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The Application of Agent-Based Modelling for The Diffusion of Innovation Research: A Case Study

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Abstract

Agent-based modelling (ABM) is considered as an important technique to study innovation diffusion and has been increasingly applied in the diffusion of innovation activities. This study investigates the opportunities to adopt ABM to diffuse innovation in a construction company in Oman, engaged in an innovative project to construct a prestigious integrated township. It proposes a new innovation diffusion model that simulates the social interactions between agents and how that interaction influences the agent's (visitors) adoption decisions. The application of ABM in this case project is analyzed through MATLAB simulation software. The result from the study shows how a more complex model of a society can be implemented in a commonly used platform. The simulation results showed how the proposed model can actually mimic the expected behavior of a complex system where static characteristics of agents such as nationality and age may influence the dynamic characteristics such as talking and frequency of visiting a certain location, which enhances the rate of decisions making process.

***Keywords*:** Diffusion of Innovation, Agent-Based Modelling, Integrated Township, Case Study.

1. Introduction

Today's marketplaces are becoming more dynamic, where innovation plays a vital role to keep them competitive. Firms need to innovate in order to respond to changing customer demands and lifestyles. Innovation practices are also necessary to capitalize on opportunities offered by technology and changing marketplaces, structures and dynamics. In an organization, innovation practices can be performed in relation to products, services, operations, processes, and people (Bessant and Tidd, 2007). Any organization should have innovation practices in order to increase the value of its asset endowment. Unless it changes what it offers and the way in which it delivers those offerings it risks its survival and growth prospects as immutable products and services no longer provide gain in the increasingly competitive market. Organizations need to innovate and orientate themselves to their customers' needs, and provide products and services, which are perceived to be valuable (Wong and Chin, 2007). Therefore, it is recognized that innovation activity plays a central role in creating value and sustaining competitive advantage.

Innovation activity is essential to organizations as it allows them to adapt to their changing internal and external business environments (Damanpour, 1991). Such changes might involve a wide range of different types of innovations which are related to new products, materials, new processes, new services, new organizational forms, employee education and educational institutions (Ettlie and Reza, 1992; Stachová et al. 2019). These, in turn, are dependent on the organization's resources, capabilities, strategies, and requirements (Baregheh et al., 2009). Damanpour and Schneider (2006) emphasized how "Innovation is studied in many disciplines and has been defined from different perspectives". Subsequently, innovation practices are of interest to practitioners and researchers across a range of business and management disciplines. Papers such as Najafi et al., (2013) and Gonzalez (2016) investigated the antecedent or dimension of innovation for new product development. On the other hand, Voss et al., (2005) and Kamboj and Rahman, (2017) focused their research on innovative operational management practices in service industries. Moreover, Chirumalla (2013) and Martinez et al., (2010) explore challenges to transform and manage innovation in product-service ecosystems.

In today's business environment, innovation is one of the key factors for the company to survive and become a competitive player in the market (Ocampo-Wilches et al., 2020). However, irrespective of whether the innovation is product-based or related to services being offered to the customer, diffusion of innovation plays a major role in the success of innovation. Therefore, in addition to innovation practices, organizations need to take necessary measures to diffuse the innovation outside of the organizations. The diffusion process helps organizations to publicize their new products, processes or services to the outside world. This publicizing process in turn offers organizations added benefit through obtaining the valuable feedback from outside. In order to increase the customer base, management needs to assess diffusion of innovation before launching new innovative products or services into the market. Based on the assessment result, they can then propose appropriate strategies that will directly impact the success of innovation (Zhang et al. 2018).

In today's competitive business environment, organizations are under pressure to cater product–service combinations to create unique value to the customer (Chirumalla, 2016). Moreover, identifying the appropriate structure or model to diffuse the innovation for such product-service combinations is a challenging task. This study focuses on a project related to the development of integrated township which caters for both product and service combinations to the customer. In terms of products, it offers luxury apartments and villas. While for services, it offers recreational activities such as marine, luxury hotels, restaurants and golf courses to internal and external customers. The study aims at addressing the following three research questions related to the case project:

RQ 1: What model or structure of innovation diffusion best suited for the case project?

RQ 2: How the social interactions between people influence the adoption decisions?

RQ 3: How the diffusion process occurs in such a project?

The innovation diffusion process follows several models or ways to publicize any innovation. Kohli and Melville (2019) have provided a systematic review related to innovation. They concluded that there exists an uneven overage of research studies as the majority of research has focused on the development, implementations, and the role of the internal organizational environment. However, less attention was given on how to balance between the competitive environment, exploitation, initiation, and innovation outcomes. In contrast, Dearing and Singhal (2020) highlighted three directions for the diffusion of innovation to be considered by researchers, among them is the implementation along with the dissemination science and positive deviance. Therefore, the suitability of the model or structure depends on the needs for innovation diffusion. Broadly, the diffusion models can be classified as macro-economic and micro-economic models (Zhang et al., 2018). Micro level models are mainly developed on an agent-based approach (Summad et al. 2018). Therefore, to address the above three research questions, this study has defined three research objectives as follows:

1. To study the overall concept of innovation practices in organizations.
2. To develop an innovation diffusion structure for the innovative case project.
3. To implement an ABM approach to understand the diffusion process in the project.

