Dynamic Simulation of Land Use Change Based on CA Model: A Case Study of Saga in Japan

アジア各国では急速な経済発展により、水陸の生態系に大きな負荷がかかっている。それを改善する土地利用の方法をさぐる。

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Abstract

This study demonstrates a combined Markov-Cellular Automata model to analyze temporal change and spatial distribution of land use stressed by natural and socioeconomic factors in Saga, Japan. Firstly, area change and spatial distribution of land use are calculated using GIS technology, and then the transition among different land use types is analyzed to obtain the transformation matrices during a period 1976–2006. Meanwhile, an integration evaluation procedure with natural and socioeconomic data is used to generate the transition potential maps. Secondly, using the transition potential maps and transition matrices, a Markov-Cellular Automata model is established to simulate spatial distribution of land use in 2006. Finally, we use this Markov-Cellular Automata model to forecast future land use changes during the period 2015–2042. As a consequence, area change simulation predicts a continuing downward trend in agricultural land and forestland areas, as well as an upward trend in built-up areas; spatial distribution simulation indicates that built-up land will expand toward suburban regions, and land use at the urban center is in the decline stage. Hence, if the current trends keep constant without holistic sustainable development measures, severe land use decline will ensue.

Keywords Land use change; GIS; Markov model; Cellular automata model; Saga in Japan

Introduction

Land use models are core subjects of Land Use/Cover Change (LUCC). In recent years, the LUCC community has produced a large set of operational models that can be used to predict or explore possible land use change trajectories. Models not only support the exploration of future land use changes under different scenario conditions. Scenario analysis with land use models can also support land use planning and policy. Until now, all these models were divided into three classes: empirical and statistical models, such as Markov chains and the Regression model; dynamic models, such as the Cellular Automata (CA) model, the Agent-based model and the System dynamic model; and integrated models, such as CLUE (Conversion of Land Use and its Effects) model. Empirical and statistical models can complement dynamic simulation models. Dynamic models appear to be better suited to predict land use changes in the future than empirical and statistical models. An integrated model that is based on multidisciplinary and combining elements of different modeling techniques will probably best serve the objective of improving and understanding land use change processes.

The objective of this study is to simulate future land use changes based on the Markov-CA model with natural and socioeconomic data in Saga, Japan. First, transition matrix is computed from the land use maps (1976, 1987, 1997 and 2006) using the Markov model to forecast area change of land use. Secondly, an integration evaluation procedure is used to generate transition potential maps based on natural and socioeconomic indicators. Finally, transition matrix and transition potential map are implemented in the Markov-CA model to simulate spatial distribution of land use from 2015 to 2042.

Material and Methods

Study area

Saga is the capital of Saga Prefecture, located on the island of Kyushu, Japan. After a merger in 2005, the city became very long in the direction of north-south, as shown in Fig. 1. It borders the Ariake Sea to the south and Fukuoka Prefecture to the southeast and north. Its total area is 431.42 km^2, population is 238,934 as of February 1, 2009, and population density is 554 per km2. For a long time, the region has been chiefly aiming at urban expansion and ignoring reasonable adjustments of the land use structure. So, potential disadvantages are threatening its sustainable development of urban land use. In this paper, land use types are divided into 6 classes (agricultural land, forestland, water, built-up land, roads and other lands) according to national classification standard of land use. Other lands include barren land and beaches.

Methods

This study employs a coupled Markov-CA model that integrates GIS software to simulate land use changes and spatial distribution in the future. The detailed steps are shown in Fig. 2. First, we obtained land use maps from 1976 to 2006 with GIS technology. Then, transition matrixes were established using Markov chain analysis. Secondly, seven assessment

