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Tuomo Heikkilä

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A decision support system to evaluate the business impacts of machine-to-machine system

Tuomo Heikkilä
Wapice Ltd, Vaasa, Finland

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Abstract

Purpose – The tightening competition and performance pressure in companies often leave no time or space for the assessment of business impacts of different investments and projects. In addition, in many cases the assessment may be challenging and there is no experience available to undertake it. Despite that companies often commit to different projects and investments without careful planning and vision of the costs it may cause. The purpose of this paper is to create a decision support system in order to facilitate and increase the assessment of business impacts of different investments concerning to machine-to-machine (M2M) systems.

Design/methodology/approach – The created decision support system is composed of cost-benefit analysis including several investment decision methods. In order to deepen the understanding on it, the system was applied to two cases from the M2M business.

Findings – During the study it was found that different financial metrics might give contradictory results when deciding whether to undertake an investment. In addition, a significant finding was how much some variables may have significance to the eligibility of an investment than others. The study also gave understanding how long payback time can be and how risky the investments might be in different M2M applications.

Originality/value – The study describes the created decision support system and it is applied to two different M2M applications. The system provides a comprehensive combination of different financial metrics, which will help any manager make decisions whether an investment is eligible or not.

Keywords Decision support system, Cost-benefit analysis, Business impacts, Machine-to-machine

Paper type Research paper

1. Introduction

Machine-to-machine (M2M) refers to devices using network resources to communicate with remote application infrastructure for the purposes of monitoring and control, either of the device itself, or the surrounding environment. It is sometimes defined simply as data communication between machines without human interaction. M2M has a multitude of applications such as automatic meter reading (AMR) and advanced metering infrastructure (AMI), building control or management systems, condition monitoring of machines or people, environmental monitoring, industrial automation, fleet management, for example, with trucks, and many others (Lucero, 2010; Asif, 2011; Lu *et al.*, 2011).

M2M applications are gaining tremendous interest from mobile network operators, equipment vendors, device manufacturers, as well as research and standardization bodies and there are numerous M2M solutions already in use all over the world. For example, over the last three decades, AMR based on one-way or two-way communication has evolved. AMI broadens the scope of AMR beyond just meter readings with additional features enabled by two-way data communication. AMR and AMI systems are replacing the manual meter reading and providing more reliable reading with greater accuracy and overall reduced cost (Steklac and Tram, 2005; Foschini *et al.*, 2011).

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One example of another M2M application where the market has entered a growth period that will last for several years to come is fleet management. It provides several benefits for a trucking company such as better operational efficiency and reduced fuel costs. There are numerous adoption drivers that speed up the market size growth of M2M applications. A major factor is that mobile network coverage is being expanded worldwide. Moreover, government mandates are increasingly requiring the use of telematics and telemetry functionality enabled by M2M. For example, Sweden mandated that all of its national utilities must read their electricity meters at least once a month, starting in 2009. Swedish utilities are using mobile connectivity as part of the AMI solution, and other Scandinavian countries are expected to follow this model. The European Commission is promoting an EU-wide e-call telematics initiative with the goal that all vehicles sold in Europe by 2013 will use a combination of global positioning system (GPS), sensors and mobile communications to automatically inform authorities in the case of an accident with location and details of the incident, and establish an automatic voice call between passengers and emergency personnel (Delehaye *et al.*, 2007; Lucero, 2010).

A fundamental question when considering whether to invest in a M2M system is what kind of business impacts it may provide. The need for this study arose when it was realized in some industrial companies how little the business impacts of different investments and projects are generally assessed and how difficult it may be in many cases. For this reason, it was necessary to clarify the methods for determining whether an investment is worth undertaking. The methods were aggregated as a decision support system. When some concrete assessment is conducted and numerical results are produced using the system, it most probably aids decision makers to understand the investment's business impacts.

In order to enable creating more reliable and general-purpose decision support system, it was applied to two practical M2M cases. The financial analysis in the cases is conducted from the customer point of view. Analysis from the solution provider side is excluded. This study neither contains detailed technical specification of any system as the purpose is to keep the focus in more general level.

2. Solution

In this chapter, the decision support system is composed and it is applied to assessment of two M2M cases. It was decided that the decision support system will be based on cost-benefit analysis including payback period, return on investment (ROI), net present value (NPV), internal rate of return (IRR), sensitivity analysis, Monte Carlo simulation and break-down analysis. These metrics are implemented as easy-to-use calculation sheets in Microsoft Excel spreadsheet software and simulations using GNU Octave software. It is a high-level interpreted language, primarily intended for numerical computations and its language is very similar to MATLAB so that most programs are easily portable (Eaton, 2012).

According to Horngren *et al.*, the cost-benefit analysis is a technique for estimating the monetary costs and benefits of an investment over a particular time period. The approach is the criterion that assists managers in deciding whether, for example, to acquire a new system instead of continuing to use an existing historical system (Horngren *et al.*, 2007, p. 11).

ROI is an accounting measure of income divided by accounting measure of investment. NPV of an investment is a way to characterize the value of an investment. It is the present value of its cash flows minus the present value of its cash outflows.

IRR calculates the discount rate at which the present value of expected cash inflows from a project equals the present value of its expected cash outflows (Horngren *et al.*, 2007, pp. 727-728, pp. 793-794; Brealey *et al.*, 2011, p. 136).

Sensitivity analysis is a technique that examines how a result will change if the original predicted data are not achieved or if some assumption changes (Horngren *et al.*, 2007, p. 193; Brealey *et al.*, 2011, pp. 271-272). As sensitivity analysis allows considering the effect of changing one variable at a time, Monte Carlo simulation is a tool for considering all possible combinations. Therefore it enables the inspection of the entire distribution of project outcomes. Break-even analysis determines the break-even level of that input, which is the level for which the investment has an NPV of zero (Brealey *et al.*, 2011, p. 273, p. 277).

The discount rate used in the financial calculations is higher than typical bank loans or the return of investment from state securities as there is certain degree of risk in the investments. The right discount rate for a cash flow is the rate of return available in the market on other investments of comparable risk and return (Berk and DeMarzo, 2011, p. 143; Brealey *et al.*, 2011, pp. 35-36). Thereby, in the financial calculations in the cases, the ROI of each company is used as the discount rate.