The paper is organized as follows: Section 2 illustrates the theoretical framework of innovation diffusion, including its generic concept, importance and available models. Section 3 discusses the ABM approach. The conceptual innovation diffusion model and the case study, including result analysis on innovation diffusion is presented in Section 4. After that, Section 5 highlights the managerial implications and limitations that have to be considered. Finally, overall research outcomes and future research are discussed in Section 6.

2. *Theoretical Framework*

2.1 Innovation Diffusion: Generic Concept

The spread of any kind of information in a market segment is referred to as diffusion. The concepts of diffusion theory are mostly related to the diffusion of an innovation. However, they are also applicable for other processes such as the spread of behavior (Damon, 2010) or a disease (Liliana and Dragicevic, 2009). Rogers (2003) defines diffusion as "the process by which an innovation is communicated through certain channels over time among the members of a social system. Many researchers explored the network structure and their relationship with opinion formation in diffusion (Jai et al. 2017), however, few considered other factors that affect the diffusion of complex innovations such as social networks, knowledge exchange (Assenova, 2018; Fang et al. 2020). To describe the process of diffusion in innovation, diffusion theory s-shaped curves are considered. The theory seeks to explain how, why and at what rate an innovation, new idea or technology spreads and is adopted (Wu and Chiu, 2015; Agag and El-Masry, 2016). The adoption rate of innovation increases as the number of adopters increases, but decreases again when approaching the maximum number of adopters, known as the satisfactory level (Dmitry and De Guio, 2011). Usually, the diffusion of innovations is orchestrated by modelling their entire life cycle from the perspective of communications and consumer interactions (Peres et al., 2010; Sopha et al., 2013; Wang et al., 2018). It has been observed that certain innovations are diffused extensively, whereas others do so partially or not at all.

Diffusion of innovation is a critical activity which can be used to measure the likelihood that an innovation will be adopted by members of a given society or culture. The adoption of an innovation depends on its relative advantage, its compatibility with the pre-existing system, its complexity or difficulty to learn, testability, potential for reinvention and its observed effects (Greenhalgh et al., 2004; de Jong et al., 2015). Some people are more apt to adopt innovation than others are. This may be related to a great extent to the level of awareness that consumers have, which if addressed by the appropriate means may lead to favorable attitudinal change (Ranta and Mehra, 2015). Further, several studies found that people who adopt an innovation at an early stage have different characteristics than people who adopt at a later stage (Valente and Davis, 1999; Wejnert, 2002; Barker, 2004; Zanello et al., 2016). It is therefore important to understand and categorize the innovation adopter (Andergassen et al., 2017). According to Rogers (2003), adopters can be categorized as innovators, early adopters, early majority, late majority and laggards. Such categorization of adopters has several advantages. Firstly, it is easy to measure the level of innovation diffusion. Secondly, the categorization offers mutually exclusive and exhaustive standardized categories; results can be compared, replicated and generalized across studies. Thirdly, continued acceptance of the product can be predicted and linked to the adopter categories.

Rogers (2003) proposes four main elements to spread innovation: the innovation itself, communication channels, time and a social system. An innovation activity is diffused in multisteps, where an opinion leader, known as an adopter, exerts a large influence on the behavior of individuals. The rate of innovation diffusion can be defined as the relative speed at which participants adopt an innovation. The diffusion of an innovation is measured by the time necessary to adopt a specific percentage of the members of a social system (Choi et al., 2010). At some point in time, the innovation reaches a critical point or critical mass, when the number of adopters assures that the innovation is self-sustaining. For instance, Gledson and Greenwood (2017) used Rogers' innovation diffusion theory to assess the 4D building information modelling (BIM) adoption in construction projects. However, in theory, the diffusion process is terminated by a decay of the number of new adopters and saturation on the market potential (Bohlmann et al., 2010; Caiazza and Volpe, 2017).

The diffusion process of any new product or service is becoming more complex. This complexity arises due to the exposure of consumers to a wide range of influences such as social networks, network externalities, technology generations, cross-market and brand concepts, as well as increasing levels of competition (Hazen et al., 2012; Hameed and Counsell, 2014). In addition, social influences, which include every kind of interdependencies among consumers and various market players, with or without their explicit knowledge, adds to this complexity. In order to decrease the complexity of innovation diffusion, it is necessary to have better knowledge towards current market trends, which includes the opening up of markets in emerging economies, web-based services, online social networks, and complex product–service structures (Dosi et al., 2018).

2.2 Available Models on Innovation Diffusion

There are several available models to diffuse any kind of innovation in a market segment. The models are generally categorized into two sub-divisions, namely, conceptual models and mathematical models. In conceptual models, various aspects of innovation are considered, such as determinants of diffusion, dissemination and implementations of innovation. This type of model represents the overall results of individual level processes of innovation diffusion, while it does not provide managers and researchers with quantitative tools to study the diffusion. Mathematical modelling, however, provides quantitative tools and it has attracted many researchers since the early 1960s.

Traditionally, the fundamental mathematical model of innovation diffusion is based on the framework developed by Bass (1969). The Bass model measures the first-purchase growth of a category of product introduced in a market segment. In general, any innovation joins in the market as a result of two types of influences, external and internal (Peres et al., 2010; Smaldino et al., 2017). The external interfaces are related to advertising and other forms of communication initiated by the firm that adopted the innovation. On the other hand, internal influences are linked with the interactions among the innovation adopters and potential adopters in the social system. This type of modelling is further divided into aggregate and disaggregate models (Kiesling et al., 2010, 2012).

