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Application of System Dynamic in Environmental Management; Forecasting of Fishing Participation

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Abstract: In the present study fishing participation activities of San Francisco Bay region has been modeled in System Dynamic modeling software Vensim, considering four affecting parameters (two quality parameters; water quality index, food web index and two socio-economical parameters; population, income) of study region. Four modeling scenarios were generated to simulate future projection of target parameter. Results showed comparatively different values in four scenarios at the target year 2015, as it could be expected by the different nature of controlling parameters. But there are some similar patterns contributed to type of parameters. For socio-economical parameters results shows the same pattern in comparison with historical change trend of fishing participation in the region (more values) and on the other side, quality parameters have shown the same pattern in a comparison basis with historical changes (less values). With the extent of available data, knowledge of affecting processes in the modeled system and not weighted usage of controlling parameters in this investigation, results can only strongly indicate the same impact of socio-economical parameters and same impact of water quality parameters on fishing participation activities of San Francisco Bay region.

Key words: System dynamic, vensim, modeling, water quality index, food web index, prediction, fishing participation

INTRODUCTION

Recently several practices with focus on environmental management and prediction oriented modeling of aquatic systems have been done. Chau (2007) presented an ontology-based system for flow and water quality modeling which assist on integration of knowledge management, artificial intelligence technology with the conventional hydraulic algorithmic models. Muttil *et al.* (2006) utilized neural network and genetic programming for modeling coastal algal blooms. Wu (2006) presented a mathematical model of water quality rehabilitation by utilising rainwater. Chau (2004) submitted a real-time three-dimensional finite difference numerical model for simulation of eutrophication dynamics in coastal waters.

Most static predicting methods like geometric average method, saturation curve method, least square method and curve extension method are based on experimental or semi experimental mathematical methods that extend data provided by a relatively large dataset. Brian *et al.* (2005) stated that these datasets may come from historical data collection or statistical operations leading to reliable datasets which finally lead to prediction of modeled parameter in a desired future time, based on the historical change trend of variables. Investigations presented in System Dynamics Society review (2006) indicated in the cases where dataset is not fully enough for a static prediction process, utilization of Dynamic analysis has played a significant role to model such problems. This provides

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ability to consider combined impact of effective parameters on the modeled parameter which some of them may be affected by complicated interrelationships in the whole problem. In fact system thinking approach assists us for a better understanding of large scale managerial problems. Sterman (2000) carried out an investigation entitled Modeling for a Complex World, used System dynamic method as a useful methodology to study and manage feedback systems. Sterman (2000) and Forrester (1971) used a usual procedure of modeling in their investigations; comprising utilization of different modeling modes and scenarios which are chosen based on available or possible managerial alternatives in the starting problem definition framework. Chen *et al.* (2000) also carried out a Grey fuzzy dynamic modeling for prediction of solid waste generation which finally led to more satisfactory prediction of modeled parameter based on the historical change trend of variables. Grey dynamic models fulfill more reliable predictions in the cases where limited databases are available or system environment (boundaries and relationships) is not well recognized.

System dynamic modeling has been used to address practically every sort of feedback systems in different categories. Sterman (2000) studied business systems, Grant (1997) carried out a study on Management practices in ecological systems, Forrester (1971) used system dynamic tool in social-economic systems modeling, Qu (1998) employed dynamic approach to assess agricultural systems, Nail (1992) used dynamic modeling to assist decision makers in political decision making systems. More interestingly, several modeling practices have been done in order to catch better management opportunities or more reliable predictions in environmental systems.

Vizayakumar (1993) has used system dynamic tool in Modeling and simulation of environmental impacts of a coalfield, Vezjak (1998) studied eutrophication processes in lakes, Ford (1999) studied pesticide control practices, Wood (1999) examined wetland metal balance measurement by dynamic simulation of processes in a specific wetland aquatic system, Abbott (1999) modeled groundwater recharge in a fracture bedrock aquifer which consist a variety of affecting parameters, Guo (2001) utilized dynamic modeling tool in lake watershed management, Deaton (2000) carried out an investigation on river pollution control and examples of scenario generation based practices has been done in solid waste management (Brian *et al.*, 2005; Mashayekhi, 1993).

