

2nd Conference of Transportation Research Group of India (2nd CTRG)

Modelling single file pedestrian motion across cultures

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Abstract

Experiments on single file pedestrian motion conducted in India and in Germany conclusively show that despite similarities in the shape of the fundamental diagram of pedestrian flow there also exist dissimilarities possibly due to cultural differences. Reported cultural differences in the perception of space is used to devise a modification to the Blue-Adler model of pedestrian motion. The modified model is shown to explain not only the generic shape of the fundamental diagram but also why different cultures produce different fundamental diagrams.

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Selection and peer-review under responsibility of International Scientific Committee.

Keywords: Pedestrian Fundamental Diagram; Perceived Space in Pedestrian Motion

1. Introduction

Speed-density relationship (or fundamental diagram) is one of the basic inputs for design of pedestrian facilities. Researchers doing experimental studies in various cultures have obtained different shapes for the fundamental diagram. This observation points to the fact that there are differences in walking pattern between people of different cultures. One of the first studies conducted to understand this cultural difference in pedestrian motion was by (Morrall, Ratnayake, and Seneviratne, 1991). They plotted parts of the fundamental diagrams using limited data (high density data was absent and number of data points were also less) from two different cultures. Also, (Morrall, Ratnayake, and Seneviratne, 1991) did not compare this data statistically.

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The authors, (Chattaraj, Seyfried, and Chakroborty, 2009), in another paper have presented data on pedestrian motion from two widely varying cultures and have shown statistically that differences in the relation between speed and density do exist. (Liu, Song, and Zhang, 2009), conducted experiments using similar set-up as used in (Seyfried, Steffen, Klingsch, and Boltes, 2005), and (Chattaraj, Seyfried, and Chakroborty, 2009). They inferred that differences in fundamental diagrams over different cultures do exist and is due to different body sizes. (Liu, Song, and Zhang, 2009), however, did not base their inference on statistical comparisons.

Yet, there are also large similarities in the shapes of the fundamental diagrams from different cultures. This led the authors to believe that there may be a single model of pedestrian movement but with different parameter values for different cultures. The purpose of this paper is to develop a model which can describe pedestrian motion across different cultures.

The paper is divided into five sections of which this is the first. Section 2 describes the data based on which the proposed model is developed. Section 3 describes the existing modelling framework for pedestrian motion and the proposed model. The next section presents the results obtained from simulating pedestrian motion using the proposed model; this is followed by the concluding section.

2. Observation on pedestrian motion

In this section a brief description of the observations on pedestrian motion obtained from two widely varying cultures are briefly described. A more detailed description of the data and associated analysis can be found in (Chattaraj, Seyfried, and Chakroborty, 2009).

Experiments were conducted in India and Germany to empirically study the motion of pedestrians in a single file without overtaking under periodic boundary condition. The idea behind choosing single file movement is to restrict the study to the impact of longitudinal distance between pedestrians (i.e. distance headway) on speed. In order to ensure single file movement the width of the corridor is kept sufficient to exclude the effect of side wall, but not enough for overtaking. The shape and size of the corridors used in the experiments in India and Germany are exactly the same and is shown in Figure 1. Different densities were created by using different number of pedestrians on the corridor. It may be noted that the authors have shown in (Chattaraj, Seyfried, and Chakroborty, 2009) that increasing the length of the straight stretch from 4 m to 8 m has no statistically significant impact on the fundamental diagram.

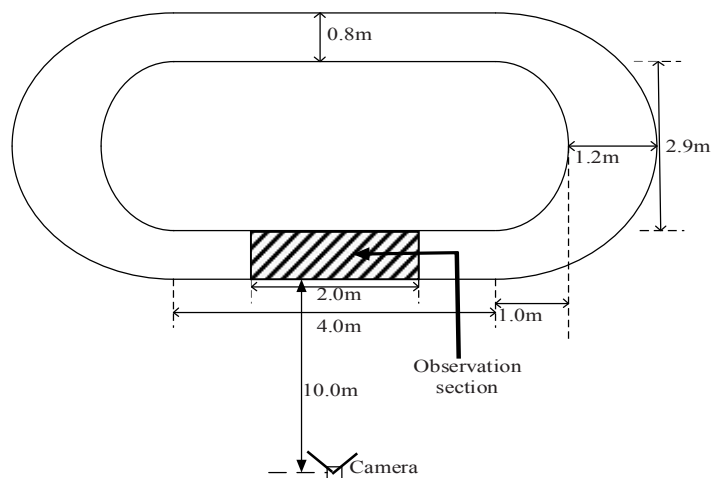


Fig. 1. Sketch of the corridor used for the Indian and German experimental study (adapted from (Chattaraj, Seyfried, and Chakroborty, 2009))