2.1 Condition-based maintenance system (CBM)

In this chapter a CBM system for a wind farm is presented and the decision support system is applied. In the calculations different costs of the conventional system and the CBM system are presented and compared one by one. The difference of those costs is savings and that provides the justification to undertake the investment. The CBM system provides means to remotely diagnose and analyze the status and maintenance needs of a wind farm. In Figure 1, Eto *et al.* illustrate the architecture of a condition monitoring system for a wind farm. The described solution consists of individual wind turbines of which each is equipped with a wind turbine controller, data logger (remote station server) that collects and distributes the data, remote monitor (remote station), and network for connecting these pieces of equipment. In this case, the wind turbine controller is an embedded device controlling the wind turbine blade angle according to wind direction. The device also performs data input processing of environmental conditions such as wind direction, wind velocity and temperature around each wind turbine, and operation conditions, for example, generated power and frequency. It transmits the data of each wind turbine to the data logger and controls the starting and stopping of the wind turbine (Eto *et al.*, 2003).

Generally, the purpose of maintenance is to extend equipment lifetime or at least the mean time to the next failure of which repair may be costly. There are different types of maintenance approaches available, such as corrective maintenance, scheduled maintenance and preventive maintenance. In the first approach a component is replaced at a certain age or when it fails. The scheduled maintenance, also known as planned maintenance, presumes that all devices in a given class are replaced at predetermined intervals or when they fail. Scheduled maintenance includes lubrication, tightening bolts, changing filters, calibration and adjustment of sensors and actuators, replacement of consumables such as brake pads and seals, and checking safety equipment.

In preventive maintenance practice maintenance is carried out when it is deemed necessary, based on periodic inspections or other means of condition monitoring. Preventive maintenance can be CBM, sometimes also known as predictive maintenance,

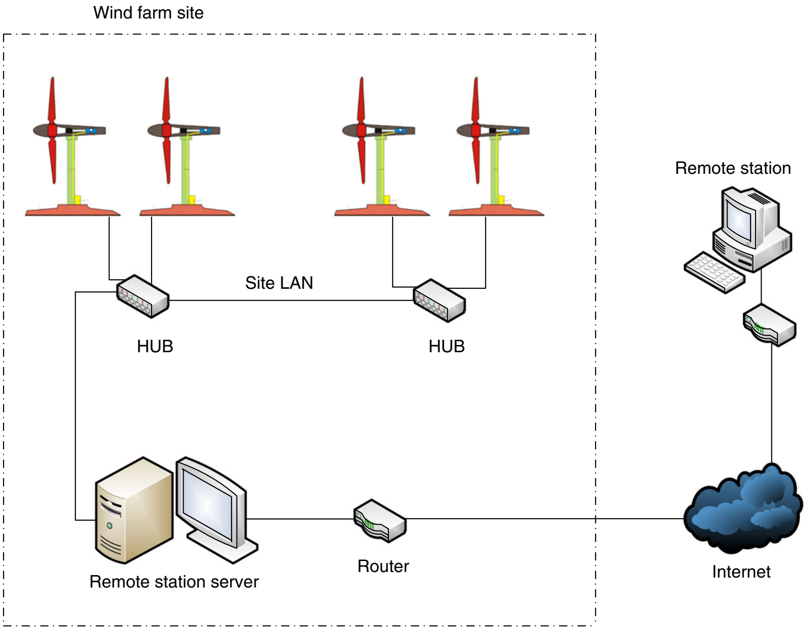

Figure 1.
Remote condition monitoring system for a wind farm

Source: Eto *et al*. (2003)

is based on the actual health of the system. In addition to periodic inspections, the health can be determined by analyzing offline measurements, oil samples, SCADA data, or online measurements. Therefore, implementing a CBM strategy is not limited to using online condition monitoring systems. Online condition monitoring is only one of many means to determine the health of a system. Thereby, online and automated condition monitoring is not a synonym for CBM (Nilsson and Bertling, 2007; Wiggelinkhuizen *et al.*, 2007; Orosa *et al.*, 2010; Zhigang and Tongdan, 2011). In this wind farm case, the focus is in CBM.

By utilizing condition monitoring information collected from wind turbine components, CBM can be used to reduce the operation and maintenance costs of wind farms. The CBM methods for wind farms deal with wind turbine components separately. In other words, the maintenance decisions can be made on individual components, rather than the whole system. In practice, a wind farm consists of several turbines and each of them has several components including main bearing, gearbox and generator. Therefore, once a maintenance team is sent to the wind farm, it is probably more profitable to take the opportunity to maintain several turbines, and when a turbine is stopped for maintenance, it might be more cost-effective to simultaneously maintain multiple components which indicate relatively high risk (Wiggelinkhuizen *et al.*, 2007; Zhigang and Tongdan, 2011).

There is numerous condition monitoring techniques developed that can be utilized in condition-based monitoring. Verbruggen and Krug, Rasmussen *et al.* and Wiggelinkhuizen *et al.* list techniques such as vibration analysis, oil analysis, thermographic analysis of electrical components, physical condition of materials, fiber optic strain measurement of blades, acoustic measurements, electrical effects, process parameters, visual inspection, performance monitoring, time and frequency domain analysis of the electrical power, trending of key component response functions, and self-diagnostic sensors (Verbruggen, 2003; Krug *et al.*, 2004; Wiggelinkhuizen *et al.*, 2007; Yang *et al.*, 2010).

As there are a multitude of possibilities how to utilize CBM, it is possible to achieve a lot of benefits with these. For example, maintenance can be planned better, the right maintenance can be carried out at the right time and unnecessary replacements can be minimized. In many cases, repairs can be done in conjunction with regular maintenance work. Basically, condition monitoring makes it possible to carry out maintenance and repairs depending on the condition of the turbine. Downtime can be reduced as failures are discovered more easily and earlier. In case of sudden failure if the wear is not detected in good time, the downtime can easily be ten times longer as material and personnel have to be transported to the plant. Transportation costs to wind farm can also be reduced due to better planning provided by condition monitoring. For example, if one gearbox needs repair, then another gearbox that may fail at a later state could be repaired at the same time. Unexpected plant standstills that cause loss of energy production can be avoided to the largest extent possible. Optimum turbine availability can be guaranteed (Verbruggen, 2003; Krug *et al.*, 2004; Nilsson and Bertling, 2007; Yang *et al.*, 2010; Schwanzer, 2013).

