/3] & [10/9,5/2] & [1,1] & [2/5,5/6] \\ [4/5,1] & [2,9/2] & [6/5,5/2] & [1,1] \end{pmatrix}$$

Calculate the relative weight of the interval number of each scheme under the single criterion. W_{x^y} consists of the column vectors of above weight matrices and the comprehensive weights W .

$$W_{x^y} = \begin{pmatrix} [0.5555, 0.6278] & [0.4394, 0.5186] & [0.0792, 0.1146] & [0.3059, 0.4298] \\ [0.2411, 0.2535] & [0.3260, 0.3546] & [0.5120, 0.5984] & [0.0968, 0.1276] \\ [0.0683, 0.1098] & [0.0994, 0.1246] & [0.1788, 0.2244] & [0.1781, 0.1990] \\ [0.0629, 0.0812] & [0.0560, 0.0814] & [0.1082, 0.1845] & [0.2645, 0.3983] \end{pmatrix}$$

$$W = W_{x^y} \bullet w = \begin{pmatrix} [0.3133, 0.5124] \\ [0.2739, 0.4022] \\ [0.1000, 0.1784] \\ [0.0777, 0.1749] \end{pmatrix}$$

Step 9. Construct the possibility degree matrix based on W :

$$K = \begin{pmatrix} 0.5000 & 0.7769 & 1.0000 & 1.0000 \\ 0.2331 & 0.5000 & 1.0000 & 1.0000 \\ 0.0000 & 0.0000 & 0.5000 & 1.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.5000 \end{pmatrix}$$

Finally, we get the rank order: $x_1 \succ^{77.69\%} x_2 \succ^{100\%} x_3 \succ^{100\%} x_4$. To synthesize the assessment information of three experts, x_1 is the best place for building solar power station, that is to say, Anhui Provence is the selected place to build more power station. This is in line with planning information in first row of Table 1, or inversely, our method could find out the reasonable solar station location.

Table 1. Key areas photovoltaic power construction scale in 2020 (Unit: gw)

Hebei Provence	1200
Shanxi Provence	1200
The Nei Monggol Autonomous Region	1200
Jiangsu Provence	800
Zhejiang Provence	800
Anhui Provence	600
Shandong Provence	1000
Guangdong Provence	600
Shanxi Provence	700
Qinghai Provence	1000
Ningxia Hui Autonomous Region	800

4. Conclusions and Future Work

In this paper, we have introduced a new method to derive the priority weights from interval positive complementary matrix. In the process of this IAHP, it is not requisite to consider the acceptably consistent of interval positive complementary matrix. And the new method reduce a complex system of MCDM, the new algorithm is also not complex. The main idea of the new method is to combine three techniques: the transformation formulate, cosine similarity measure and the interval numbers possibility degree matrix. The features of techniques can be consider as sufficient compensation for the process of deriving. Moreover, The new method does not need to assume any statistic and provides consistency indication for a PCM. Finally, we use a siting case of solar power station in China to verify the method is doable. We can get the information that distribution of solar energy in China partly play an important role in the selection of solar location.

However, it is necessary to extent the method for incomplete and imprecise PCM. Therefore, in the future research, we will improve the current prioritization methods with more projects and more extensive criterions, and the case study can be done in the comparison between IAHP with another model to solve the solar power station problem[25], for example, Fuzzy-AHP, Analytic Network Process, or comparison between TOPSIS and Maximise Agreement Heuristic, as can be seen in[24,27].

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