The aggregate model of innovation diffusion has been used since the 1960s in forecasting sales of new products and describing the spread of new products in marketplaces (Mahanjan et al., 2000; Feola and Butt, 2017). This kind of seminal diffusion model describes the innovation diffusion by means of simple mathematical formulations, which is based on a mathematical description of flows between mutually exclusive and collectively exhaustive subgroups in a population. The concept of the Bass model, which is a derivative of the aggregate model, conceptualizes the diffusion of consumer by mass communication and spread by word-of-mouth (Norton and Bass, 1987). The Bass model describes the innovation diffusion process by means of a differential equation as shown in Equation 1. This model captures a wider variety of diffusion patterns that can be observed in practice (Wang et al., 2006).

$$n(t) = (p + q\frac{N(t)}{M})(M - N(t)) \quad \text{.......} \quad (1)$$

Where,
M = potential market,
$N(t)$ = portion of M that has already adapted at time t
$n(t)$ = portion of M that adapts at time t
p = coefficient of innovation and
q = coefficient of imitation

The disaggregate model is used predominantly in social sciences. This type of diffusion model starts at the micro level having a rich potential in terms of a better understanding of the diffusion process and a tool for managerial action (Bhatnagar, 2015; Raynard, 2017). The disaggregate diffusion model is widely used to forecast the total market response and typically measured by the adopters' numbers (Mahajan et al., 1990; Karakaya et al., 2014). This model is categorized in three broad areas namely, microeconomic models, stochastic models and agent-based-simulation models.

Microeconomic models typically characterize the effect of risk attitude and learning under uncertainty on the adoption level. It assumes uncertainty associated with understanding of the innovation's attributes, its price, pressure from other adopters to adopt it and their own budget (Heinrich et al., 2016). The stochastic model, as a branch of the disaggregate model, deals with consumer behavior in marketing, including brand choice and purchase incidence model. It also propagates the diffusion of innovations that consumers are not already familiar with, due to the lack of elementary diffusion mechanism (Manrai, 1995; Long et al, 2016). As a result, there were a number of attempts proposing models and frameworks trying to define the key to consumer acceptance of technological innovations related to products and services (Reyes-Mercado and Rajagopal, 2015; Roy et al., 2019). Lastly, the agent-based model defines the distribution of individual-level consumer characteristics and/or limited analysis of aggregate variables (Wolf et al., 2015; Rai and Henry, 2016). This model deals with the elementary unit of modelling as a whole rather than as an individual or agent. It is usually limited to the analysis of rational individuals' decisions on the micro-level and does not incorporate diffusion processes on the macro level.

Other innovation diffusion models were developed and proposed in literature. For example, the crowdsourcing platforms designed for social innovation (Sivula and Kantola 2016). However, such models still require deeper analysis related to their feasibility and the influence of different factors such as the community collaboration and the market competitiveness on their design (Kohler and Chesbrough, 2019). Moreover, interest in open innovation has also gained an increasing attention among researchers. Some researchers proposed open innovation models for R&D collaboration, the impact of public funding on SMEs, etc., while others examined the factors influencing open innovation models and the role of intermediaries such as living labs in implementing open innovation (Jang et al., 2017; Gascó, 2017; Sivam et al., 2019; De Marco et al., 2020). More insight related to open innovation can be found in West and Bogers (2017) and Bogers et al. (2018).

3. *Agent-based Modelling for Innovation Diffusion*

Microeconomic models of diffusion assume that markets can be divided into several perfectly mixing segments. The major disadvantage of these models is their inability to consider the impact of network structure or individual heterogeneity (Xiao and Han, 2016). In reality, individuals differ in their adoption behaviors as each one has different preferences, different channels to obtain information and associations with different types of social networks. ABM overcomes the drawback of macroeconomic models by modeling the diffusion process at the individual level. Bonaneau (2002) defines ABM as a mind-set consisting of describing a system from the perspective of its constituent units rather than as a technology. These units are called 'agents' and may represent all kinds of actors (Bonaneau, 2002, Bouarfa et al., 2016; Moglia et al., 2017). According to Weiss (1999), an agent can be described as "…a computational entity such as a software program (...) that can be viewed as perceiving and acting upon its environment and that is autonomous in that its behavior at least partially depends on its own experience". ABM has been increasingly adopted in innovation diffusion research. This modelling approach includes heterogeneity effects and influences of different types of social network structures (Sanchez-Marono et al., 2015; Sopha et al. 2017; Liu et al., 2018). It has been implemented in aid of building theory, analyzing real-world scenarios, supporting decision-making, and obtaining policy recommendations (Kiesling et al., 2012; Jensen and Chappin, 2017; Yang et al., 2018, Al-Hinai et al. 2020). This kind of modelling is a bottom-up modelling approach that aims to capture emergent phenomena in complex systems by simulating the behavior and interactions of entities (Jensen et al., 2015; Borracci et al., 2018).

An important advantage of ABM is that it has the ability to capture the complex structures and dynamics of diffusion processes without knowing the perfect global interdependencies (Borshchev and Fillipov, 2004; McCoy and Lyons, 2014; Pearce and Slade, 2018). This approach makes it possible to account for micro-level innovation drivers by modelling the adopters' behaviors and attitudes in a social network. The agent-based modelling and simulation differs from other available models in that it is not limited in its capacity to account for heterogeneity and social structure. This model has been applied in various fields such as, ecosystems management (Bousquet and Page, 2004), epidemiology (Auchincloss and Roux, 2008), pedestrian movements (Turner and Penn, 2002) and criminology (Malleson, 2010). Due to the enormous advantages of ABM over other models, the ABM approach is implemented in this research to analyze the process of diffusion in the case project. In ABM, the agent possesses its own characteristics, enabling it to interact with other agents and to make decisions through analyzing the environment.