Based on the benefits discussed above, financial calculations can be conducted on how eligible a CBM solution in a wind farm would be. An energy company is randomly selected for the calculations. In this case, it is assumed that Vapo Group builds a new onshore wind farm with eight wind turbines ($n_w = 8$). Vapo Group is a leading supplier and developer of bioenergy in Finland and in the Baltic Sea Region (Vapo Group, 2012). At the moment, Vapo Group has eight wind turbines installed in Finland (The Wind Power, 2013). The calculations are based on the assumption that new wind turbines are built instead of retrofitting the old ones with condition monitoring devices. Typically, the lifetime of the wind farm is designed to be 20-30 years (Nilsson and Bertling, 2007; Hau, 2006, p. 698). Therefore it is assumed that the lifetime of Vapo wind farm is $\mathrm{lt} = 20$ years.

(1) Investment costs of CBM system:

- *Costs of equipment*

  The equipment that needs to be purchased for one wind turbine are the analysis devices such as oil quality sensors and temperature sensors, wind turbine controller and other material such as cables. According to Fredrik Larsson, managing director on SKF Condition Monitoring Center, price of a condition monitoring system for a wind turbine is €20,000 (Nilsson and Bertling, 2007). Therefore, it is assumed that the analysis equipment costs $c_{analysis} =$ €18,000 since it is assumed that prices go down as the technology develops. The controller costs $c_{ctrl} =$ €300 and the installation material for each meter costs $c_{material} =$ €500. The price of the equipment of one installation can be calculated using equation:

  $$C_{inst} = C_{analysis} + C_{ctrl} + C_{material}$$

  The equipment costs for the whole wind farm when the number of turbines $n_{turbines} = 8$, hub price $C_{hub} =$ €200, router price $C_{router} =$ €150, server price $C_{server} =$ €1,000 and software $C_{software} =$ €5,000 can be calculated using equation the equation below. It is assumed that two hubs and two routers are needed:

  $$C_{equipment} = n_{turbines} \times C_{inst} + 2 \times C_{hub} + 2 \times C_{router} + C_{server} + C_{software}$$

- *Installation of the equipment*
  The assumption was that the analysis and controller equipment is mounted only to the new wind turbines as retrofitting is too costly. It is assumed that mounting cost is $c_{mnt} =$ €1,500 per turbine as the aim is that the mounting is done before the wind turbines are moved to wind farm. Only the cables are connected on-site. Installation of other equipment such as hubs, routers, servers and software is estimated to cost $c_{inst,other} =$ €1,000. Therefore, the total installation costs of the equipment for the CBM system is:

  $$C_{inst,eq} = n_{turbines} \times C_{mnt} + C_{inst,other}$$

  The total investment for equipment and installation of the wind farm can be determined with equation:

  $$C_{inv} = C_{equipment} + C_{inst,eq}$$

(2) Annual wind farm operations and maintenance costs in conventional system
In the conventional system, the annual maintenance costs are composed of corrective maintenance costs C_{cm} and costs of scheduled maintenance costs C_{sch}. The equation to calculate the total maintenance costs per year is:

$$C_m = C_{cm} + C_{sch}$$

The corrective maintenance costs consist of unscheduled maintenance costs C_{usch} and costs of replacing major components C_{rmc}. The equation to calculate corrective maintenance costs is:

$$C_{cm} = C_{usch} + C_{rmc}$$

The unscheduled maintenance costs are calculated using equation:

$$C_{usch} = C_{man} \times \left(n_{diag} + n_{maint}\right)$$

where n_{diag} is the number of man hours used for diagnostics of wind turbines and n_{maint} is the number of man hours used for actual maintenance work. It is assumed that there is diagnosis work $n_{diag} = 12$ hours for and maintenance work $n_{maint} = 16$ hours for two men per turbine in a year categorized as unscheduled maintenance.
The cost of replacements C_{rmc} is built on the assumption that the gearbox is changed twice ($n_{gb} = 2$) and the generator is changed once ($n_g = 1$) during the lifetime of a wind turbine. Two transformers ($n_{tr} = 2$) and two blades ($n_b = 2$) are replaced for the whole wind farm during its lifetime. Therefore, the equation to calculate the total cost of replacements over the lifetime:

$$C_{rep} = C_{rgb} + C_{rg} + C_{rtr} + C_{rb}$$

where C_{rgb} is the cost of replacing gearboxes in the wind farm; C_{rg} the cost of replacing generators in the wind farm; C_{rtr} the cost of replacing transformers in the wind farm; and C_{rb} is the cost of replacing blades in the wind farm.
The annual replacement costs in the wind farm can be calculated using equation:

$$C_{rep,year} = \frac{n_{gb}}{lt} \times C_{rgb} \times n_w + \frac{n_{rg}}{lt} \times C_{rg} \times n_w + \frac{n_{tr}}{lt} \times C_{rtr} + \frac{n_{rb}}{lt} \times C_{rb}$$

where each cost variable C is calculated using equation:

$$C = n_{man,task} \times C_{man} \times 2 + C_c$$

where $n_{man,\,task}$ is the number of hours needed to perform the specific task, C_{man} is the price of one hour and C_c is the price of the component. It is assumed that there are always two men doing the replacement. The assumed values for the equation above are:$n_{man,\,gb} = 8$ hours, $n_{man,\,g} = 6$ hours, $n_{man,tr} = 7$ hours and $n_{man,b} = 5$ hours. The component prices are estimated to be gearbox $C_{gb} =$ €300,000, generator $C_g = 150{,}000$, transformer $C_{tr} = 100{,}000$ and blade $C_b = 200{,}000$ (Nilsson and Bertling, 2007). Normally, there are two scheduled maintenances per year and typical availability percentage in onshore wind turbines is 97.5 percent (Hau, 2006; Nilsson and Bertling, 2007; Orosa *et al.*, 2010). In this case, it is also assumed that a scheduled maintenance is performed twice a year and the availability percentage $p_{avail,conv} = 97.5$ percent in the conventional system. The scheduled maintenance cost per year is calculated with equation:

$$C_{sch} = 2 \times C_{man} \times n_{sch} \times n_w$$

It is assumed that scheduled maintenance of one wind turbine takes seven hours for two men in a year, so $n_{sch} = 7$. According to Vapo Group, the annual energy production of its eight wind turbines is about $E = 15{,}000$ MWh (Vapo Group, 2012). If assumed that without any unavailability time the maximum energy production in a year could be:

$$E_{\max} = \frac{E}{P_{avail,conv}} \times 100 \text{ MWh}$$

The electricity energy price including transfer costs on September 1, 2011 is 0.092 €/kWh that is $P_e = 92$ €/MWh (Vaasan Sähkö, 2011). Therefore, the costs of production losses in the conventional system in a year are:

$$C_{pl,conv} = (E_{\max} - E) \times P_e$$

The total costs C in the conventional wind farm in a year are:

$$C_{tot,conv} = C_m + C_{pl,conv}$$

(3) Annual wind farm operations and maintenance costs with CBM system

As the condition of the wind turbine and the possible cause for a fault is known better when using CBM system, it is assumed that time needed for diagnosis work in the wind farm equipped with CBM system is only 30 percent of the time compared to conventional system. The diagnosis time cannot be set to zero as the CBM system will not detect all possible problems, and faults may occur also in it. Thereby, the equation to calculate the costs of unscheduled maintenance per year is:

$$C_{usch} = C_{man} \times \left(0.3 \times n_{diag} + n_{maint}\right)$$

In addition, it is assumed that availability of the wind turbines is 1.3 percent higher than in the conventional system so $p_{avail,\,CBM} = 98.8$ percent due to shorter time needed for diagnosis work and better planning which CBM system enables. Due to awareness of the states of the wind turbines provided by the CBM system, the spare parts can be ordered earlier than with the conventional system. This also reduces the turbine downtime. The production losses when CBM system is used are:

$$C_{pl,CBM} = \left(E_{\max} - \frac{p_{avail,CBM}}{100} \times E_{\max}\right) \times P_e = E_{\max} \times \left(1 - \frac{p_{avail,CBM}}{100}\right) \times P_e$$

The other equations concerning corrective maintenance costs are the same as in the conventional system. The total costs $C_{tot,CBM}$ in the CBM-equipped wind farm in a year are:

$$C_{tot,CBM} = C_m + C_{pl,CBM}$$

(4) Return calculation

The difference of the costs between the conventional system and the system equipped with CBM is:

$$\Delta C = C_{tot,conv} - C_{tot,CBM}$$

The value of ΔC is the amount of money that the CBM-based system saves per year. Thereby it can be considered as income. However, there are some fixed costs per year as some equipment such as servers will have to be replaced during the system lifetime. Therefore, the income can be calculated using equation $I = \Delta C\text{-}C_f$, where $C_f =$ €2,000. From the general payback equation a simple payback period can be formulated in the following way:

$$\text{payback period} = \frac{C_{inv}}{I}$$

where C_{inv} is the total investment of CBM system; and I the income per year from the wind farm.

When the calculations are performed, it results payback period of 8.6 years.

ROI of the investment can be calculated using the equation:

$$ROI = \frac{I}{C_{inv}} \times 100\% = 11.6\%$$

According to Vapo Group, its *ROI* in 2010 was 9.5 percent (Vapo Group, 2011). The calculated *ROI* is slightly higher than Vapo Group's *ROI*. Therefore, the investment is eligible. In addition to *ROI*, the eligibility of the investment is assessed also using *NPV*. Its equation is:

$$NPV = \sum_{t=0}^{N} \frac{CF_T}{(1+r)^T} = CF_0 + \frac{I}{(1+r)^1} + \frac{I}{(1+r)^2} + \ldots + \frac{I}{(1+r)^{20}}$$

where CF_T is the expected net cash flow at time t; N the investment's projected life; r the discount rate or opportunity cost of capital = *ROI* of Vapo Group in 2010.

The result from the *NPV* calculation is €4,033 . Horngren *et al.* (2007) state that only investments with zero or positive *NPV* are acceptable (p. 727). Thereby the investment is eligible also from *NPV* point of view.

The third method for evaluating the eligibility of the investment is *IRR*. It can be solved from the equation (Brealey *et al.* 2011, p. 136):

$$NPV = C_0 + \frac{C_1}{1+IRR} + \frac{C_2}{(1+IRR)^2} + \ldots + \frac{C_T}{(1+IRR)^T} = 0$$

The calculated *IRR* is 10 percent. According to Brealey *et al.* (2011) the *IRR* rule states that an investment should be accepted if its *IRR* is greater than discount rate (p. 137).

As the *IRR* was 10 percent, which is higher than Vapo Group's *ROI*, the investment is noticed to be eligible.

In order to assess the extent of variation in different variables may cause to payback time, sensitivity analysis is conducted. The examined variables are price of analysis equipment, diagnosis work amount in CBM system and energy price. Each variable is analyzed separately. All the variables are analyzed with three different wind farm availability percentages per year. In Figure 2, it can be seen how dramatic effect the availability percentage has on the payback time. The analysis equipment price has less significance on the amortization time of the investment than the availability percentage.

In Figure 3, the effect of the availability percentage is also obvious. If the availability percentage is close to 97.5, that is the typical value in onshore farms, the payback time exceeds the estimated wind farm lifetime even with the analysis equipment of the lowest price. Therefore it is vital for the investment that higher availability percentage is achieved. The diagnosis time reduction has only a minor role in the payback time. In Figure 4, availability percentage is still the crucial factor in the payback time but the rising energy price can shorten it significantly. Monte Carlo simulation is also performed by using the same variables as in the sensitivity analysis to figure out the entire distribution of the payback periods. The values of the variables are changed according to the Normal distribution by using the value that was used in the described basic calculations as midpoint. The results of the Monte Carlo simulation are shown in Figure 5. It can be seen that the distribution of the payback periods is very well balanced around the calculated payback period.