Figure 2 (a) presents the observed data on speed-density from India and Germany. The data clearly shows that although the basic shape is similar, the value of speed for a given density is always higher for India. In the rest of the analysis presented here the data is viewed as distance headway versus speed. The reason behind doing this is that such a representation seemed more amenable to a linear fit than the speed-density data (see Figure 2 (b)). It can be shown that the slope as well as the intercept parameters of the lines fitted (using ordinary least squares regression analysis) to the German and Indian data are statistically significantly different (Chattaraj, Seyfried, and Chakroborty, 2009). As stated earlier the purpose of this paper is to develop a model which can explain not only the basic shapes of these relations but also the differences in these relations across cultures.

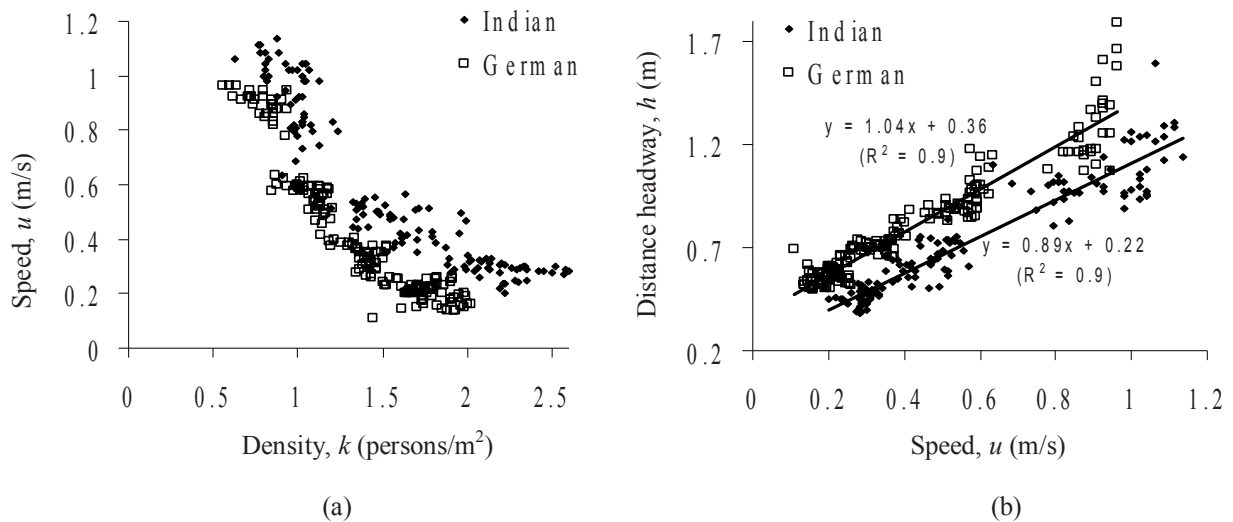


Fig. 2. (a) Speed-density data from Indian and German study and; (b) linear fit for distance headway-speed relation for Indian and German data (adapted from (Chattaraj, Seyfried, and Chakroborty, 2009))

3. Proposed model

Models for pedestrian dynamics can be classified into models defined on a continuous representation of space and cellular automata.

Models which use a continuous representation of space typically assume that pedestrians move in a force field created by static obstacles and dynamic obstacles like other pedestrians. These models have been used in the past to explain the general shape of the speed-density relationship (Helbing, Johansson, and Al-Abideen, 2007). Although there is no work illustrating whether these models can explain cultural differences in the fundamental diagram it is felt that by modifying the force field emanated by dynamic obstacles (like other pedestrians) one may be able to explain cultural differences in the fundamental diagram. These models, however, suffer from a serious drawback in that they are extremely computationally intensive.

Cellular automata based models on the other hand are computationally cheap and can effectively describe many aspects of pedestrian motion through simple and logical rules of pedestrian movement. However, none of the existing models have any mechanism by which they can explain why the fundamental diagram is different in different cultures. In this paper an attempt is made to introduce a variant of the simple cellular automata based Blue-Adler model, which can effectively describe not only the observed shape of the fundamental diagram, but also the differences that exist between different cultures.