Indeed, the Bass model or classical aggregate diffusion models cannot explain why the diffusion of innovation occurs. Hence, an agent-based modelling approach has been introduced. This paper presents a novel diffusion model that integrates agent-based modelling (ABM) and social networks to assess the acceptance of township project. The proposed model incorporates the heterogeneity of individuals' personal preferences into a real decision process to determine one's willingness to visit or not visit township. In addition, the adoption (decision) matrix takes into account various types of decision's makers based on their individual preferences shaped by age, status, gender…etc. Section 4 includes further discussion on these aspects of agents.

4. *Conceptual Innovation Diffusion Model and Case Study*

The case company is situated in Muscat, the capital city of the Sultanate of Oman. The country is located in the southeast of the Arabian Peninsula. With a population of approximately 4,655,000 and a surface area of 309,500 km^2, Oman has a relatively low population density.

Around 40% of the population are expatriates who mainly come from Asia, Middle East and North Africa. The case company is working on a prestigious integrated township project. The township caters for the needs of luxury-seeking tourists in offering shopping and dining opportunities, luxury housing and recreational activities. The construction began in 2006 and today the area includes a golf course, private yachting hub, multiple internationally managed luxurious hotels, shopping malls and over 1400 residences spread along a 6km stretch of coast.

The diffusion of this project was studied by collecting the data related to the number of visitors interested in the township and incorporating the collected data in an ABM simulation algorithm. The spreading of popularity of the project is a highly social process and the ABM offers the opportunity to include the high complexity and diversity of a social system. The model is implemented in MATLAB, since this is a universal platform used by many researchers. The steps followed in the model development and analysis of the diffusion process are illustrated in Algorithm 1. The flowchart in Figure 1 shows that the model starts with a 'Build up' process where the diffusion model main characteristics and requirements are initiated, followed by a 'Run' and 'Postprocessing'.

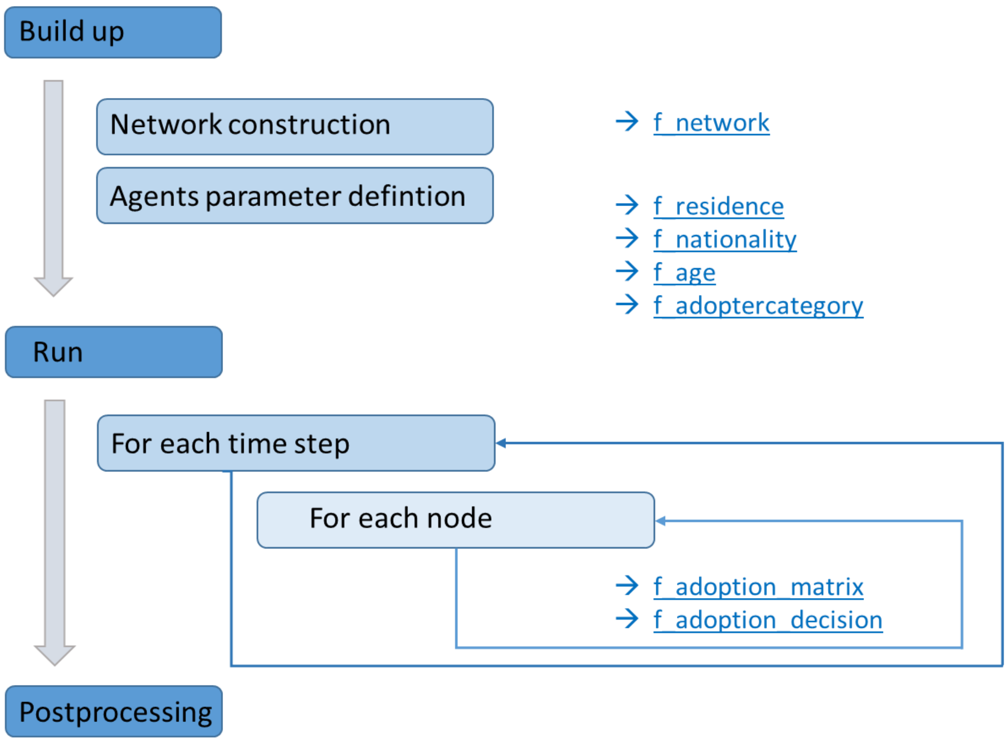

Figure 1. Conceptual Diffusion Model Flowchart

Algorithm 1: Innovation Diffusion Model

Initialization;

  Define Agents Parameters
  Construct maximum number of Population Networks
  Initiate total number of Agents

Static Characterization of the Agents;

  Generate characteristics vector (v_{ch})
  For *each Agent* **do**
    Agent i ← Residence
    Agent i ← Nationality
    Agent i ← Age
    Agent i ← Adopter Category {Innovator, Early Adopter, Late adopter}
    v_{ch} ← Agent i

Dynamic Characterization of the Agents;

  Generate visitor expectation matrix (M_{ex})
  For *each Agent* **do**
    Set the Population Network of Agent i
    Agent i ← Talking
    Agent i ← Contact Counter
    Agent i ← Current State
    Agent i ← Number of Visits
    M_{ex} ← Agent i