It is also necessary to find out how high the availability percentage has to be in order to amortize the total costs. Therefore, a break-even analysis is conducted. In order to find out the percentage, the present value of inflows and outflows is calculated under different assumptions about the availability percentage. Based on the calculated values, equations of the lines of present value of inflows and outflows can be composed. Using these equations, the accurate break-even point can solved algebraically.

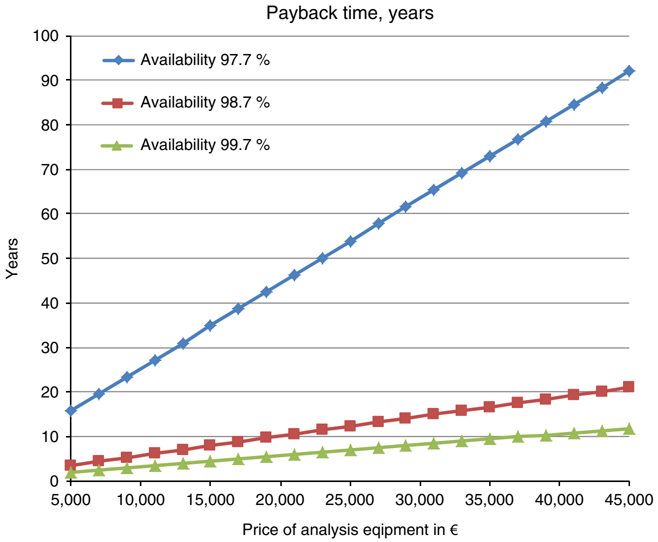

Figure 2. Price of analysis equipment effect on the payback time

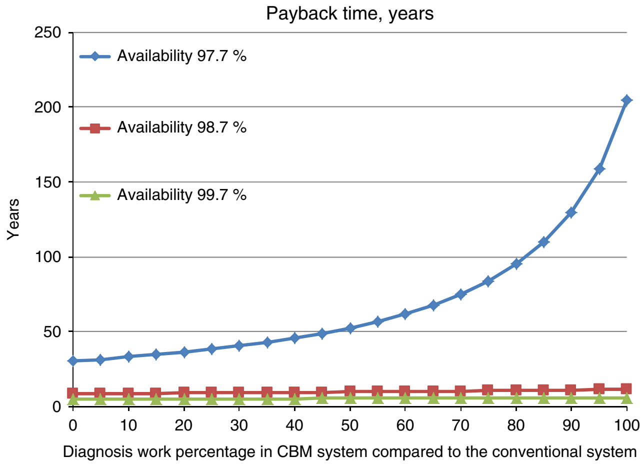

Figure 3.
Effect of CBM system diagnosis work amount on the payback time

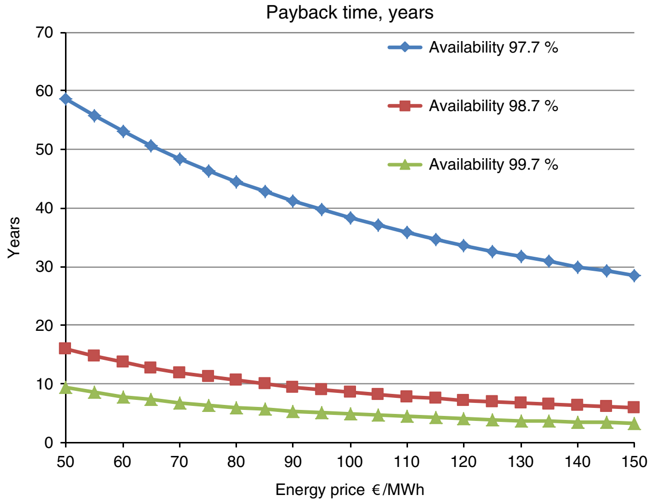

Figure 4.
Effect of energy price on the payback time

The intersection point of the lines of inflows and outflows indicates the break-even point. In this case it is 98.9 percent.

2.2 Fleet management

In this chapter a fleet management system for a trucking company is presented and the decision support system is applied. In the calculations different costs of the conventional system and the fleet management system are presented and compared piece by piece. The difference of those costs is savings and that provides the justification to undertake the investment. All the savings are eventually based on the availability of data collected real-time from the trucks.

A fleet management system provides a means to manage a fleet of trucks using specialized software and hardware. In a typical solution, there may be a tracker device

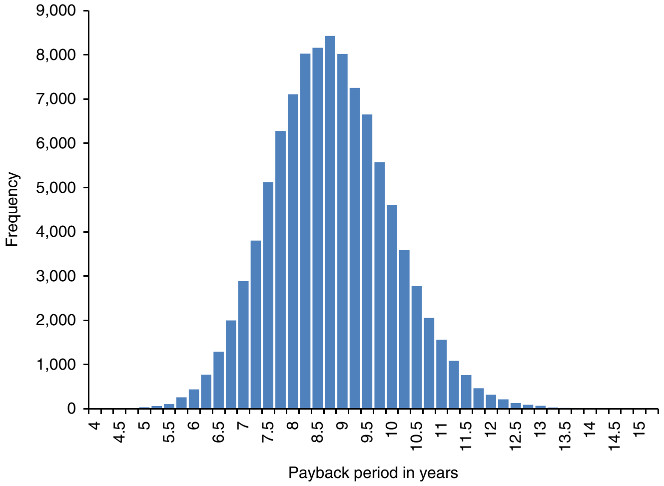

Figure 5. Distribution of the payback periods in the Monte Carlo simulation

mounted on the vehicle being tracked. The tracker contains GPS receiver, General Packet Radio Service modem, a microcontroller and a local memory for storage of position, time, speed and telemetry data. The tracker device sends the data periodically or on request via wireless communication network to the control center's server. There the data are stored and processed within a database system and application components (Stojanović *et al.*, 2009).