The Blue-Adler model describes pedestrian motion through the following rules which are applied sequentially (while describing the rules it is assumed that the unit of distance is cells and the unit of speed is cells/time-step and the update time is equal to one time-step):

Rule 1: For each lane calculate movement possibility of a person, i , as $\text{Min}(\text{gap}, \text{desired speed})$; here, gap is equal to the number of vacant cells between person i and the person immediately ahead of i in that lane. Later in this paper this gap is referred to as the physical gap, P_{gap} .

Rule 2: Move Person i to that lane which gives highest movement possibility; if a tie exists then break it randomly.

For the present case as there is only one lane the Blue-Adler model collapses into one which moves a person i by an amount $\text{Min}(\text{gap}, \text{desired speed})$. In this paper the following modification to the Blue-Adler model is suggested to address the issue of cultural differences in the fundamental diagram.

It is assumed that, unlike in the Blue-Adler model, the “gap” which stimulates a pedestrian to move is not the physical gap that exists, but rather a perceived gap. It is further assumed that this perceived gap is different for different cultures for the same physical gap. In other words the same physical gap is perceived differently in different cultures. It is proposed that the perceived gap, λ_{gap}

$$\lambda_{\text{gap}} = P_{\text{gap}} - B \quad (1)$$

where, B is the buffer and is given by

$$B = c_1 + c_2 \cdot v \quad (2)$$

In Equation 2, v is the speed of the person who is perceiving the physical gap; c_1 and c_2 are parameters which possibly vary from culture to culture.

The above modification in the definition of gap to be used in a Blue-Adler like model suggests that human beings always desire to maintain some buffer between himself/herself and the pedestrians in his/her vicinity. Further, since the distances covered at higher speeds (for the same time durations) are more, the buffer is instinctively maintained at a higher value so as to reduce the chances of colliding into one another. Another way of looking at this buffer is that every pedestrian acts as an obstacle for other pedestrians in his/her vicinity; and that this area or distance over which a pedestrian acts as an obstacle increases with the speed of the approaching pedestrians.

Returning to the assumed definition of buffer in Equation 2, it is seen that it depends on two parameters c_1 and c_2 . The parameter c_1 represents the minimum distance that a pedestrian would like to keep with others around him/her even in a stopped condition. The parameter c_2 represents the sensitivity of buffer to speed. In some sense both c_1 and c_2 indicate a person’s notion of “personal space” (or aversion to collision) while walking with others.

It is accepted that the concept of personal space varies from culture to culture. For example, (Hall, 1966) writes that people of middle-eastern cultures do not mind bumping into one another while Germans “go to almost any length to preserve his ‘private sphere’.” Hence it is expected that (assuming Indian behavior to be close to middle-eastern behavior) c_1 and c_2 will be different for these two cultures.

The proposed model can be described through the following rules:

Rule 1: Person i calculates the buffer required for his movement

$$B_i^t = c_1 + c_2 \cdot v_i^{(t-1)} \quad (3)$$

Where, B_i^t is the buffer that person i wants to keep from his/her predecessor at time step t and v_i^t is the speed of person i in time step t . Non-integer values of B_i^t are converted to integer values, IB_i^t probabilistically in the following way:

$IB = \lfloor B_i^t \rfloor$ with probability p and

$IB = \lceil B_i^t \rceil$ with probability $1 - p$

where p is chosen such that $p \cdot \lfloor B_i^t \rfloor + (1-p) \cdot \lceil B_i^t \rceil = B_i^t$

Rule 2: Person i calculates the perceived gap, $\lambda_{gap_i^t}$ as

$$\lambda_{gap_i^t} = P_{gap_i^t} - IB_i^t \quad (4)$$

where, $P_{gap_i^t}$ is the physical gap available to person i at time step t .

Rule 3: Person i moves by the amount $\text{Min}(\lambda_{gap_i^t}, v_d^i)$; where, v_d^i is the desired speed of person i . Note v_i^t is also equal to $\text{Min}(\lambda_{gap_i^t}, v_d^i)$.

4. Results

The results are presented in two distinct parts. The first part presents a study on how c_1 and c_2 impacts the distance headway-speed relationship. The second part presents a study on how well the proposed model can explain differences in the distance headway-speed relationships from different cultures.

