Multi-agent modelling of whale-watching excursions in the Saguenay St. Lawrence Marine Park (SSLMP) in Quebec, Canada

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1. Introduction

The Saguenay St. Lawrence Marine Park (SSLMP) in Quebec, Canada is one of the best regions in the world for whale watching. It covers a territory of exceptional biodiversity including 12 species of marine mammals, nearly half of which are considered to be endangered species. In addition to whale-watching, other human activities related to commercial shipping, tourism and recreation generate intensive traffic in this park, which poses cumulative threats to the marine wildlife, including risks of collision, disruption of feeding and reproductive activities, and risks of exposure to toxic chemical spills and noise (DFO, 2004). In collaboration with the SSLMP managers, the GREMM (Group for Research and Education on Marine Mammals) and the DFO (Department of Fisheries and Oceans Canada), a multidisciplinary research project has been undertaken which aims at developing a multi-agent system (MAS) to investigate the impact of marine traffic on marine mammals. This paper describes the prototype that has been implemented to address the first objective of the project, namely to explore how different decision strategies of the whale-watching boat operators can influence marine mammals. The framework proposed by Batten (2007) has been used to conceptualize the decision strategies of the boat operators in the context of common pool resource management.

2. Methodology

2.1 Model calibration

The main data source used for model calibration is a database encompassing an on-board series of observations on whale-watching activities collected in the study area from 2000 to 2002. A total of 341 excursions were monitored on 27 boats. At every ten minutes after departure from a port, the time, speed and position of the boat given by a GPS were registered. If the boat was involved in whale-watching activities, data were collected about the characteristics of the animal under observation and the context of the observation. Other data sources include a bathymetric, a toponymic and a coastline maps, and maps showing the locations of ports, islands and various geological attractions. In addition, several documents on whale-watching activities in the SSLMP have been consulted to derive the principal components of the multi-agent model and the decision behaviour of the boat operators (Michaud et al., 2001). Field work including whale-watching tours has also been conducted by the authors to complement this information. Using the GPS point samples of the 341 excursions and associated data, the spatiotemporal trajectory of each whale-watching boat was built and stored within an ArcGIS database. An attribute was associated to each excursion segment corresponding respectively to periods of whale watching, whale seeking and observations of other attractions. A cartographic representation of the total number of sampled excursions was produced and displayed, from which the study area was selected. It is a section of the SSLMP covering an extent of 1,200 km^2 that encompasses the territory used by the whale-watching boats operating from the ports of Tadoussac, Grandes Bergeronnes, and Anse aux Basques. This area has been chosen because it includes the highest concentration of whale-watching activities in the St-Lawrence estuary.

2.2 Conceptualization and implementation of the multi-agent model

Two raster maps of 100 m resolution were used to represent the physical environment where the agents are located and interact with each other: a land-use map representing land, reefs, water, ports, other attractions, and intensively used zone (subset of the class water), and a bathymetric map. A water depth of six meters was chosen as the threshold for safe watercraft navigation. A virtual grid was overlaid on these two maps. This grid provides an environment to the agents and allows their movement from one cell to the next cell (one of its eight neighbours).

The whale-watching boats are represented as cognitive agents: they are associated to a specific port and have a mental representation of their environment; they can plan their activities, communicate with other agents and have some memory. Their goal is to maximize whale observation time during a given trip, which is translated in the model as the *happiness factor* given by the ratio of total whale observation time over a trip duration. A decision model encompassing the behavioural rules of the boat agents was built including the following options. When they leave their port and plan their excursion, the boat agents check their memory about the previous location of marine mammals, communicate with other boat agents to obtain information on the location of marine mammals, follow a random trajectory seeking for marine mammals, observe other attractions, and come back to their port. The boat agents can exhibit two types of behaviour: cooperative, and non-cooperative. A cooperative agent chooses to send messages via broadcasting to other agents about the location of marine mammals that can be observed, while a non-cooperative agent does not share this information.

A generic whale agent was used to represent all the species of marine mammals in the estuary. There are a number of factors that drive the distribution and navigation of the whales in the St. Lawrence estuary. However, in this prototype, the distribution and navigation patterns of the whale agents are kept simple since our main objective is to explore the behaviours of the whale-watching boats. 80% of the whale agents were randomly located within the intensively used zone while the remaining 20% were randomly distributed in the rest of the water body. The behaviour of the marine mammals was simulated according to the following rules: they move at each iteration of the model, they randomly choose a direction, they move in that direction during five iterations by checking if the next cell is available, they change their direction randomly after five iterations, they change their direction if the next cell is not available. The whale agents have two attributes: floating and diving. A whale can only be observed when being in the state of floating.