The system provides numerous benefits to its users. Optimization of fuel costs is more and more important nowadays as the price of fuel is getting higher and higher. Fleet management system saving fuel, for example, as it enables finding very easily the closest vehicle to provide transport service from a specific location to another. Fuel saving can be achieved also with better route planning. The routes can be programmed and it can be ensured with the system that the drivers do not deviate from the authorized routes as the entire movement history can be looked afterwards. The routes and the fuel consumptions can be compared and the driver can be instructed if it turns out that a certain driver causes significantly larger fuel costs than others. The labor costs can be also reduced as the idle time can be minimized by better planning according to the data that the system provides. This also helps verify that drivers have met expected appointments and service calls. The unauthorized vehicle use can be reduced as use of take-home vehicles can be monitored. The system may even lower insurance rates as it can be accurately documented where all vehicles are at all times. With this information, it is possible to reject frivolous property damage claims (Rodin, 1993; Alvarez *et al.*, 2008; iTrak, 2012; Telogis, 2012).

According to the benefits discussed above, it can be noticed that the system would be useful for all managers involved in transport planning and scheduling, financial managers and also supervisors that have responsibilities in human resource management. In order to illustrate the benefits mentioned in practice, a trucking company is randomly selected for more careful investigation. It is assumed that Werner Enterprises trucking company in the USA starts to use a fleet management system. It is assumed that the system lifetime is $lt = 20$ years. The number of trucks in the Werner Enterprises in the end of 2010 was $n_{trucks} = 7{,}275$ (Business Wire, 2012). The charging of the system use is based on the number of users of the system there are in a month.

In order to determine the costs per month, the monthly fee has to be decided. It is assumed that it is $C_{month} = €20$ per user per month. In the following a cost-benefit analysis concerning to the whole investment is conducted. The conventional system concept refers to the system without a fleet management system.

(1) Investment costs:

- *Purchase of equipment*
  The trucking company has to purchase a terminal device to each truck. It is assumed the price of one device is $C_{dev} = €500$. Thereby, the total equipment purchase costs are:

$$C_{eq} = C_{dev} \times n_{trucks}$$

- Installation costs
  It is estimated that installation of a terminal device into a truck takes four hours so $n_{inst} = 4$. The price of one man hour is $C_{man} = €50$. Therefore, the installation costs are:

$$C_{inst} = n_{inst} \times C_{man} \times n_{trucks}$$

- Training

  In order to enable successful use of the fleet management system, the users have to be provided with some training. It is assumed that each user is provided with two working days of training and each user uses four days on average for his/her own working time to learn to use the system. Therefore, the amount of hours used in training, $n_t = 8 \times 6 = 48$. The assumption is that one hour of work costs $c_h = €50$. Thereby, the total cost of training per office employee is:

$$C_t = n_t \times c_h$$

  The production losses of office employees during the training are excluded in the calculations. According to TruckFLIX, there are total of 1,406 officers, supervisors, administrative and clerical employees at Werner Enterprises (TruckFLIX, 2012). It is assumed that almost all supervisors and half of the officers use the fleet management system. The estimated number of users is $n_u = 400$.
  In addition, it is estimated that the truck drivers and helpers also need two days on training to use the terminal device installed to the truck. They also use about one day of working time for training on their own. The total driver and helper training time is $n_{t,dh} = 8 \times 3 = 24$ hours. According to TruckFLIX, there are total of $n_{dh} = 10{,}003$ drivers and helpers at Werner Enterprises (TruckFLIX, 2012). The assumption is that one hour of driver or helper work costs $c_{h,dh} = €40$. In addition, as the truck is not on the road during the training, losses are gained from that time. It is assumed that a lost hour costs $c_{lh} = €80$ for the company. The cost of a driver or helper training can be calculated using equation:

$$C_{t,dh} = n_{t,dh} \times \left(c_{h,dh} + c_{lh}\right)$$

Therefore, the total training costs in the company are:

$$C_{t,tot} = n_u \times C_t + n_{dh} \times C_{t,\,dh}$$

The total investment costs are:

$$C_{inv,tot} = C_{eq} + C_{inst} + C_{t,tot}$$

(2) The annual fuel costs in the conventional system:
In order to calculate the annual fuel costs, few variables have to be found out. According to Business Wire, the average number of miles each Werner Enterprises truck is driven in a month is 9,970 that is $s_{month} = 16{,}042$ kilometers (Business Wire, 2012). The fuel consumption of a truck is dependent on the load, speed and other factors. The consumption typically varies between 34-41 liters per 100 km (Natural Resources Canada, 2005). Therefore, an average consumption of 35 liters per 100 km can be assumed, that is, $c = 0.35$ l/km. The average diesel price per gallon on 27 February 2012 in the USA was \$4.051 (*Journal of Commerce*, 2012). That is: $C_1 = \frac{3.07}{3.7854} = 0.811€/l$ using exchange rates on March 2, 2012.The total fuel costs of a truck per year can be calculated using equation:

$$C_{fuel,conv} = 12 \times s_{month} \times c \times C_l = €54{,}642$$

(3) The annual fuel costs with fleet management solution
As mentioned, the fleet management solution enables finding the closest vehicle more easily, better route planning, and instructing drivers to drive more economically and reduction of idle time. It has been notified that by using objective data from fleet management system and personalized coaching, a mean diminution on fuel consumption on short-term period can be 13.6 and 6 percent on long term (Delehaye *et al.*, 2007). In order to avoid being too optimistic about reduction on fuel consumption, it is assumed that four percent in fuel costs per year are saved. Therefore, fuel saving coefficient $c_{fs} = 0.04$. The equation to calculate the total fuel costs of a truck per year can be calculated using equation:

$$C_{fuel,fleet} = 12 \times s_{month} \times (1 - c_{fs}) \times c \times C_1 = €51{,}910$$

(4) Annual maintenance costs with fleet management solution:

- *Equipment costs*
  The estimation of the lifetime for the terminal device was $lt_{td} = 4$ years. Therefore, the terminal device has to be replaced $n_{rep} = 5$ times during the system lifetime in average. The total equipment maintenance costs during the system lifetime are:

$$C_{eq,maintenance} = n_{rep} \times C_{dev}$$

- *Maintenance labor costs*
  The terminal device replacements and other diagnosis work due to coincidental faults in the system in other parts of the system cause some labor costs. The assumption is that the replacement of a terminal device takes $n_{rep,h} = 1$ hour. It is estimated that each truck needs $n_{fmm} = 12$ hours of fleet management maintenance-related work caused by coincidental faults during the system lifetime. This includes also the cost caused by the replacements of trucks with new ones and the installations of new trucks

with the fleet management-related devices. The price of one maintenance hour is $C_{man}=€50$. The maintenance labor costs are:

$$C_{l,\,maintenance}=n_{rep}\times n_{rep,\,h}\times C_{man}+n_{fmm}\times C_{man}$$

- Production losses during maintenance

  As the truck is not on the road during the maintenance, it causes production losses. It is assumed that a lost hour costs $C_{lh}=€80$ for the company. The equation to calculate production losses is:

$$C_{pl}=n_{rep}\times n_{rep,\,h}\times C_{lh}+n_{fmm}\times C_{lh}$$

The total maintenance costs during the system lifetime per truck are:

$$C_{maintenance}=C_{eq,\,maintenance}+C_{l,\,maintenance}+C_{pl}$$

The costs for one year are:

$$C_{maintenance,year}=\frac{C_{maintenance}}{lt}$$

(5) Return calculation:

The costs due to the use of the fleet management system per year can be calculated using equation:

$$C_{fm}=n_u\times C_{month}$$

The difference between the fuel costs per truck in the conventional system and the fleet management system in a year:

$$\Delta C_{fuel}=C_{fuel,conv}-C_{fuel,fleet}$$

In addition, data transfer from truck terminal device to server causes some costs. It is assumed that the data transfer cost per month is four euros so per year it is $C_{dt}=€48$. Thereby, the income per year is:

$$I=n_{trucks}\times\left(\Delta C_{fuel}-C_{maintenance,year}-C_{dt}\right)-C_{fm}$$

From the general payback equation a simple payback period can be formulated in the following way:

$$\text{payback period}=\frac{C_{inv,\,tot}}{I}$$

When the calculations are performed, it results payback period of 2.5 years.

ROI of the investment can be calculated using the equation:

$$ROI=\frac{I}{C_{inv}}\times 100\%=39.4\%$$

In this case, the discount rate is calculated by dividing the net income by total assets. According to Business Wire, the net income of Warner Enterprises in 2010 was

$80,039,000 and total assets were $1,151,552,000 (Business Wire, 2012). The division produces $ROI = 7.0$ percent.

The ROI of the fleet management investment is greatly higher than the company's ROI. Therefore, the investment to the fleet management system is very eligible. In addition to ROI, the eligibility of the investment is evaluated using NPV. The result from the NPV calculation is €110,726,415, that is greatly larger than 0. Horngren *et al.* state that only investments with zero or positive NPV are acceptable (Horngren *et al.*, 2007, p. 727). Thereby the investment is very eligible also from NPV point of view.

The third method for evaluating the eligibility of the investment is IRR. The calculated IRR is 39 percent. According to Brealey *et al.* (2011) the IRR rule states that an investment should be accepted if its IRR is greater than discount rate (p. 137). As the calculated IRR was 39 percent, that is more than ROI of Werner Enterprises, the investment is noticed to be eligible.

In order to assess the effect of fluctuations in different variables on the payback time, sensitivity analysis is conducted with truck kilometers per month, fuel savings per month and fuel consumption per kilometer. Each variable is analyzed separately in the following figures. In Figure 6, the effect of truck kilometers per month on the payback time is shown with three different assumed fuel saving percentages. As it can be seen, the fuel saving has a dominant effect on the payback time. If the savings are low, the payback time is very long. In that case, the truck kilometers have significant effect on the payback time. On the other hand, if fuel savings are at least few percent per month its effect on the payback time is lower.

In Figure 7, the effect of fuel saving percentage is shown. The same phenomenon as in Figure 6 can be seen in this case. The fuel price has a crucial effect on the payback time. As fuel saving increases from 1 to 3 percent, payback time is shortened substantially. When fuel savings are more than 3 percent, fuel saving effect is reduced, but it is still significant. The fuel price does not have that significant effect on the payback time. In Figure 8, the effect of fuel consumption on the payback time is shown. In this case it can be noticed again that fuel saving is the major factor. For the investment payback time, fuel saving has a vital role. Fuel consumption has only a minor effect.