4.1. Studies on the impacts of c_1 and c_2

The proposed model was used to simulate single file pedestrian motion for various c_1 and c_2 values. Figure 3 shows the distance headway-speed plot obtained from the simulated pedestrian stream for two different sets of values of c_1 and c_2 . As can be seen from the figure the values of c_1 and c_2 have an impact on the distance

headway-speed plot. For example, the distance headway-speed plot for higher c_1 and c_2 lies above a similar plot for lower c_1 and c_2 . In order to present a more comprehensive analysis of the impact of c_1 and c_2 on distance headway-speed plot the following analysis is done. First, for given c_1 and c_2 values

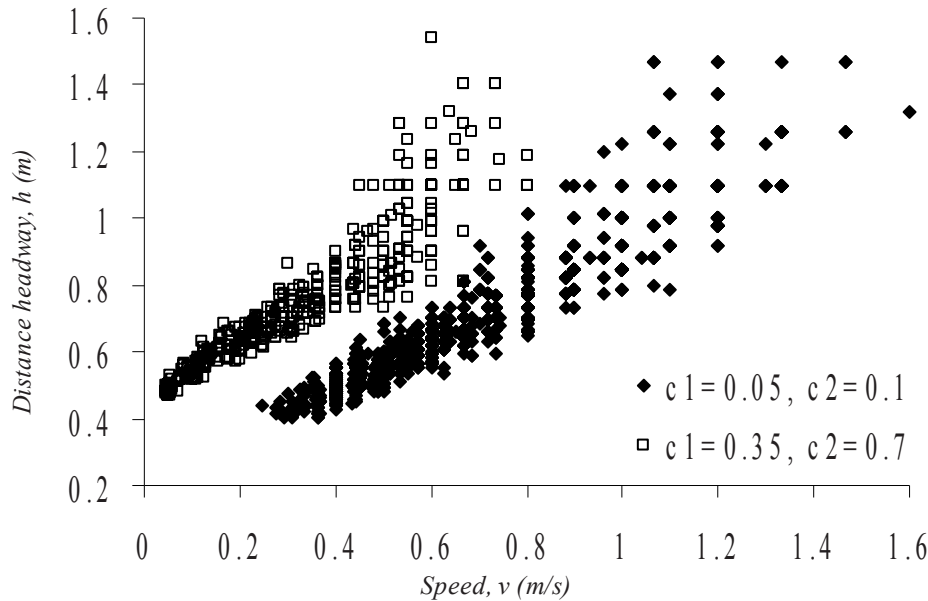


Fig. 3. Distance headway-speed plots for two different sets of c_1 and c_2 values

the simulated distance headway-speed data is obtained. Second, like in Section 2, a linear distance headway-speed relationship is fitted to the simulated data. The intercept and slope terms of such a fitted relationship are then noted.

4.2. Explaining cultural differences through c_1 and c_2

As hypothesized earlier the cultural variations in the distance headway-speed plot can be explained through different choices of c_1 and c_2 . It is expected that in a culture where the personal space is larger the c_1 and c_2 values will be larger than in the case where the personal space (at least in public activities) is smaller. In order to choose the c_1 and c_2 values which most accurately describe the German and Indian data the following procedure is used.

First, the steps outlined in Section 4.1 are followed to determine the intercept and slope terms for a fitted linear relation to the distance headway and speed data obtained from a simulated stream for a given c_1 and c_2 values. Let, the relationship fitted to the simulated data be referred to as

$$h_s^{(c_1, c_2)} = a_s^{(c_1, c_2)} + b_s^{(c_1, c_2)} \cdot v_s^{(c_1, c_2)}$$

(5)

