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LEARNING MAINTENANCE, REPAIR AND OPERATIONS (MRO) CONCEPTS IN OFFSHORE WIND INDUSTRY THROUGH GAME-BASED LEARNING

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ABSTRACT

Digital Education Games (DEGs) have become increasingly popular as an educational tool in schools and for training professionals. However a review of literature has shown the limited use of such games in teaching concepts related to Maintenance, Repair and Operations (MRO) in the engineering field. The contribution of this paper and the DEG is specific to MRO in offshore wind energy. In our DEG the player mimics the behavior of a single decision maker, namely, the manager of the MRO facility who is responsible for the day-to-day allocation of resources for the upkeep of two offshore wind farms. The game enables the player to learn from a complex planning task wherein idle MRO resources must be minimized. The aim of the game is to prevent loss of revenue brought about through inadequate maintenance of the windfarms. The game is developed in Microsoft Excel using the VBA programming environment.

1 INTRODUCTION

A Digital Educational Game (DEG) has been defined by Aslan and Balci (2015) as a game that is developed for the purpose of teaching a subject in the form of software that can be executed on a computer; the computer can be a traditional PC, a mobile computing device or indeed a game console (Aslan and Balci 2015). Some authors refer to a DEG as a Serious Game (SG). However, it is arguable that the term DEG is more appropriate since the latter does not necessarily imply computer-based implementation through the development of a software artifact. For example, there exist a multitude of SG on sustainable development; some of these games can be categorized under board games (e.g., Shrub battle, Go Wild!), card games (like Learning Sustainable Development or LSD for short), quiz games (e.g., Build a Prairie, Environman) or indeed computer simulation games like Tragedy of the Tuna, The Solar PV Industry Simulation, The UVA Bay Game (Katsaliaki and Mustafee 2015). In this example only the computer-based games which are used for teaching sustainable development concepts will qualify as DEG. Some authors do however focus on computer-based SG and these have been defined as computer games and simulation approaches and/or technologies, which cover just about any non-game industry and therefore are used for applications unrelated to mere entertainment or traditional games (Blackman 2005; Michael and Chen 2005). Thus there appears to be some overlap among the definitions. In this paper we refer to both DEG and SG; the game that is presented is an example of DEG; our reference to SG is primarily for the purposes of discussing extant literature where author may have used the term to refer to games based pedagogy.

DEGs have become increasingly popular as an educational tool in schools, as a training device for professionals and as a means of educational entertainment! A number of studies confirm that such games help students increase their awareness of real world issues and comprehension of course subjects (Hirose, Sugiura, and Shimomoto 2004; Philpot et al. 2005, Katsaliaki and Mustafee 2015). Other studies confirm the positive effects of educational video games on youth learning and engagement (Evans et al. 2013). Serious Games include all aspects of education – teaching, training, and informing – and at all ages (Michael and Chen 2005). They can be applied to a broad spectrum of application areas, e.g. public policy, defense, corporate management, healthcare, training, and education (Zyda 2005). Their obvious advantage stems from the fact that, (a) they allow learners to experience situations that are impossible in the real world for reasons of safety, cost, time, etc. (Corti 2006; Squire 2002), (b) they engage the user in the pedagogical journey and can have a positive impact on the players' development of a number of different skills, such as analytical and spatial skills, strategic skills and insight, learning and recollection capabilities, psychomotor skills, visual selective attention, etc. (Mitchell and Savill-Smith 2004), and (c) they enable improved self-monitoring, problem recognition and problem solving, decision making, better short-term and long-term memory, and increased social skills such as collaboration, negotiation, and shared decision-making (Mitchell and Savill-Smith 2004).

The focus of this paper is on the use of DEGs for learning concepts related to Maintenance, Repair and Operations (MRO) in the offshore wind industry. MRO is an essential but time consuming and cost intensive undertaking which usually continues throughout the lifetime of capital assets. This is especially true in the context of wind farms located in an offshore environment and which are prone to long-term severe weather events. Optimizing resource utilization for MRO activities (resources can be engineers and technicians, boats and crew, spare parts) can have a significant impact on the uptime of individual wind turbines and consequently on the financial performance of a wind farm. Thus, it is critical that students complement their technical knowledge with an understanding of operational and business aspects of MRO. The use of DEGs in the classroom environment is a step in this direction as it has the potential to be used as an effective teaching and training tool for not only students but also stakeholders engaged in the development and running of offshore wind farms.