Reliable prediction of annual American's Participation in Fishing activities in regional, state and national scales may be of great importance in managerial schematizations, regarding economical, social, recreational and environmental issues (United States fish and wildlife service, 2001). It is mainly because of relatively considerable money exchange due to fishing activities and indirect associated activities that may include boating, wildlife watching, equipment preparation and etc. and water quality effects of this participation. In the present study, the amount of public participation in fishing activities in the San Francisco Bay region at the year 2015, has been chosen as target parameter of modeling. System dynamic modeling Software Vensim version 5.5a has been used to perform analysis.

MATERIALS AND METHODS

About complexities of system it should be stated that, system is complex not only because of not predefined relation between parameters and not only because all parameters are involved in the problem simultaneously and affected by each other (e.g., effects of participation activities on water quality level of region, that has not been considered in this study with limited amount of information available) but also because of the fact that parameters are changing dynamically through time.

However, statistical issues specifically in the case of small degree of freedom, prohibits trying more than two explanatory variables in the model due to scarcity of datasets. With no longer dataset available in this case, employment of system dynamic model to predict target value of Fishing Participation in year 2015 can help the key environmental-managerial planners to attain desired goals based on more reliable results. In this investigation four different scenarios have been supposed to be future projection of Fishing Participation in study region.

This scenario generation is performed by adequate consideration of possible managerial scenarios. Taking into consideration possible water quality control efforts, population change trend and economic growth rate consideration in environmental management, with serious limitation of scarce datasets which led us to choose present scenarios. In each scenario two explanatory variables have been utilized. Two water quality parameter and two socio-economical parameters have been supposed to be controlling factors in public fishing participation in the region San Francisco Bay, including:

- Water Quality Index, which has directly been considered to be adequate representative of water quality of region and has been considered that the water quality can affect fish population and sequentially can affect fishing activities in proposed region in amount and multiplicity of occurrence. It has also been assumed that the main parameters affecting water quality had been considered in water quality index development (San Francisco Estuary institute).
- Food Web Index, which has been supposed to be representative of total biomass in the aquatic system that has direct relation with fish population in the region and subsequently can affect fishing participation activities in the Bay (San Francisco Estuary institute).
- Region population, it has been supposed that with increase in population, total fishing participation activities in the region is increased by the time, as normalized trend of participation per population agree this assumption.
- Median household income, participation change trend associated with this parameter is similar to population trend, i.e., increase in participation by increase in income, with less trend line slope than for population.

Data collection includes water quality data, population data and economic data. Regional data for San Francisco county and San Francisco bay, including population data of region, median household income of residents is collected from USA bureau of census annual statistical reports (US Bureau of Census, 1991-2004) and water quality data of San Francisco Bay including, Water Quality Index (WQI) and Food Web Index (FWI) is obtained from San Francisco Bay institute home page (San Francisco Estuary institute reports).

With available water quality, population and economic data for years 1997 to 2004 and data on public participation in regional fishing activities for years 1991, 1996 and 2000 growth or decay of these parameters have been regressed individually versus time with least square method, for periods of US census data available. Results are depicted in Table 1 and 2. It should be stated that, with three points normality is not assumed nor relation of cause and effect is sought but an indication of goodness of fit is assumed as appropriate basis for reliability of input data. For all parameters, values of R^2 are in acceptable range 0.85 to 0.98 except for food web index ($R^2 = 0.32$). Effect of this low goodness of fit for food web index is assumed to convert to negligible due to normalization process to target parameter. Results of normalization process considerably support this assumption, $R^2 = 0.32$ for

Table 1: Statistical data on economic, population and fishing participation of study area

Years	1991	1996	1997	1998	1999	2000	2001	2002	2003	2004	R^2
MHI[1]			43405	48000	50900	52300	53500	53087	52400		0.855
P[2]				`	746777	776665	774479	761983	751908	744230	0.967
FP[3]	268889	270875				271270					0.910