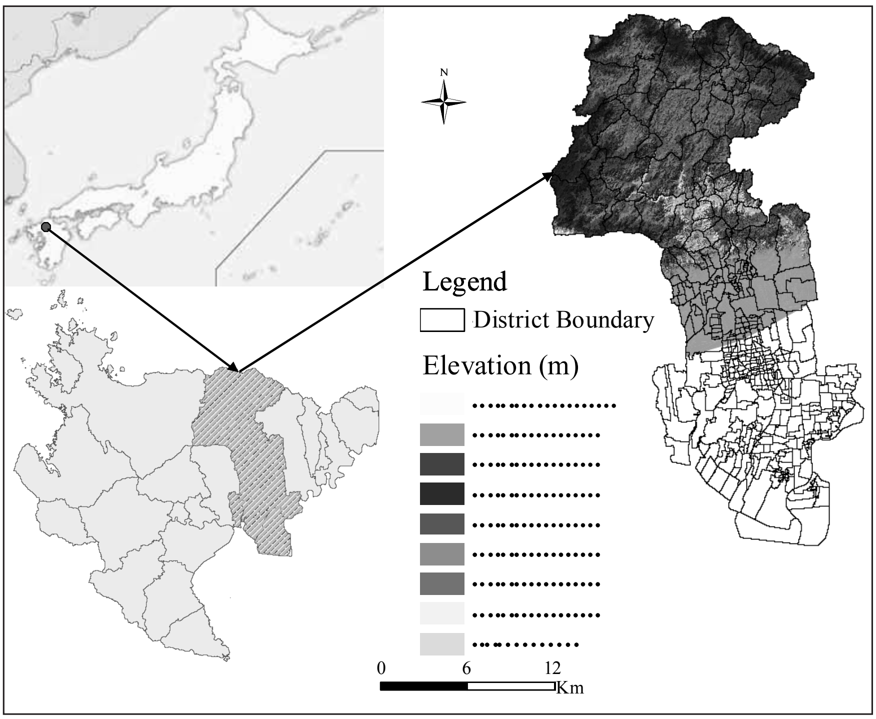

Fig. 1 Location of study area

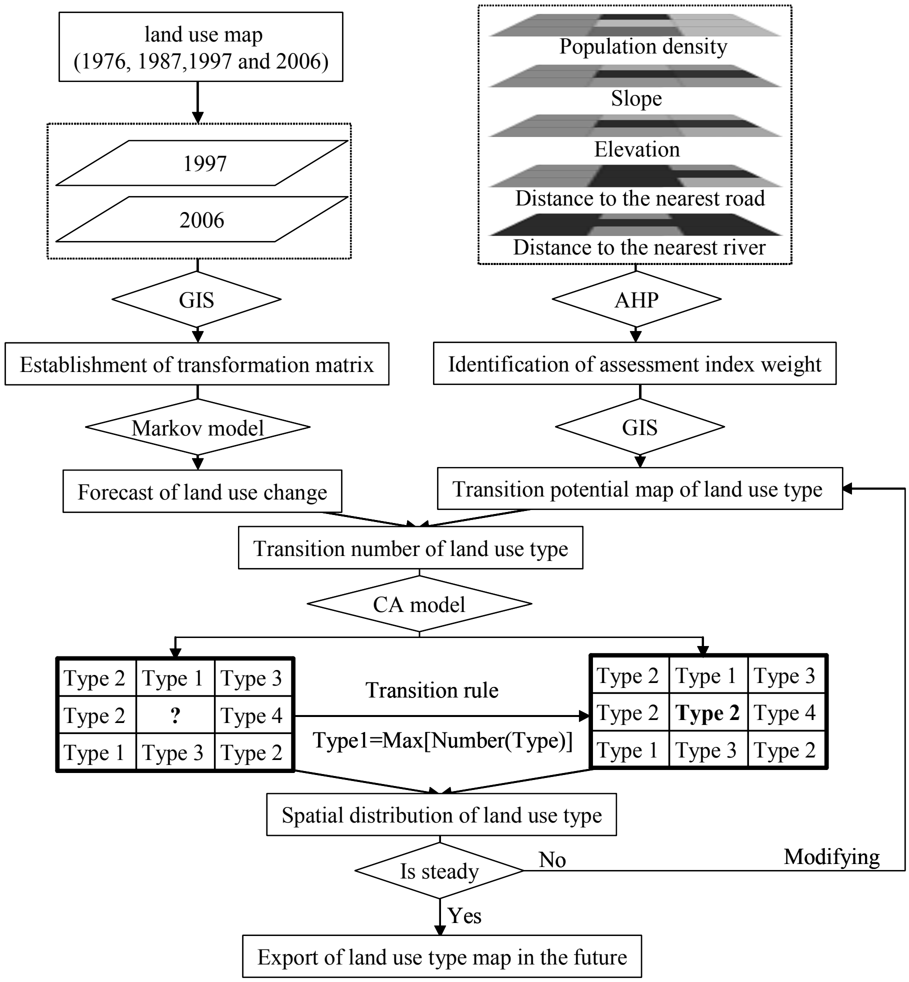

Fig. 2 Research flow chart

indicators were selected to compute transition potential maps of land use. Finally, we used the transition matrixes and transition potential maps to simulate spatial distribution of land use on the basis of the transition rule of CA model.