The remainder of this paper is structured as follows. A brief outline of offshore wind industry is presented next. This is followed by section three which reviews literature on DEGs in engineering education. Section four discusses the pedagogical purpose of our DEG (the game is subsequently referred to as the MRO game). Section five presents an outline of the game with section six on future work.

2 CONTEXT: OFFSHORE WIND FARMS AND THE IMPORTANCE OF MRO

An offshore wind farm is defined as a collection of wind turbines and associated equipment to generate electricity from wind power. Europe is the world leader in developing such farms with expertise from the Nordic countries, such as Sweden and Denmark, through to Holland (Pineda et al. 2014). In terms of installed capacity, in 2011 Europe had more than 90% of the world's installed capacity in offshore wind energy (European Wind Energy Association; http://www.ewea.org/). Taking the example of UK, it has over 1000 operational offshore turbines with an installed capacity of over 4GW; in addition to this a further 5.7GW is either under construction or has planning approval (RenewablesUK n.d.). UKs commitment towards generation of renewable energy through offshore wind is perhaps best demonstrated by the operationalization of the world's largest offshore wind farm in 2013 – the London Array. The 175 turbines that constitute the array are capable of generating power for nearly 500,000 homes whilst also contributing to the reduction of CO2 emissions by more than 900,000 tonnes a year (LondonArray; http://www.londonarray.com/). Several other EU countries are interesting in off shore wind energy, such as France, which expects to have operational offshore farms developed by 2018. A major obstacle to the ongoing development of this source of energy is the high cost of installation, operation and maintenance compared with other sources of energy (Pineda et al. 2014). As a result, it is estimated that the cost of maintaining offshore wind turbines makes up between 25%-30% of the total kWh cost of electricity, compared with 10%-15% of onshore terrestrial sites. Reducing maintenance costs through intelligent MRO strategies is thus a key step in establishing the future of offshore wind farms. The European Mer-innovate project (2013-2015; http://www.merinnovateproject.eu/en/) was a Franco-British collaboration that aimed to address the cost of maintenance programs of assets at sea (Marine Renewables) through the development of new procedures, protocols, modeling tools and DEG.

3 LITERATURE REVIEW

The purpose of the literature review was to identify DEGs related to Operations Management (OM) in the context of engineering education; this was achieved by conducting a search for scholarly literature as well as for online games available through the Internet/World Wide Web. However, an initial search for the latter revealed that gaining online access to such games is difficult compared to some other fields, e.g., the review on SG for sustainable development accessed several such games which were available for free over the Internet (Katsaliaki and Mustafee 2015). As a result we narrowed our methodology and primarily focused on identifying relevant scholarly literature. The underlying method for selecting articles, which either presented a review of literature in the field or described/tested the use of a game, involved two stages: (a) Keyword Identification – identifying a set of keywords with the purpose of selecting relevant articles (games), and (b) Screening – reading the title of the paper, the keywords and the abstract to identify articles suitable for inclusion in the study. Articles were searched using the Web of Science (WOS) and the SciVerse Scopus journal databases, as well as Google Scholar and the use of snowballing technique (reference chasing). To identify articles that would form our initial dataset the following criteria were used: inclusion of the words, *"game** AND *engineering"* or *"virtual reality** AND *repair"* in the title, abstract, or keywords of the published articles. Other keyword combinations were also tested, however most of them did not yield relevant results. The search resulted in a total of 16 articles that had references to games in engineering, including various forms of a game (SG, simulation, virtual environment, 3D augmented reality tool, etc.). Three additional articles were retrieved using Google Scholar. Table 1 presents the list of 19 papers that were identified at this stage.

Table 1: Articles identified using search criterion.