[1]: San Francisco county Median Household income (http://www.census.gov); [2]: San Francisco county Population, (http://www.census.gov); [3]: San Francisco region fishing participation (http://www.census.gov)

Table 2: Statistical data on water quality parameters of study area

Years	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	R^2
FWI[4]	21.27	18	17	14	13.65	14	16.3	12	16.7	16	14	15	0.315
WQI[5]									70.0	65	65	55	0.852

[4]: Food Web Index of San Francisco Bay region (<http://www.sfei.org); [5]: Water Quality Index of San Francisco Bay region (<http://www.sfei.org)

FWI regression has converted to $R^2 = 0.78$ for normalized participation per FWI variation versus time which is a little bit lower than other slopes. As regressed amounts of normalized values are used as rate inputs to model, low goodness of fit for food web index is supposed to be impeccable.

Using obtained data, values of certain parameters needed for modeling practice have been regressed versus time in year steps. These parameters include normalized values of target parameter (Fishing Participation) to different affecting parameter considered in modeling scenarios: Participation per population growth, participation per income growth, participation per water quality growth and participation per FWI (food web index) growth. Slopes of regressed lines have been used as annual growth rate in different scenarios in the model. It should be stated that goodness of fit for regressed terms are in acceptable levels (R^2 = 0.8 to 0.99) except for term participation per food web index ($R^2 = 0.78$), as stated above this low goodness of fit is supposed to be negligible (Table 3).

Software Vensim (Ventana systems, inc.) ver. 5.5a has been used in this modeling practice. Figure 1 depicts an overall diagram of processes in a common dynamic modeling which involves stocks, flow and converters. Stocks represent accounting of system component, flows are the rate at which a component flows in or out of stocks and converters modify rates of change and unit conversions (System Dynamics Society, 2006).

By data processed above, growth rates, required input parameters to different proposed scenarios, are available. Scenario generation involves consideration of two socio-economical parameters (Median household income and Population) and two water quality parameters (Water quality index and food web index). Finally four modeling scenarios have been developed as depicted graphically in Fig. 2-5. In scenario 1, fishing participation has been supposed to be controlled by population change trends of study region, in scenario 2, by quality of water, where water quality index of aquatic system has been chosen as adequate representative of total water quality of system, in scenario 3, by food web index generated based on available biomass in aquatic system of study region, in scenario 4, by median household income in study region.

Table 3: Normalized values of parameters of interest (slopes as input flows to software)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	S	R^2
NPI[6]	4.957[a] E-03	4.940 E-03	4.923 E-03	4.906 E-03	4.889 E-03	4.872 E-03	4.856 E-03	4.839 E-03	4.823 E-03	4.807 E-03	4.791 E-03	4.775 E-03	4.759 E-03	4.744 E-03	4.73 E-03	2 E-05	0.99
NPP[7]	6.28 E-05	6.22 E-05	6.15 E-05	6.09 E-05	6.03 E-05	5.97 E-05	5.92 E-05	5.86 E-05	5.80 E-05	5.75 E-05	5.70 E-05	5.65 E-05	5.59 E-05	5.55 E-05	5.50 E-05	6 E-07	0.99
NPW[8]	4.75 E+01	5.16 E+01	5.65 E+01	6.24 E+01	6.96 E+01	7.87 E+01	9.06 E+01	1.07 E+02	1.30 E+02	1.65 E+02	2.27 E+02	3.64 E+02	3.90 E+02	4.55 E+02	4.95 E+02	31.54	0.86
NPF[9]	2.10 E+02	2.21 E+02	2.33 E+02	2.47 E+02	2.62 E+02	2.79 E+02	2.98 E+02	3.20 E+02	3.46 E+02	3.76 E+02	4.12 E+02	4.55 E+02	5.09 E+02	5.76 E+02	6.65 E+02	29.34	0.78

[6]: Normalized participation per income; [7]: Normalized participation per population; [8]: Normalized participation per water quality index; [9]: Normalized participation per food web index. S: Regressed line slope. [a]: In the years where data from statistical reports had not been available, data from initial data regression have been used for normalization