Results

Analysis of transition matrix

Analysis of land use area changes in Fig. 3 indicates that agriculture, forestland and built-up land were the dominant types of changed land use in the studied area. From 1976 to 2006, forestland areas decreased from 43.33% to 43.03%, while in 1987 they slightly

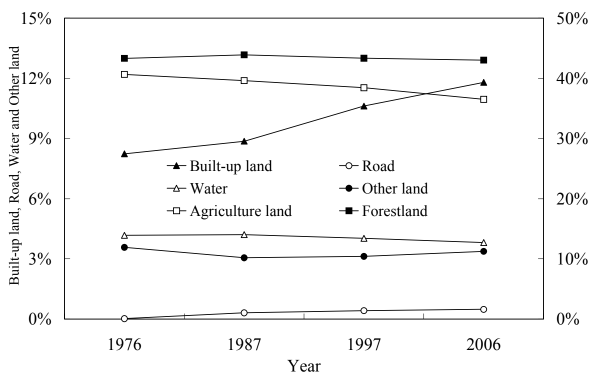

Fig. 3 Area change of land use from 1976 to 2006 in Saga

increased to 43.93%. However, agriculture areas decreased significantly from 40.67% to 36.51% during 1976–2006. During this period, the built-up area increased from 8.24% to 11.80%. Other land area reduced by 3.05% from 1976 to 1987, and then dramatically increased by 3.38% from 1987 to 2006. The area of water and road increased slightly.

Spatial distribution of land use types in Saga city at the four year nodes were also obtained by virtue of GIS spatial technology. From Fig. 4, we can see that the spatial pattern of land use in the four periods was mainly characterized as changes of patch distribution. First, agricultural land, built-up land, and unused land patch showed continual fragmentation and dispersion, indicating that the extent of human expansion and utilization intensity became larger and larger. Secondly, patch numbers and patch areas of built-up land continued to increase and showed the diffused distribution patterns from urban center to suburban region. This is because urban construction of Saga city accelerated urban development and 1ed to rapid expansion of urban land use. Thirdly, urban centers appeared in more patches of other land type from 1987 to 2006, suggesting that land use extent of Saga city had entered a declining stage.

As a result, the total region transformation tendency of land use types from 1976 to 2006 appeared as an unbalanced tendency of unidirectional-transformation. The built-up land continuously increased, and the agriculture land continuously decreased. The increasing source of built-up land was changed from the previous agriculture land and other land, to the present forestland and agricultural land.