Where, $h_s^{(c_1, c_2)}$ and $v_s^{(c_1, c_2)}$ are the distance headway and speed data obtained from the simulated stream for given c_1 and c_2 values, respectively; $a_s^{(c_1, c_2)}$ and $b_s^{(c_1, c_2)}$ refer to the intercept and slope term for the fitted relationship, respectively. Further let,

$$h_o^c = a_o^c + b_o^c \cdot v_o^c$$

(6)

be the relationship fitted to the observed data (h_o^c, v_o^c) . In this relationship the superscript c can be either I or G , where I stands for Indian condition and G for German condition. Second, for given c_1 and c_2 the values of $a_s^{(c_1, c_2)}$ and $b_s^{(c_1, c_2)}$ are statistically compared with a_o^I and b_o^I , respectively and again with a_o^G and b_o^G , respectively. If on comparison the differences, between a_o^I and $a_s^{(c_1, c_2)}$ and b_o^I and $b_s^{(c_1, c_2)}$ (or between a_o^G and $a_s^{(c_1, c_2)}$ and b_o^G and $b_s^{(c_1, c_2)}$) are not statistically significant then the corresponding (c_1, c_2) value is assumed to explain the given data. All such c_1 and c_2 values for Indian and German data are shown in Figure 4. AVI contains all the $(c_1$ and $c_2)$ values for which the differences between a_o^I and $a_s^{(c_1, c_2)}$

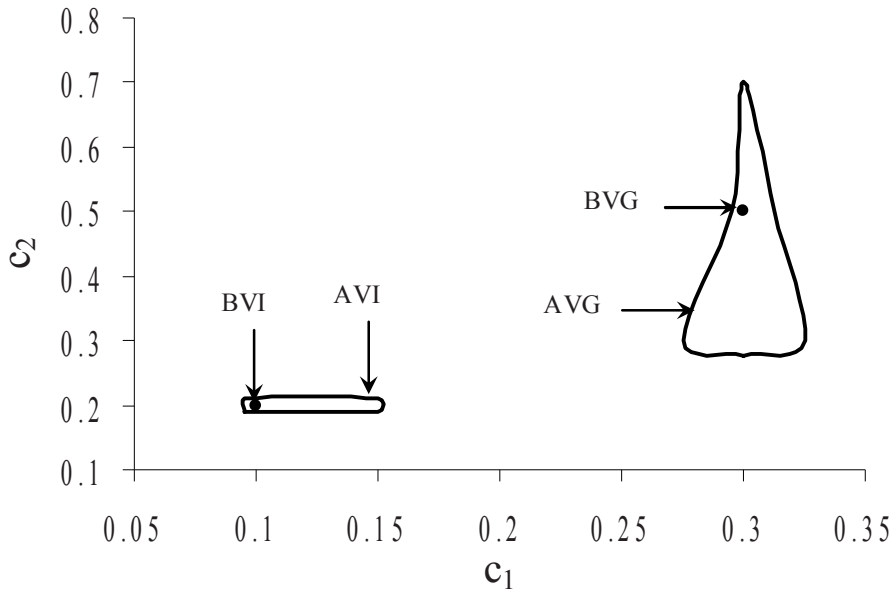


Fig. 4. (c_1, c_2) showing acceptable and best values for Indian and German experimental data

and b_o^I and $b_s^{(c_1, c_2)}$ are not statistically significant; i.e., this area contains all the acceptable c_1 and c_2 values for the Indian data. A similar area for the German data is shown as AVG. Third, amongst all the points in AVI, that c_1 and c_2 value is chosen for which the deviation between the $h_o^I - v_o^I$ relationship and $h_s^{(c_1, c_2)} - v_s^{(c_1, c_2)}$ relationship is the least. This value is marked as BVI in Figure 4. Similarly a BVG is determined for German data. It may be noted here that the deviation used to determine BVI and BVG are obtained as

follows: (i) random values of speed (within the range of observed values) are chosen, (ii) for those values of speed, the values of distance headway as predicted by the $h_o^I - V_o^I$ (or $h_o^G - V_o^G$) relationship and $h_s^{(c_1, c_2)} - v_s^{(c_1, c_2)}$ relationship are noted, and (iii) the difference between the above values of distance headway are squared and summed to give the deviation metric used to obtain BVI and BVG.

From Figure 4 it can be seen that any (c_1, c_2) value which is acceptable for the German data (i.e., $(c_1, c_2) \in \text{AVG}$) is higher than any (c_1, c_2) value which is acceptable for the Indian data (i.e. $(c_1, c_2) \in \text{AVG}$). Further, the c_1 value corresponding to BVG is substantially greater than that corresponding to BVI; the c_2 value corresponding to BVG is substantially greater than that corresponding to BVI. These observations also corroborate the general understanding