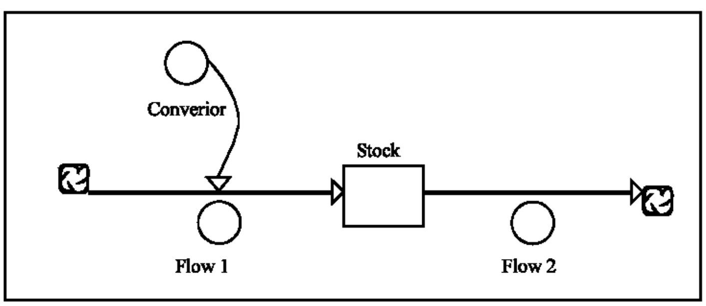

Fig. 1: Schematic of typical processes in dynamic modeling environment

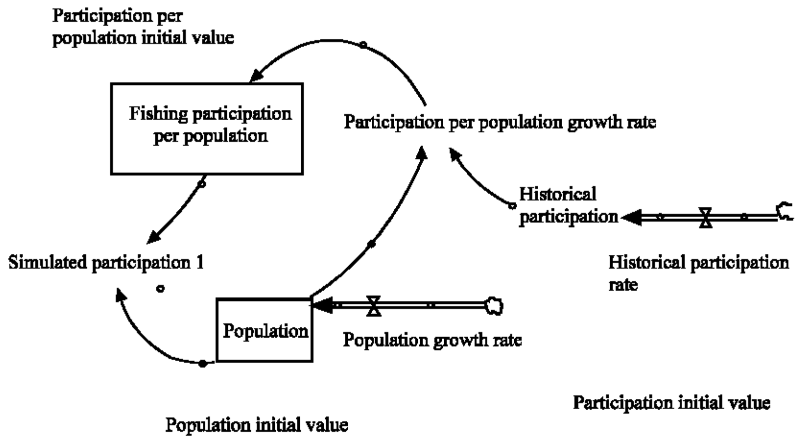

Fig. 2: Scenario 1, Fishing participation controlled by population growth rate

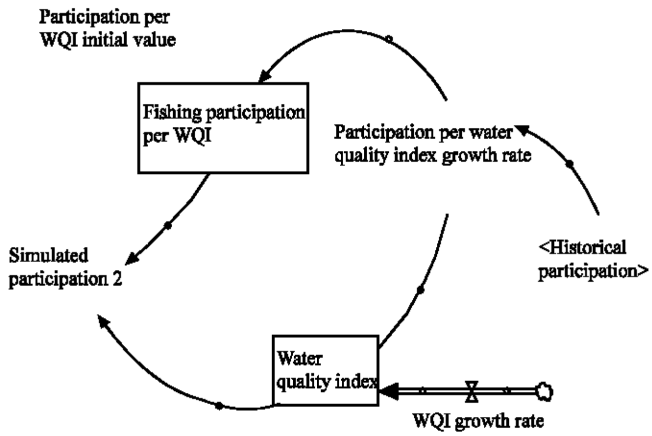

Fig. 3: Scenario 2, Fishing participation controlled by water quality index

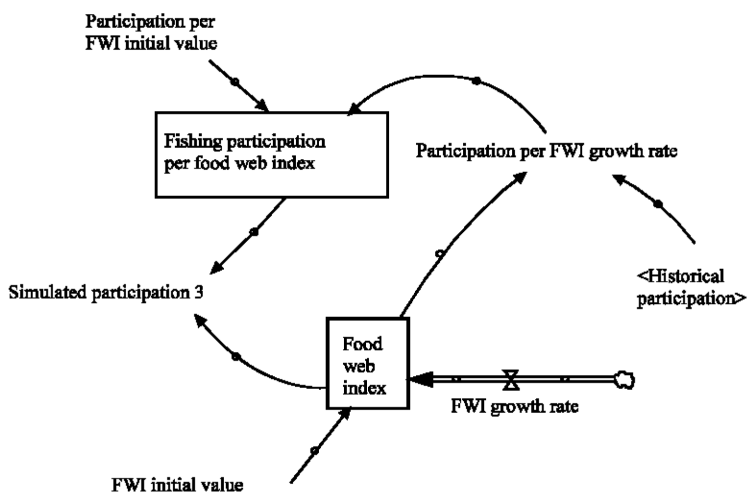

Fig. 4: Scenario 3, Fishing participation controlled by food web index

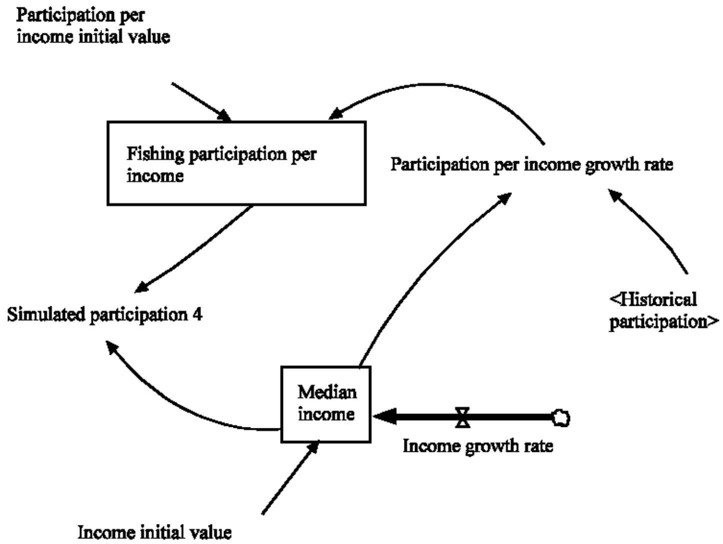

Fig. 5: Scenario 4, Fishing participation controlled by median household income

Inside the model, the main dynamic part of scenarios takes place in generation of secondary growth rates that generates updated rates each year by considering average of beginning and end of time step (one year). Having updated rates, normalized values of target parameter to controlling parameter is produced for each year. Amount of target parameter is measured by multiplying updated normalized values (e.g., in scenario1, Fishing participation per population) in regressed values of explanatory variable (e.g., in scenario1, Population) in each scenario and in every time step. Finally obtained values are regressed versus time and represented as final simulated values for participation activities in that scenario.

RESULTS AND DISCUSSION

The simulated amounts of target parameter (fishing participation) for four developed scenarios in year 2015 have been shown in Table 4. Obtained amount for scenario 2 is 272170 and for scenario 3 is 272770 which are considered to be fairly close results. Obtained amount for scenario1 is 275520 which stand slightly farther from amount for scenario 4 which is 278020. Regressed amount of historical participation data, obtained from regressed line for data of years 1991, 1996 and 2000 ($R^2 = 0.9$), have been plotted in Fig. 6 to provide a comparison basis between historical change trend amount and that of obtained from the models.

As it is obvious in Fig. 6, values obtained by considering quality parameters as controlling parameters (scenario 2 and 3) have resulted clearly in less values than historical regression trend in fishing participation. Values obtained by considering socio-economical parameters as controlling parameters (scenario 1 and 4) have resulted in relatively higher amounts for fishing participation activities in year 2015 compared to scenarios 2 and 3.

Difference between these results can strongly be contributed to different nature of controlling factors considered in this problem definition framework. In fact the philosophy behind such problem

Table 4: Simulated amount of different scenarios in target year 2015

	Historical regression	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Target values in year 2015	274090	275520	272170	272770	278020