Authors (year)	Title	Source Title	Year
Van Bussel and Schoentag (1998)	Operation and Maintenance Aspects of Large Offshore Windfarms	Delft University of Technology	1998
Badler, Erignac, and Liu (2002)	Virtual Humans for Validating Maintenance Procedures	Communications of the ACM	2002
Susi, Johannesson, and Backlund (2007)	Serious Games – An Overview	Technical Report - University of Skoevde	2007
Liang (2010a)	Design and Implement a Virtual Learning Architecture for Troubleshooting Practice	Computer Applications in Engineering Education	2010
Liang (2010b)	Scaffolding for Automotive Air Conditioning Learning Environment	Computer Applications in Engineering Education	2010
Deshpande and Huang (2011)	Simulation Games in Engineering Education: A State-of-the-Art Review	Computer Applications in Engineering Education	2011
Henderson and Feiner (2011)	Exploring the Benefits of Augmented Reality Documentation for Maintenance and Repair	IEEE Transactions on Visualization and Computer Graphics	2011
Rueppel and Schatz	Designing a BIM-based serious game	Advanced Engineering	2011

(2011)	for fire safety evacuation simulations	Informatics	
Kuk et al. (2012)	Using a game-based learning model as a new teaching strategy for computer engineering	Turkish Journal of Electrical Engineering & Computer Sciences	2012
Li, Chan, and Skitmore (2012)	Multiuser virtual safety training system for tower crane dismantlement	Journal of Computing in Civil Engineering	2012
Vosinakis and Koutsabasis (2012)	Problem-Based Learning for Design and Engineering Activities in Virtual Worlds	MIT Press Journals	2012
Geng et al. (2013)	A modelling approach for maintenance safety evaluation in a virtual maintenance environment	Computer-Aided Design	2013
Zhu, Ong, and Nee (2013)	An authorable context-aware augmented reality system to assist the maintenance technicians	The International Journal of Advanced Manufacturing Technology	2013
Dib and Adamo-Villani (2014)	Serious Sustainability Challenge Game to Promote Teaching and Learning of Building Sustainability	Journal of Computing in Civil Engineering	2014
Qiu et al. (2014)	Virtual human hybrid control in virtual assembly and maintenance simulation	International Journal of Production Research	2014
Aziz et al. (2014)	A Multi-User Virtual Laboratory Environment for Gear Train Design	Computer Applications in Engineering Education	2014
Kerga et al. (2014)	A serious game for introducing set-based concurrent engineering in industrial practices	Concurrent Engineering: Research and Applications	2014
Venter and Coetzee (2014)	Interactive learning through gaming simulation in an integrated land use-transportation planning course	Journal of Professional Issues in Engineering Education and Practice	2014

This initial review showed that the majority of games developed, including augmented reality (3D models) and virtual environments, are designed to prepare and train engineers and mechanics for work on the job (Badler, Erignac, and Liu 2002; Liang 2010a; Liang 2010b; Rueppel and Schatz 2011; Li, Chan, and Skitmore 2012; Aziz et al. 2014; Geng et al. 2013; Qiu et al. 2014; Kerga et al. 2014) or to assist them whilst carrying out a physical task (Henderson and Feiner 2011; Zhu, Ong, and Nee 2013). SG/DEG that approached engineering issues from an operations management perspective were not found using the initial set of keywords. As the main theme of the paper is on the use of DLE to help students and stakeholders make efficient resource management decisions (rather than on-job tools that directly assisted or informed maintenance and repair operations), it was considered pertinent to rethink the search strategy. We decided to expand our research focus to include business games in all application areas. We performed a subsequent search using the following keywords: *"business game" and "business game* AND *operations management"*. The search retrieved several papers on "game theory" and which were excluded. In total we were able to identify six articles using the two journal databases, four articles through Google Scholar and a further eight articles through snowballing (taking note of the references of relevant articles to identify additional articles). Table 2 lists the OM games that were identified in this phase of literature search. For these games it was fairly easy to retrieve a description and explanation of how the game works, what is required and its pedagogic purpose. In addition to the games identified in Table 2, the keywords used also filtered a number of journal papers discussing game-based learning in education and research more generally (Keys and Wolfe 1990; Nakano and Terano 2004; Lainema and Hilmola 2005; Lewis and Maylor, 2007) and some focusing upon its suitability and effects in various application areas (Goodwin and Franklin 1994; Haapsalo and Hyvonen 2001; Petty, Hooker, and Barber 2001; Zabawa and Mielczarek 2007; Nemoto et al. 2014).

Table 2: OM games identified using revised search criteria.