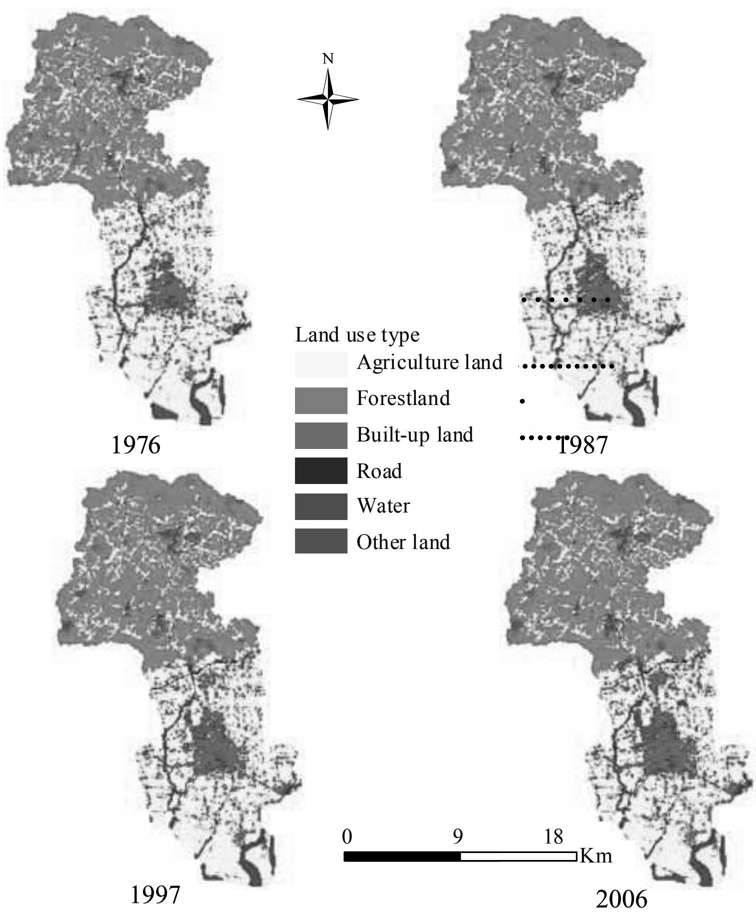

Fig. 4 Space distribution of land use from 1976 to 2006

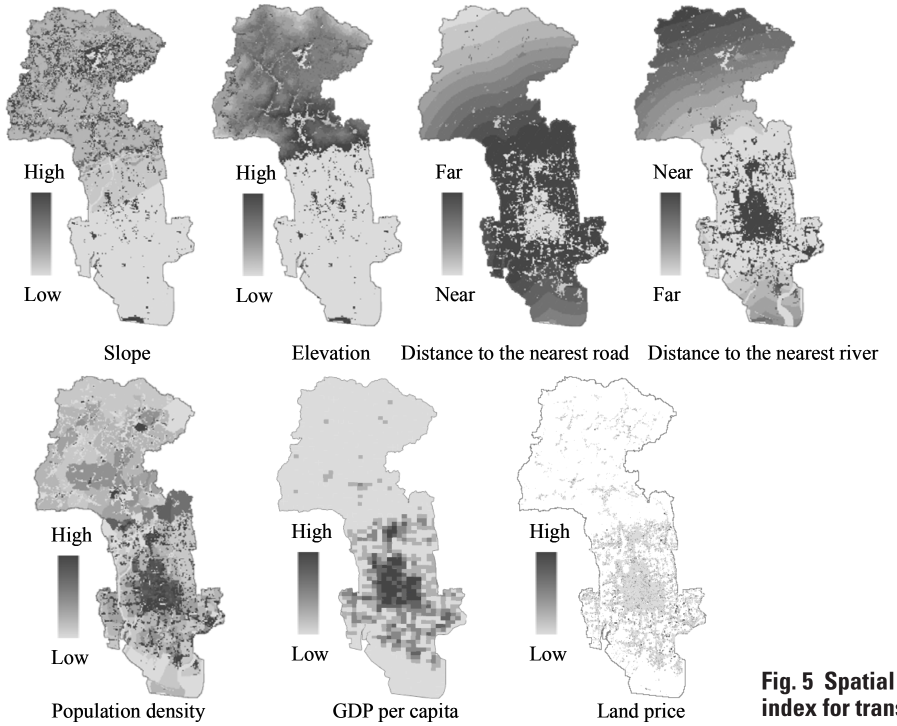

Fig. 5 Spatial distribution of assessment index for transition potential map

Analysis of transition potential

Seen from Fig. 5, the south region is the urban center of Saga city, where population density, GDP per capita, and land prices are high, and distance to river and road is short; slope and elevation are high in the north region. Transition potential of each land use type is obtained by combining spatial distribution, standard and weight of assessment index. Fig.6 represents the transition potential from one land use type to all other land use types. For example, transition potential of agricultural land indicates the transition potential of agricultural land to all other land use types (forest, built-up, water, road, and other land). Also seen from Fig. 6, the transition potential of agriculture land and forestland are high; transition potential of built-up land and other land are low.