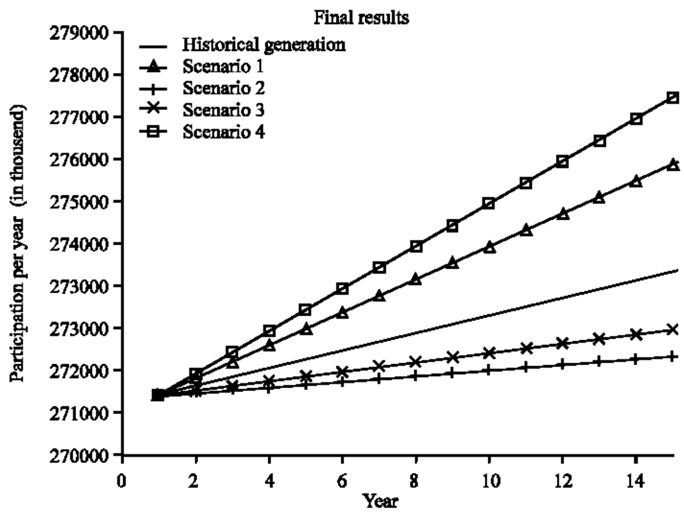

Fig. 6: Model outputs in different scenarios in comparison with historical regression

definition framework with different scenarios (these scenarios should be prepared based on plausible managerial alternatives) is to involve the most appropriate parameters controlling the system behavior. Present scenario generating process has been done based on several considerations including; data availability, system boundaries, knowledge about interrelationship of considered parameters and etc. Final simulation results have shown comparatively large variation but there are some similar change patterns associate with different types of parameters that include water quality parameters and socio-economical parameters. With regard to similar trends in predicted values for fishing participation relevant to water quality parameters; water quality index and food web index, it can be strongly concluded that, these quality parameters have the same impact on the target parameter. On the other side, the same pattern for socio-economical parameters can strongly defend the hypothesis that these parameters can have the same impact on fishing participation activities in the future. But with a relatively great variation in obtained amounts of different scenarios, absolute conclusion on the most appropriate scenario to model this problem is not recommended with such level of dataset and information available. Compared to a similar approach used in waste generation prediction (Brian *et al*., 2005) intrinsic difference in the nature of problems will be more obvious. Brian (2005) has performed similar scenario generating process to predict waste generation amount, results have shown more regular patterns and have end to same patterns in different scenarios. This may be contributed to more statistical data available on the history of study region and more importantly because of relatively same impact associated with different controlling parameters. Notably because of the fact that no one of parameters are of quality parameters, that may have more irregular patterns, results have shown more consistency in patterns in Brian (2005) study.

Another point which may be considered as weakness of this modeling practice is that, the effect of different explanatory parameters on each other is not effectively and directly considered in scenario generating. As stated former, there are some complexities connected to the nature of problem, in the other word it is mainly because of lack of knowledge about the whole affecting processes in the system boundaries (here, aquatic system of bay and related processes). For instance, effect of participation on water quality of the region, biomass reduction in changes of natural habitat condition and inevitable consequences of such factors are not effectively considered in this study. It is likely that in the future by having more accurate data on correlated parameters or newly recognized parameters, model be developed in several sub-models. In this way, the present intricate problem could be divided into it's subsystems with more tractable relations which can better be used to help us to come up with more reliable and sensible results. To perform a more robust analysis, it is more precisely recommended that, a weighting scheme be designated for the considered parameters and available data, by planners or authorities to obtain more reliable results. This may result in fuzzy dynamic or fuzzy gray dynamic models to make more reliable answers Chen *et al.* (2000).

CONCLUSIONS

In this study prediction of Fishing Participation in San Francisco Bay region in a desired future time; year 2015 is investigated. As a relatively state of the art tool for prediction in situation where slight dataset is available (System Dynamics Society, 2006), system dynamic environment have been chosen for this purpose. System dynamic modeling tool Vensim has been used for this modeling practice.

Scenario generating is performed based on available data and managerial considerations. Final simulation results have shown comparatively large variation but there are some similar change patterns associate with different types of parameters. With a relatively great variation in obtained amounts of different scenarios, absolute conclusion on the most appropriate scenario to model this problem is not recommended with such level of dataset and information available. Due to some inherent unknown relations and unavailable information about the considered system, there exist some complexities in modeling practice. It is likely that in the future by having more information about affecting parameters or newly recognized parameters, model can be developed in several sub-models to better conquer the complexities inside the system boundaries. Also assigning weighting schemes to considered parameters may result in fuzzy dynamic or fuzzy gray dynamic models in future studies.

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