Year	Name of OM game
1986	RED BEAD EXPERIMENT (Ammar and Wright 1999)
1994	BEER GAME (Ammar and Wright 1999)
1995	CRAC BUSINESS GAME (Chapman and Martin 1995)
1997	LEGO OF MY SIMPLEX (Ammar and Wright 1999)
1999	BALANCING PLANES (Ammar and Wright 1999); THE DISTRIBUTION GAME (Ammar and Wright 1999); THE MANUFACTURING GAME (Ammar and Wright 1999)
2000	DICE GAME (Baranauskas, Neto, and Borges 2000)
2002	LEAN LEAP LOGISTICS GAME (Holweg and Bicheno 2002); GOLDRATT'S GAME (Johnson and Drougas 2002)
2006	BEER DISTRIBUTION GAME (Yan Wu and Katok 2006)
2007	CUPPA MANUFACTURING GAME (Ammar and Wright 1999)
2010	HECOpSIM (Pasin and Giroux 2011); LOGISTIC GAME (Battini et al. 2009)
2014	BLOOD SUPPLY CHAIN GAME (Mustafee and Katsaliaki 2010; Katsaliaki, Mustafee, and Kumar 2014)

Next we categorizes the OM games based on application area (Table 3). As discussed in Lewis and Maylor (2007), the dominance of manufacturing as an application area of SG still persists, raising questions on whether the developments in OM have been appropriately addressed through the use of DLE/SG. For example, Lewis and Maylor (2007) pointed out that the content of OM-related games has not developed in the same way as the taught subject (there is, of late, an increased emphasis on OM in service scenarios). A finding of this study is that the games too have not sufficiently progressed to support engineering education in terms of providing students with an OM perspective since the majority of games developed are primarily designed to train and aid maintenance and repair personnel as opposed to provide training in decision making related to resource optimization. Our MRO game is designed to fill this dearth of literature in game-based learning as applied to engineering and maintenance operations.

Table 3: Findings on application area.

Categorization of Application Areas	#Number of Games	Name of OM game
Manufacturing	7	BEER GAME; CRAC BUSINESS GAME; HECOpSIM; DICE GAME; CUPPA MANUFACTURING GAME; GOLDRATT'S GAME; BEER DISTRIBUTION GAME
Distribution	2	LEAN LEAP LOGISTICS GAME; LOGISTIC GAME
Healthcare	1	BLOOD SUPPLY CHAIN GAME

4 PEDAGOGIC PURPOSE OF THE MRO GAME

We have seen in the introduction section that various definitions and forms of games exist. However most of them emphasis on similar themes, for example, a simplified abstraction of a situation related to the business world, decision-making in a simplified and abstracted business environment in either a group or as an individual, participants projecting themselves into the game, a complement to the static nature of traditional education. DEG allow students to directly experience the challenges associated with managing specific operations in a risk free environment and this makes such games an exceptionally attractive learning tool. As a result, they can often be more effectively in conveying complex and challenging operations management scenarios than strictly theoretical settings (Lewis and Maylor 2007). The pedagogic purpose of the MRO games is as follows:

- To improve students' understanding of MRO associated with offshore wind farms.
- To highlight to the students the importance of variables like reported turbine faults, resource availability, weather windows, etc. and how it affects the MRO operations.
- To train students in making decisions under pressure and in complex situations where an outcome arises from interaction of multiple factors and interventions.
- To provide a computer-based game environment or DEG for the students to play with various strategies and reflect on the outcome of implementing such strategies.
- To enable students to compare alternative strategies.

5 THE MRO GAME FOR OFFSHORE WIND FARMS

In this section the MRO game is discussed at length. The game is developed in Microsoft Excel using the VBA programming environment. Version 1 of the game can be downloaded from the following website http://www.merinnovateproject.eu/en/the-project/serious-game-exeter/ (last accessed 9th June 2015).

The MRO game is a single-player game where the player (the student) mimics the behavior of a decision maker, namely, the manager of the MRO facility who is responsible for the day to day allocation of resources for the upkeep of two offshore windfarms. The game enables the player to learn from a complex planning task; the objective is to minimize idle resources and prevent loss of revenue brought about by inadequate maintenance of the windfarms.

The game models two windfarms, windfarmA (nearshore windfarm) and windfarmB (offshore windfarm) with 60 and 100 turbines respectively. By default the number of resources that exist to serve the two windfarms is four; these resources are shared amongst the two windfarms. It is assumed in the game that the MRO facility is operational 365 days year. In a subsequent version of the game it will be possible to change both the number of turbines associated with the windfarms, as also the number of resources available for MRO activities. The simulation is time-stepped and progresses from one day to the next. The game is played for 15 simulated days (however, this can be easily extended to one month or indeed even longer periods of time).