Run Simulation;

  Create Adoption Factor vector ($v_{adoption}$)
  For each time step **do**
    If (*number of agents in node* ≥ 3)
      Initiate Agents talking for 2 Timesteps
        If (*agent i talk*)
          agent i Contact Counter ++
    If (*agent i Contact Counter* > 20)
      Take Decision of *agent i based on* ($v_{adoption} = M_{ex}\, v_{ch}$)
        If (visit)
          Update *agent i* ← Current State = 1
            agent i Number of Visits ++
            agent i Contact Counter = 0
        Else
          Update *agent i* ← Current State = 0
          Continue
    $v_{adoption}$ ← Agent i
    Record Total Number of visits per node

Results;

  Report postprocessing results

a. Build-up

At the build-up stage, agent characteristics are defined and an agent network is constructed. The following subsections provide a thorough explanation related to how agents and social networks are initiated to incorporate the heterogeneity of individuals' personal preferences.

4.1.1 Agent Characteristics

A visitor of the case township is considered as an 'agent'. The various characteristics of each agent are divided into two distinct divisions namely, static characteristics and dynamic characteristics as shown in Figure 2. The static characteristics of an agent consist of agent's residence status (citizen and non-citizen), agent's nationality, agent's age group and agent's adopter categories. Three age groups are considered in this study, children (0-19 years), adults (20-70 years) and seniors (70+ years). The last static characteristic, ‘adopter categories’, is a description of the personal preferences of the agent concerning his/her visit to the studied township project. There are three expectation groups defined based on the innovation adopter categories: the innovators, early adopters and late adopters (Rogers, 2003). They differ in the way they respond to the concept, number of shops, promotional activities and the social influence after the township project already gained certain popularity.

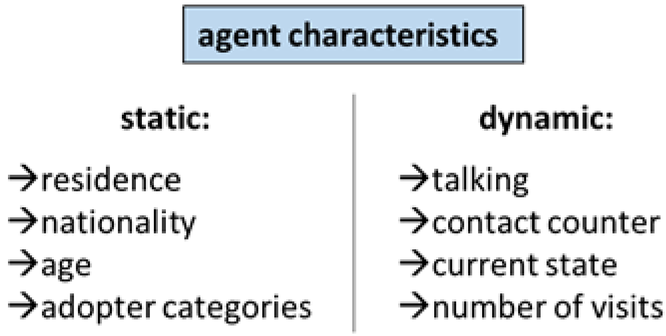

Figure 2. Static and Dynamic Agent characteristics

The dynamic agent characteristics are the determinants for the spreading process. They consist of talking, contact counter, current state and number of visits. The ‘talking’ represents the conversation between visitors in the shopping mall, while ‘contact counter’ highlights the number of counters within the shopping mall that the visitors can use to know more about the specialties of the shopping mall. The ‘current state’ illustrates the status of the visitors, whether they are active or passive during their visits to the township. The last dynamic characteristic outlines the total number of visits to the township within a certain period during the year.

4.1.2 Network Structure

The diffusion of innovation in the case project was analyzed through the recording of the number of visitors and the extent of their concentration on various counters or nodes within the township project areas, which include various shops, restaurants, offices and service points. The innovation process is spread over the boolean parameter ‘talking’. Since small world and scale free networks are widely used in real situations (Hazhir and Sterman, 2008), a Watts-Strogatz Small World Graph is used for the spreading purpose in this study. This corresponds to a weighted combination of a ring lattice network and a random network. Using this general approach both, the grouped interactions in real-world society with family and friends and random encounters in daily life are considered. For this application, the network structure is built according to the local/social position of the potential visitor. Therefore, separate small world networks are built for residents in the project property, the remaining residents of Muscat and the tourists present in Muscat.

Figure 3 displays the network diagram that consists of three nodes A, B, and C. Each of the connections within a node or intra node represents the interaction or talking between the visitors. From the figure, it can be seen that node B contains the most densely populated visitors, representing the highest interactions or communications between the interested visitors or agents. For each time step, each node that has at least three talking neighbors starts talking for two time steps. Each time an agent starts talking; its contact counter is increased by one. As soon as the contact counter reaches a value higher than 20 a visiting decision is made. In case the agent chooses to visit, the current state switches to positive, the number of visits is increased by one and the contact counter is reset to zero. If the agent decides not to go, it will proceed as before. For each node, the number of visits is recorded. The novelty of the proposed diffusion methodology is its ability to simulate the social interactions between agents. This social interaction can influence the agent's adoption decisions. To illustrate this, Figures 4 and 5 show the impact of interactions between agents on the final status of a low-social networking compared to higher-social interactions, respectively.