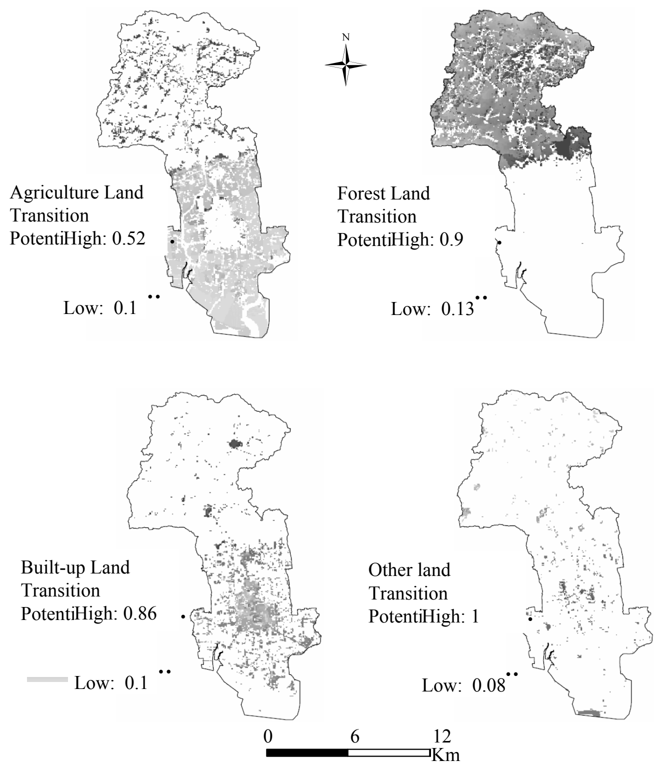

Fig. 6 Transition potential maps of land use type in 2006

Analysis of simulation results

Because the accuracy of forecasts cannot be guaranteed if different potentials are used we therefore only used the transition probability matrix of the latest 1997–2006 period to forecast land use change in the future 30 years. First, 2006 is set as the starting year; transition probability matrix of 1997–2006 periods is used to forecast 2015 year land use change; then, 2015 year is set as the starting year; transition probability matrix of 1997–2006 periods is used to forecast 2024 land use change; thirdly, 2024 is set as the starting year; transition probability matrix of 1997–2006 periods is used to forecast 2033 land use change; finally, 2033 year is set as the starting year; transition probability matrix of 1997–2006 periods is used to forecast 2042 land use change. Based on the successful simulation of area change and spatial distribution in 2006, we forecast the area change of future land use and land use maps from 2015 to 2042 as shown in Fig. 7 and Fig. 8, by using land use base map in 2006, transition probability matrix of 1997–2006 period, and transition potential maps in 2006. Seen from Fig.7, area change results show that agriculture land areas would decrease from 36% to 28% in the study area, while built-up land would increase slightly from 12% to 16%. Other land areas would also increase from 3.3% to 3.7%. Conversely, forestland areas would slightly decrease from 44% to 41%. As shown in Fig. 8, spatial distribution results indicate that all land use type would exhibit the concentrated spatial distribution patterns; urban built-up land would expand to suburban, because agriculture land in the suburban areas would rapidly convert into built-up land. Meanwhile, the transformation tendencies for forestland and built-up land into other land would be enhanced. In the view of total study area, we can see very strong transformation tendencies of all land types into built-up land.

Discussion and Conclusions

In this study, using land use maps (1976, 1987, 1997 and 2006 year), and natural and socioeconomic data, we combine Markov-CA model with GIS technology to successfully simulate the land use changes in Saga, Japan. Our model is validated with the actual data of 2006 and shows very high reliability. Based on the validation, the Markov-CA model is used to simulate the future land use changes up to 2042. The area change results show the decrease in agricultural land and forestland, and the increase in built-up land. From the aspect of spatial pattern change of land use from 2015 to 2042, urban built-up land would expand to suburban, because a certain proportion of agricultural land would be transformed into