The model was implemented in the agent-based modelling platform RePast. A series of simulations were run using different numbers of boat and whale agents to analyze the sensitivity of the model and to assess the impact of different decision strategies of the boat agents. For each simulation, the model computed: 1) the happiness factor (HF) given by the ratio of the time spent observing marine mammals over the duration of the excursion, 2) the degraded happiness factor given by the happiness factor reduced by half when more than three boats are observing a marine mammal, 3) the intensive observation index provided by the number of times a specific marine mammal is observed simultaneously by more than five boats, and 5) the risk of collision between boats and marine mammals represented when a marine mammal that is swimming under the water surface is located in the same cell as a boat.

3. Results

The results reveal that the HF is always higher when the boat agents behave cooperatively. It also increases when the number of whale agents increases (Fig.1). The degraded happiness factor is considerably higher when the agents behave cooperatively (Fig. 2). Although cooperative behaviour ensures higher average HF, this strategy boosts the traffic congestion around a whale, reducing the quality of the observation and potentially imposing a serious threat on the mammals. Results show that some whales (i.e. ID 15) were severely observed during 40 trips simulation when boat agents behave cooperatively (Fig. 3). This behaviour also increases the risk of collision between boat and whale agents (Fig. 4).

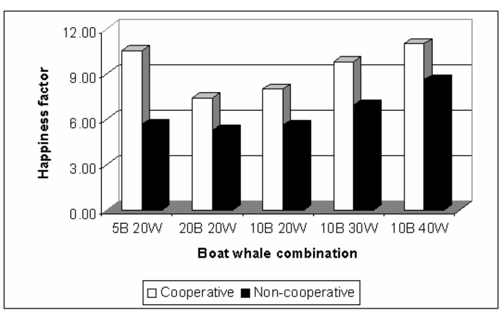

Fig. 1

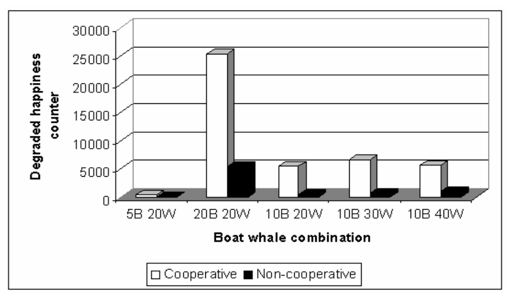

Fig. 2

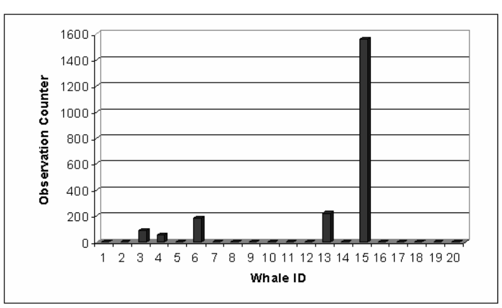

Fig. 3

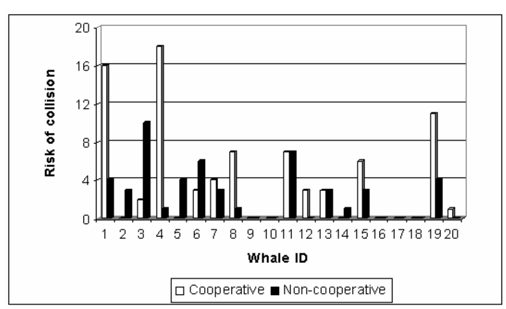

Fig. 4

4. Conclusion

The model illustrates that the cooperative behaviour of the boat agents generates a higher happiness factor when compared to the non-cooperative behaviour; however, it creates higher risks for the marine mammals. These results are intuitive, but offer a first quantitative estimation of the impact on the marine mammals that is not easily measured in the field. This prototype demonstrates the potential of a multi-agent model to better understand the interactions between marine traffic and marine mammals. To ensure that it could be used in the near future as a management tool, a series of improvement are currently being introduced including: 1) a decision module for the boat agents that encompasses various categories of boats such as commercial ships, fishing and pleasure boats, 2) ecological behaviour rules for the marine mammals that takes into account the specificity of different species, age, stress due to traffic, and their reaction mechanisms, and 3) a more dynamic representation of the environment. Additional data on traffic and marine mammal behaviour collected over the last five years are also being incorporated in the calibration and validation of the model.

5. References

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