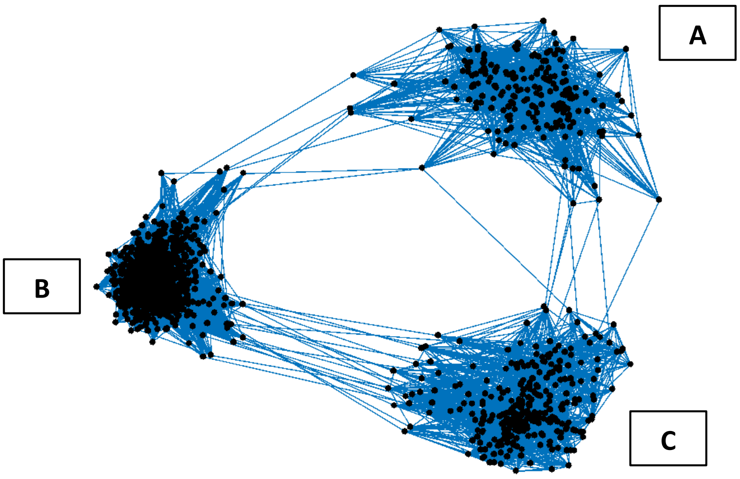

Figure 3. Representation of interactions between the visitors or agents in three different nodes

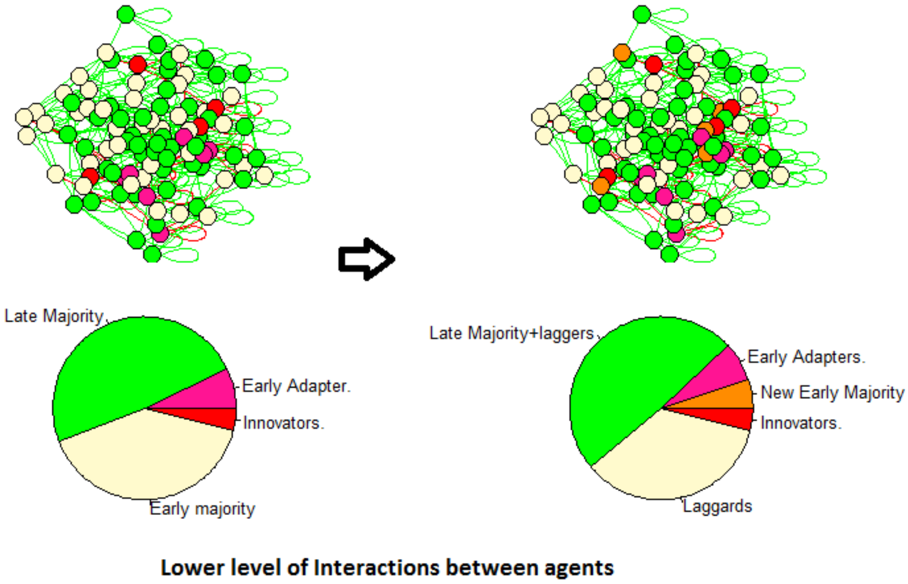

Figure 4. State representations (initial and final) and impact of low social interaction

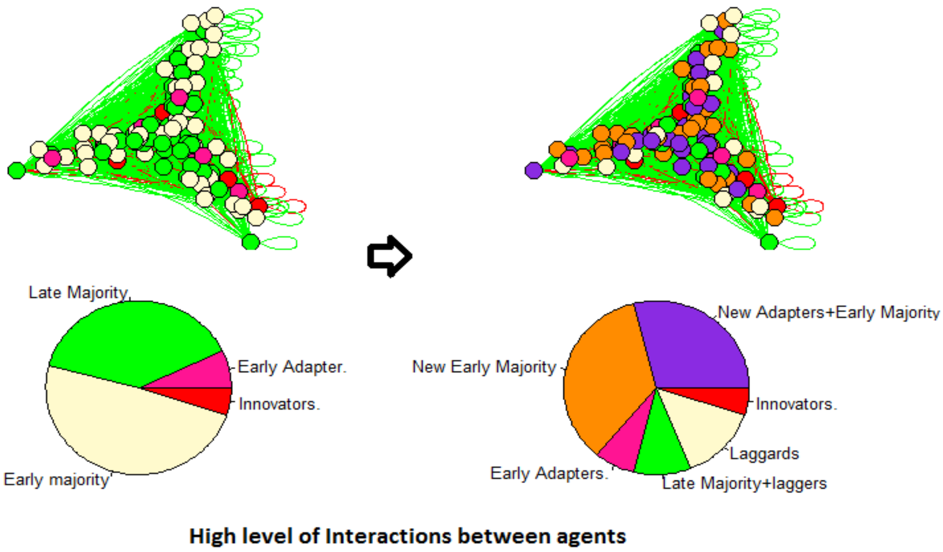

Figure 5. State representations (initial and final) and impact of high social interaction

b. Run

At the run stage, each time step for each node is allocated. For each time step, an adaptation matrix and adoption decision are defined for each node.

4.*2.1 Adoption Matrix*

The adopter categories differ in their expectations concerning the characteristics of the case company. The total expectation of 1 splits up to the aspects concept, number of shops, promotional activities and social influence in the shopping malls. The values between 0 and 1 for all aspects and all adopter categories build up the visitor expectation matrix M_{ex}. Imagine that you have *c* number of visitors where each one will be influenced by the single company characteristics with a total of *r* characteristics. At any time (*t*) some of the visitors may adopt the technology given their personal attitudes, social status (i.e. positions in the network). Section 4.2.2 further illustrates the adoption decision. The aim is to understand the impact of the variations of the visitors in the adoption long run decision. In each time step, the M_{ex} is updated and hence, $v_{adoption}$ is also updated resulting in a more or a less adoption rate.