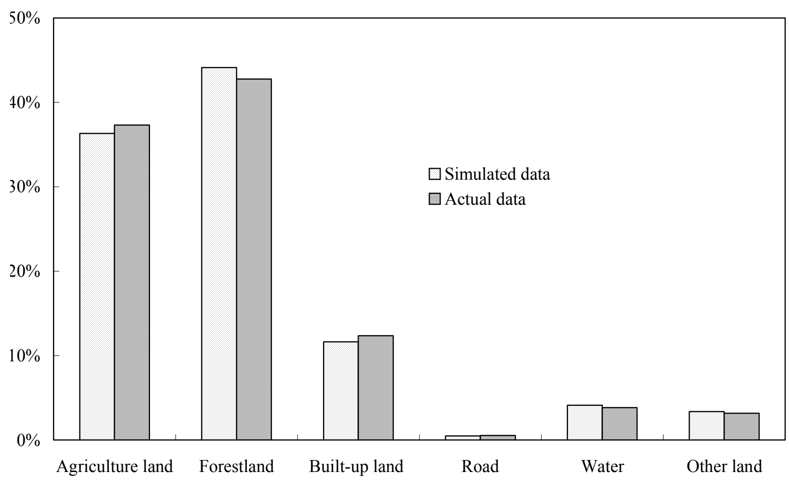

Fig. 7 Area change of land use from 2015 to 2042 in Saga

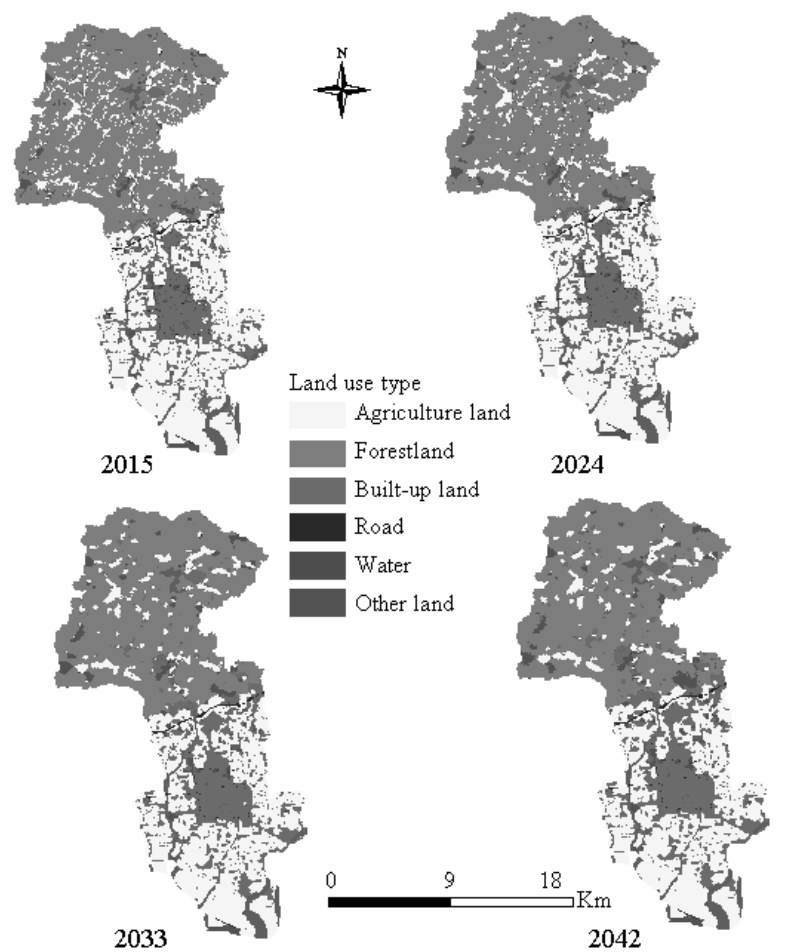

Fig.8 Simulated map of land use type from 2015 to 2042

urban land, reflecting that agricultural land would be used for urban land in the future; whereas, other land at the urban center would increase, suggesting that Saga city is at a declining stage of urban development. As a consequence, if the sustainable development policies with the cooperation of resident are not constituted to improve the current trends of land use, land use condition will seriously deteriorate and threaten urban sustainability.

In summary, our study presents an important contribution to land use modeling, which logically integrates natural and socioeconomic data into a spatially explicit Markov-CA model with GIS technology to successfully simulate and forecast the temporal and spatial changes land use. Facing the problem of declining urban land in Saga, the simulated future land use maps can serve as an early warning system for understanding the future effects of land use changes. The acquired information is beneficial to other communal areas in Asia experiencing similar land use changes. The simulation results can also be considered as a strategic guide to urban land use planning, and help local authorities better understand a complex land use system and develop the improved land use management that can better balance urban expansion and ecological environment conservation. We also suggest that to further improve our Markov-CA model, e.g. using Markov model to reveal the transition rule of CA in the case of land use as proposed by Liu et al, and to demonstrate how such models can help solve practical planning issues are required. For instance, besides the prediction purpose, the Markov-CA model may interactively simulate different evolution scenarios and further provide certain solutions to the present problems as suggested recently.

Acknowledgments

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