To reduce game complexity the resources have not been categorized into specific sub-types (like boat, engineers) and the assumption that is made is that for each MRO activity there is a need for one resource. There are some costs associated with the resources:

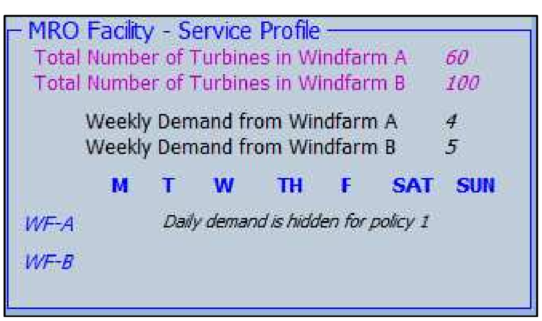
- A resource that is idle (not used for repair activity) costs 100 units per resource per day.
- Loss of revenue associated with each failed turbine (i.e., which requires MRO operation) in the nearshore windfarm (windfarmA) is 500 units per day per turbine.
- Loss of revenue associated with each failed in the offshore windfarm (windfarmB) is 800 units per day per turbine (thus, turbines in windfarmB generate more electricity; please note this is a simplification since it does not consider other factors like wind speed).
- A resource which is sent to the nearshore windfarm (windfarmA) costs 250 units per resource per day.

- A resource which is sent to the nearshore windfarm (windfarmA) requires one day to complete a MRO task.
- A resource which is sent to the offshore windfarm (windfarmB) costs 600 units per resource per day (takes into account the need for more expensive parts to service the turbine, increased fuel costs for travelling further away from the coast, etc.).
- A resource which is sent to the offshore windfarm (windfarmB) requires two days to complete a MRO task (to cater for the increase in travel time).

The game enables both deterministic and stochastic game play (Figure 1a). In the deterministic version (also referred to as standard play) the weekly demand for resources do not vary - weekly demand for MRO resources for windfarmA and windfarmB are 4 and 5 units respectively. For probabilistic play (also referred to as advance play) the weekly demand varies. For deterministic play the number of resources requested per day of the week is also fixed and there is no variation from one week to the next. Thus, it is coded in the model that windfarmA will request one resource every Monday, Wednesday, Thursday and Friday; windfarmB will request two resources on Tuesday and Thursday and one resource on Sunday. For the probabilistic version of the game resource request per day of the week naturally varies.

Figure 1a: Players can play either the deterministic or stochastic version of the game. Figure 1b: Players can select three different game play options.

There are three policies that can be selected for game play (Figure 1b). If policy 1 is selected (assign resources on demand) then the weekly requirement is not shown in the "MRO Facility – *Service Profile"* summary panel (Figure 2a); this is true for both the deterministic and the stochastic version of the game. If policy 2 is selected (assign resources collectively) then the weekly requirement is shown (Figure 2b) and this enables the player to do forward planning. Policy 3 is on assigning resources collectively and takes into account the weather windows. This functionality will be implemented at a future date.



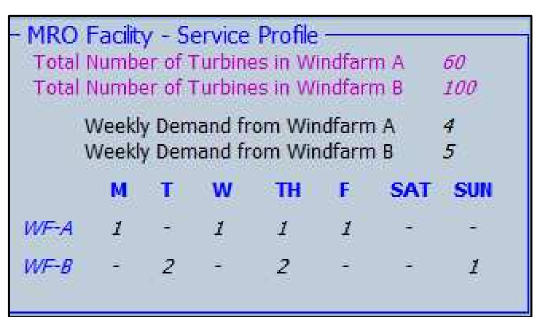


Figure 2a: Resource demand for weekday is hidden if policy 1 is selected. Figure 2b: resource demand for weekday is shown if policy 2 is selected.

Having discussed the input options we now focus on how the game is played. As mentioned earlier, the game is played for 15 simulated days and it advances time in 24 hour increments. In other words the MRO game advances time from Monday to Tuesday, Tuesday to Wednesday and so on so forth. The gameplay screen (Figure 3) shows the day of the week under the Mer-innovate logo.