The characteristics of the case company build up the characteristics vector v_{ch}. The dynamic characteristics consist of the number of shops, the current state of promotion and the social influence. In addition, there is the concept of the case company's project as a static parameter. For each time step, the adoption vector is evaluated by using the following Equation 2:

$$v_{adoption} = M_{ex} v_{ch} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

4.2.2 Adoption Decision

In case an agent is faced with the adoption decision, a random value between 0 and 1 is calculated. If the random value is smaller than the respective value of the adoption vector, adoption takes place. To account for the influence of summer and winter seasons, for the summer months, the probability of a positive decision is decreased by decreasing the values of the characteristics vector v_{ch}.

All of the static characteristics of the agents have an influence on its adoption decision in a certain way. The residence determines the position in the social network, the nationality determines how likely the agent is to belong to a certain adoption group and the age determines after how many contacts an adoption decision is made. The adopter category determines the expectation values and has therefore a direct influence on the likeliness of adoption. However, this way of influencing the decision can be changed and adapted in multiple ways. The likelihood of adoption depends on whether the visitors communicate with each other about the company technology, each visitor's personal view of the technology, their social status and as a result, the influence this behavior creates on each other. It is very crucial that this dynamic process is taken into consideration in simulation especially for innovation diffusion in closed societies. Moreover, the model allows us to see how different factors influence this diffusion process.

4.3 Post Processing

Finally, the collected data is analyzed to get the necessary information in the post processing step. After collecting the necessary data from the network, it is processed by using the MATLAB - MathWorks software following the algorithm as highlighted previously in Algorithm 1. The outcomes from the analysis are presented accordingly. To have an insight into the working mechanism of the simulation, the main output in terms of visitor numbers over time is plotted and presented in Figure 6. The results as highlighted over Figure 6 excludes the influence of the summer and winter seasons. The resulting graph in Figure 6 showed a relatively fast increase in the number of visitors until saturation value, at around 350 visitors, where it oscillated irregularly. Overall, the behavior looks as expected. However, the time until saturation is rather short even though it was supposed to be the main topic of this study. The reaching of a saturation value at a certain point was expected, but it is oscillating by relatively large amplitude.

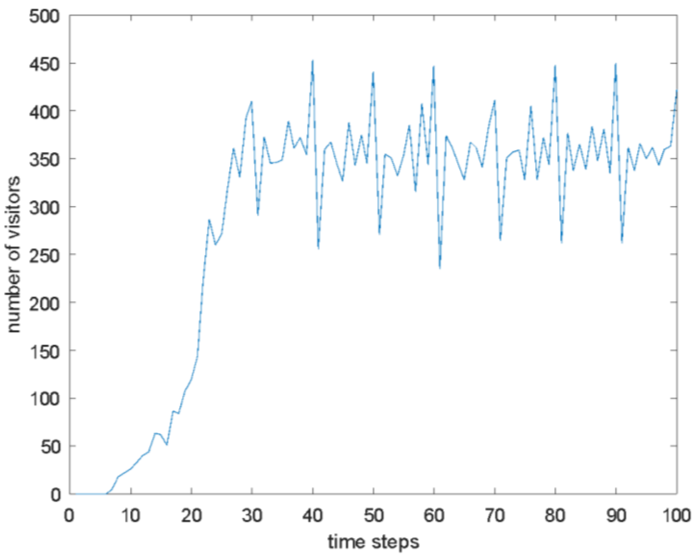

Figure 6. Test run results without season

Figure 7 presents the result after including the effect of the summer and winter seasons. As the figure shows, the amplitudes increased and the saturation value decreased from 350 to around 250. This shows the effect of different seasons, as visitor numbers varied considerably between seasons.

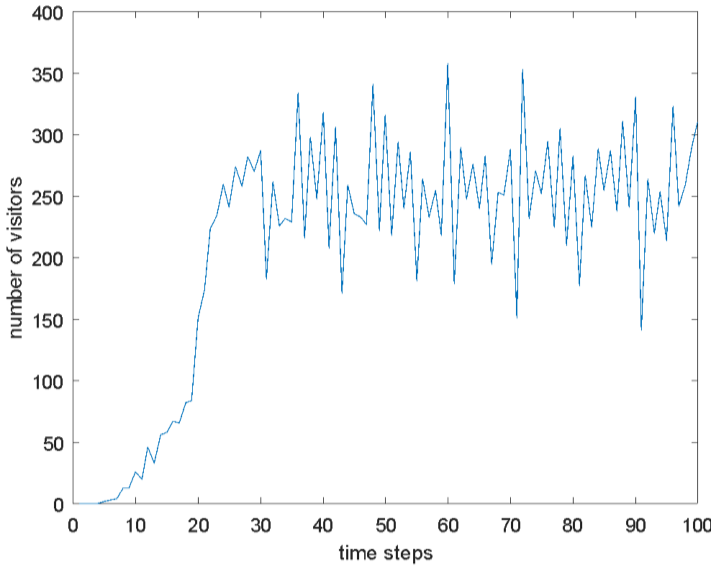

Figure 7. Test run including seasons

After varying the static parameters of nationalities, age group, residence, and adopter's categories, the diffusion model shows that it requires less number of contacts until an adoption decision is made. Furthermore, the high oscillations that were noted before are smoothened. The oscillations become smoother after 600 visitors, as displayed in Figure 8. It is also noted that continuing the variations of the study parameters increases the saturation value further.