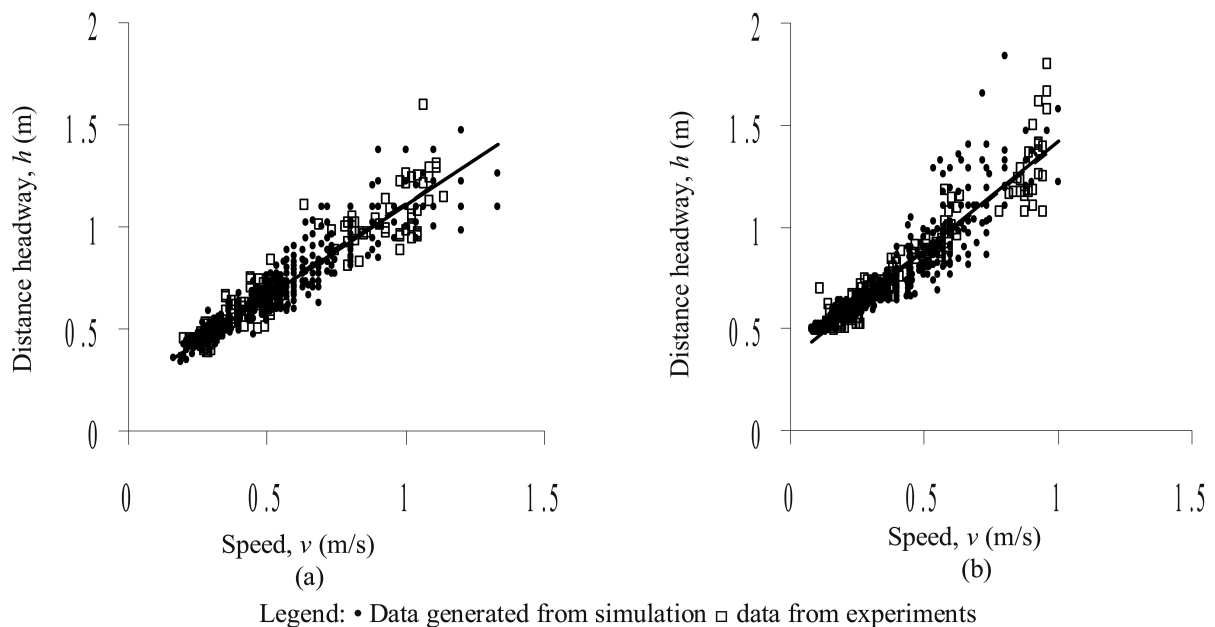


Fig. 5. (a) Simulated and observed distance headway-speed data and fitted relationships for Indian conditions and; (b) Simulated and observed distance headway-speed data and fitted relationships German conditions

that Germans are more averse to restricted personal space than Indians (recall (Hall, 1966) observations cited earlier).

Figure 5 (a) shows a comparison between the observed Indian distance headway-speed data (i.e., $(h_o^I - V_o^I)$ points) and the simulated distance headway-speed data (i.e., $(h_s^{(c_1, c_2)}, v_s^{(c_1, c_2)})$ points) obtained with a value of (c_1, c_2) corresponding to BVI. Figure 5 (b) shows a similar plot for the German data; the (c_1, c_2) values used to simulate the data in this case corresponds to BVG. The plots show that the simulated and observed values match quite well.

Figure 5 (a) also shows the line of best fit for the $h_o^I - V_o^I$ data as well as the line of best fit for the $(h_s^{(c_1, c_2)}, v_s^{(c_1, c_2)})$ data shown in the figure. These lines, as can be seen, are almost coincidental; same is case for Figure 5(b).

From these observations it can be stated that the proposed model describes (i) the nature of the distance headway-speed relationships, and (ii) the differences that exist between these relationships between cultures through the use of different c_1 and c_2 values.

5. Conclusions

Despite the similarities in certain aspects of the fundamental diagram of pedestrian flow in different cultures there are also differences that exist in these relations between cultures. Observations presented here from Indian and German data from exactly the same experimental set up attest to these facts. A modified Blue-Adler model is presented. This modified model, unlike other cellular automata based models, can describe the fundamental diagram from different cultures effectively. The modification to the Blue-Adler model made here is motivated by the differences that exist between people's perception of space in different cultures.

Acknowledgements

The project was partially funded by the Deutsche Forschungsgemeinschaft (DFG) under Grant-Nr.: SE 1789/1-1. The support of the Department of Civil Engineering, IIT Kanpur is also acknowledged.

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