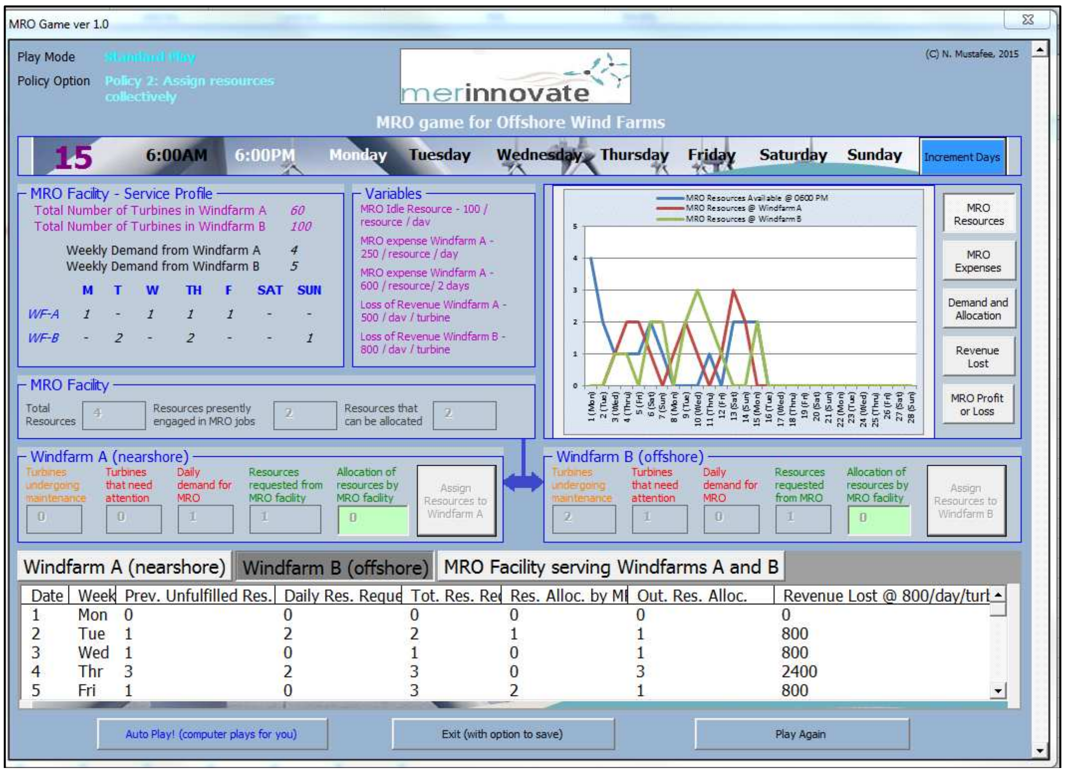


Figure 3: The game play screen.

For every simulated day, and based on the policy selected, the resource request is presented for both windfarmA and windfarmB. This can either be sequential resource request (windfarmA followed by windfarmB; policy 1) or collective resource request (policy 2). This information is displayed in two panels - *"Windfarm A (nearshore)"* and *"Windfarm B (offshore)"* with a host of other information like the number of turbines presently undergoing maintenance, turbines that require attention (previously resource request was unfulfilled), the new demand for resources (based on the weekly demand), and the total number of resources requested (Figure 4). Based on resources available (see panel on *"MRO Facility"*; Figure 3) and other future considerations on MRO tasks, the player assigns a certain number of resources for both the turbine. This value is input in the textbox with green background (see Figure 4 below). The game thus advances from day 1 to day 15 with the player making the decision on the allocation of resources based on daily-updated values.

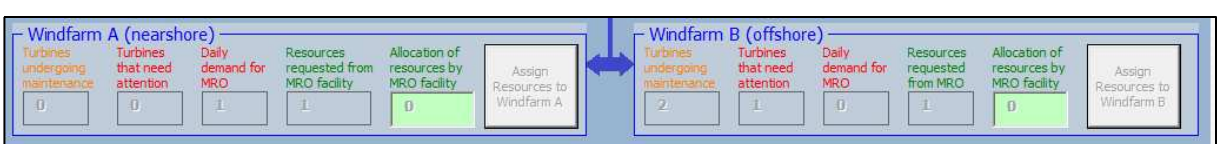


Figure 4: Request for resources and allocation based on availability and other considerations (an extract from the game play screen).

As the game progresses, graphs are generated at run time which allow the player to monitor resource use (Figure 5; top left) and resources requested against those allocated (Figure 5; top right). One objective of the game is to maximize MRO resource utilization and to reduce MRO expenses related to idle time (Figure 5; bottom left) and to reduce revenue lost from the windfarms (Figure 5; bottom right), which happens when the turbines are in a state of disrepair.