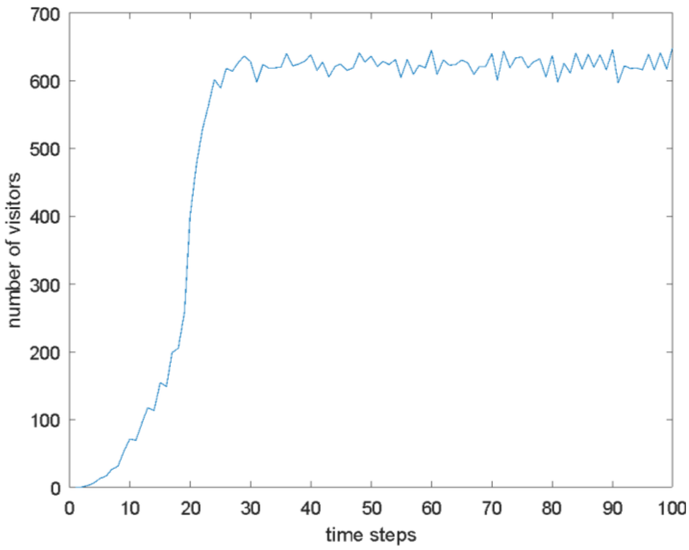

Figure 8. Test run smoothed after varying the study parameters (e.g. residence status, age group, nationalities, adopters categories)

From the above results, it can be concluded that based on the characteristics of the visitors, as in the case township project, the saturation points of the diffusion process vary. For instance, the saturation point of the diffusion process varies noticeably from the summer to winter season. It also varies when changing study parameters such as age group, nationalities and residence status. It is therefore evident that the saturation point of the diffusion process is substantially influenced by the characteristics of its agents and varies from case to case. Hence, this emphasizes how the proposed innovation diffusion model actually mimics largely the expected actual behavior of real complex systems. It reveals how the variation of the static characteristics of agents may affect their dynamics characteristics and the adoption decision-making process.

5. Managerial Implications and Limitations

As like the necessity of innovation in organizations, it is crucial to diffuse such innovations to the benefit of the mass market. Diffusion of innovations, which means to explore the new knowledge, technologies and practices within the societal network, contributes towards the revision of innovative works. Such revision of innovations supports organizational managers to find out bottlenecks with respect to potential adopters, typically via communication and influences (Rogers, 2003). In the realm of innovation, the diffusion process depends on various social interactions and levels such as macro level or micro level (Zhang and Vorobeychik, 2019; Kumar and Sinha, 2021).

The diffusion of innovation is considered as a complex ecosystem, where the objective is to spread information about an innovation to a social system through various mass media and personal communications. Such necessity influences organizational managers to deploy an emergent phenomenon that results to conduct interaction from individuals and make it sustainable (Shibeika and harty, 2015; Crespin-Mazet et al. 2021). In general, there presents heterogeneity among individuals within a social system that influences to select an appropriate model of diffusing an innovation whether it is a product or service. For an organizational manager, it is essential to consider such heterogenic social structure and choose an absolute model to spread new ideas within the agents or adopters of innovation outputs. Nevertheless, heterogeneity among different market segments or domains are also needed to be considered by the organizational managers during defusing the innovations.

In any innovation, the diffusion is dependent on the broadened bandwidth of the communication scope to the potential adopters (Allameh et al., 2017). In business settings, diffusion of innovation demands to address the need to make wider teams in organization with the objective to increase acceptance and implementation of new ideas (Carreiro and Oliveira, 2019). In such perspective, organizational managers need to identify the well-connected innovators in order to forward the innovation message towards the wider societal segments and to make the innovation successful. This strategic methodology allows pinpointing how initial implementation of the innovation is visible from innovators to the adopters.

The results from this case study revealed that managers should pay careful attention to market network structure due to the high adoption thresholds. It is also noticed that there is a potential lack in clustering of existing markets that makes the diffusion complex throughout the market and might cause failure to innovation's commercial success. On the other hand, established market networks provide an easy-to-diffuse innovation process, which may not require a careful targeting of well-placed innovators (Bohlmann et al., 2010). Nevertheless, the study also revealed that follower adoption is importantly necessary for an innovation eventually to saturate the heterogeneous market. Moreover, it is also observed that for a successful quick adoption for the innovators, the case company has to target the visitors with proper characteristics variation. Hence, adopting an agent-based modelling approach reveals the importance of individual positions within a network that influences the diffusion of innovation.

6. Conclusions and Future Research Direction

Diffusion of innovation is critical to any organization as the survival of innovative products/ services depends highly on the rate at which members of a given society adopt it. This study develops a possible structure for an agent-based innovation diffusion model. The model is implemented using MATLAB software in a case study related to an innovative construction project. Agents are used to mimic visitors and their interactions in the case project. Moreover, an interconnected small-world network is developed for the project to describe the overall social structure. The developed model involves a complex decision-making process considering the static and dynamic characteristics of each agent.

The developed model is based on a large number of parameters. Some of the parameters can be obtained from statistical data. However, most of them are not as easily identifiable, especially the parameters describing individual decision-making and personal preferences, as they are not objectively quantifiable. This could partly be counteracted by creating customer surveys. It would be not only helpful for this model, but for general strategic decisions concerning the case project. Depending on how detailed the model should be, there are many other factors that could be included in the diffusion model. For instance, the change of visitor numbers during the seasons or more detailed personal characteristics of the agents such as income level and job type can also be considered for the study. The next relevant research could be to modify the developed model to be able to forecast the rate of diffusion of newly conceptualized/constructed projects for managerial decision-making. The model can also be improved to determine strategies to facilitate the rapid diffusion of innovations.

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