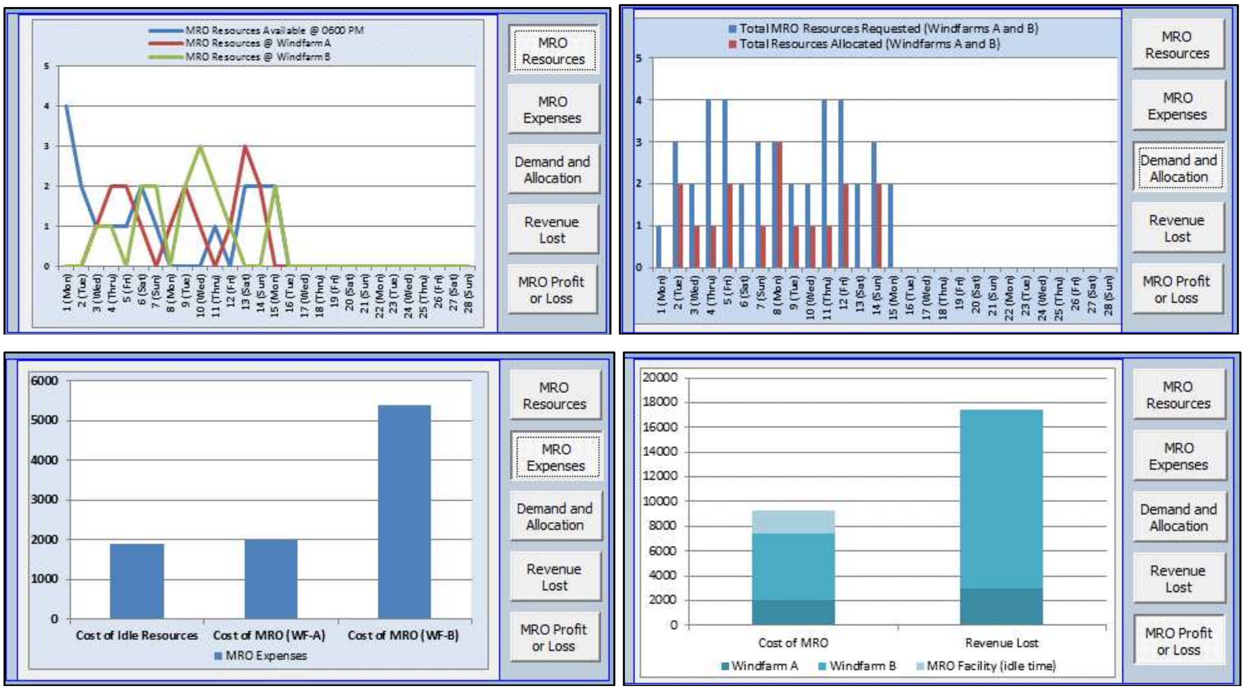


Figure 5 (top left, top right, bottom left and bottom right): Graphs that allow the player to monitor the progress of the MRO game (game play screen).

Figure 5 (bottom right) illustrates the MRO profit and loss graph which is generated subsequent to the game having been played for 15 days. For this particular instance of game play, the graph shows that the MRO costs for resource idle time is roughly equal to the costs incurred for MRO activities pertaining to windfarmA. The costs for such activities for windfarmB is approximately 2.5 times more than that of windfarmA. However, the revenue lost in case of windfarmB is approx. 3.5 times more the revenue lost due to maintenance not taking place in windfarmA. Thus it is arguable that more resources could have been allocated for MRO activities in windfarmB. It is therefore expected that the player learns from this outcome and reflects on changes in decision making that may be required in the subsequent iteration of game play.

6 FUTURE WORK

The MRO game had been demonstrated at the concluding Mer-innovate stakeholder/research showcase event that was held in Portsmouth in March 2015. Feedback from the users (including the project partners) have been noted and a subsequent version of the game is under development. Further, additional functionality that has been included in the GUI will need to be implemented, notably, allowing a player to vary the MRO parameter (refer to Figure 1a; third tab), enabling Policy 3 (Figure 1b), and incorporating weather windows (Figure 1a; fourth tab) – this is work in progress and will be reported in a subsequent academic publication together with the evaluation of the game by its intended audience.

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