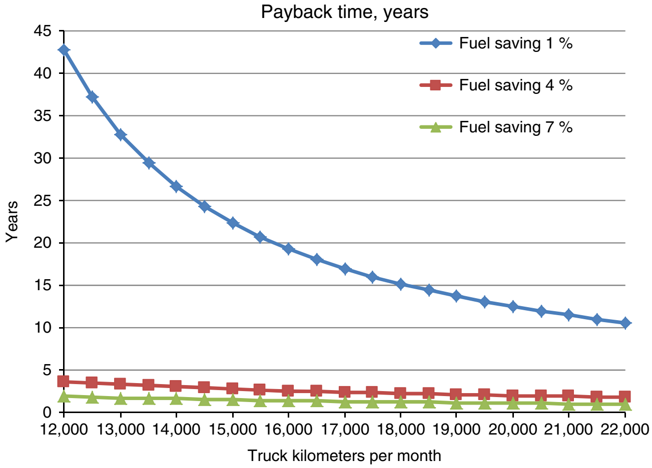

Figure 6.
Truck kilometers per month effect on the payback time

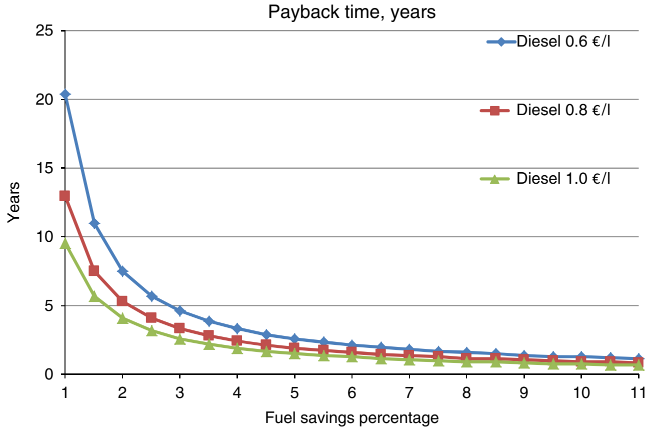

Figure 7.
Fuel savings percentage effect on the payback time

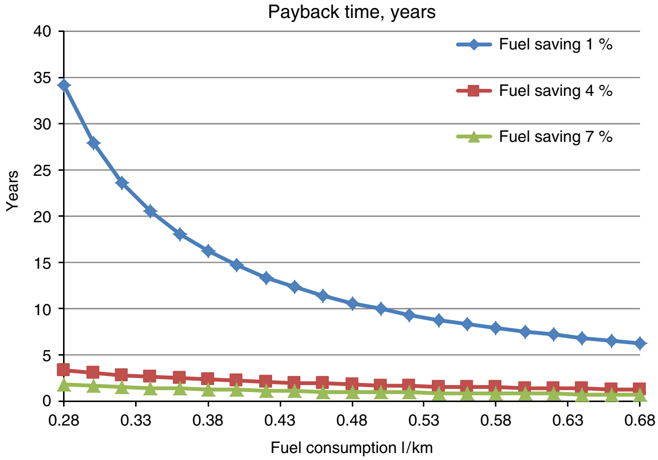

Figure 8.
Fuel consumption effect on the payback time

Monte Carlo simulation is also performed by using the same variables as in the sensitivity analysis to figure out the entire distribution of the payback periods. The values of the variables are changed according to the Normal distribution by using the value that was used in the described basic calculations as midpoint. The results of the Monte Carlo simulation are shown in Figure 9. It can be seen that the calculated payback period matches very well with the highest number of the payback periods in the graph. It also indicates that the probability of a longer payback period is very low.

It is also necessary to find out many trucks have to be connected to the fleet management system in order to amortize the total costs. Therefore, a break-even analysis is conducted. In order to find out the number of trucks, the present value of inflows and outflows is calculated under different assumptions about number of trucks. Based on the calculated values, equations of the lines of present value of inflows and outflows can be composed. Using these equations, the accurate break-even point can solved algebraically. The intersection point of the lines of inflows and outflows indicates the break-even point. In this case it is 1,583 trucks.

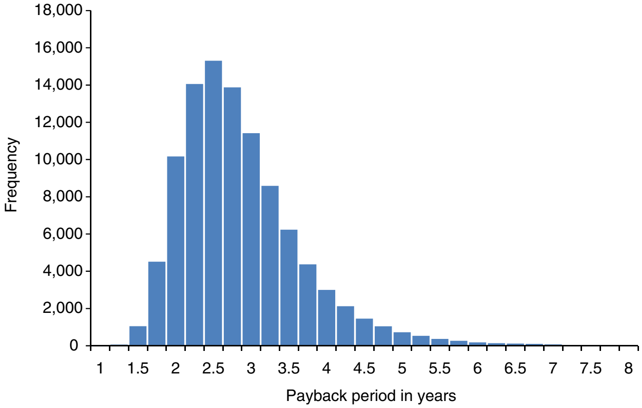

Figure 9. Distribution of the payback periods in the Monte Carlo simulation

2.3 Summary

In this chapter the common factors of the two presented cases are summed up and analysis is discussed. Table I summarizes the most important figures of the presented cases.

The payback time in the CBM case is more than a reasonable one. The reason for this long payback time is mainly caused by high equipment costs needed in the CBM solution. Another reason is the relatively low production per wind turbine in a year. According to NPV and IRR the investment should be undertaken. However, both NPV and IRR are only slightly over the investment acceptance level. In some cases NPV and IRR may give contradictory results whether to accept or reject the investment. If NPV indicates that the investment should be rejected and IRR indicates opposite, IRR should be preferred in decision making (DeFusco *et al.*, 2007, p. 45).

The availability percentage of the wind farm has a major effect on the NPV. It is also a very uncertain factor in spite of the benefits the CBM solution can provide. Minor reduction in availability percentage will turn the investment unprofitable. This is a risk but as there is no evidence against undertaking the investment and as ROI, NPV and IRR indicate acceptance, the investment is worth undertaking. In addition, as the payback period distribution in the Monte Carlo analysis is slightly weighed to the left,

	CBM	Fleet management
Payback time	8.6 years	2.5 years
ROI (%)	11.6	39.4
NPV	€4,033	€110,726,415
IRR (%)	10	39
Discount rate (%)	9.5	7.0
The significant factors on payback time according to sensitivity analysis	Availability percentage of the wind farm	Fuel saving percentage and fuel price
Break-even point	Availability percentage 98.9	1,583 trucks
Terminal device features	Collects production, status and information on environmental conditions and sends them to server	Collects fuel consumption, position data, etc., and sends them to server
Terminal device price	€300	€500

Table I. Summary of the main figures in the cases it also indicates that the investment should be accepted. The break-even point in terms of availability percentage is very high. It is even higher than the assumed percentage that is achievable with the CBM system.

The payback time of the fleet management solution for the trucking company is definitely acceptable. Also ROI, NPV and IRR strongly indicate that the investment should be undertaken. The discount rate is relatively low, but still there is a lot of buffer before the investment becomes worth rejecting. Although there are several uncertain factors such as the number of fleet management system users and the amount of hours needed to train the employees to use it, they have only a minor effect on the payback time. As the sensitivity analysis indicates, fuel saving percentage is the only variable that has a major effect on the payback time. The payback period distribution in the Monte Carlo analysis is well balanced with the calculated payback period and indicates mostly relatively short payback period. Based on these facts, the investment is definitely worth undertaking. The break-even point in terms of number of trucks connected to the fleet management system is very reasonable.

3. Conclusions

In this study a decision support system was created to facilitate the assessment of business impacts of different M2M investments and projects. In order to deepen the practical understanding of the decision support system, it was applied to two M2M cases with a detailed cost-benefit analysis including the use of several investment decision methods.

In the cases it was noticed that an investment to a M2M system is not automatically profitable for a company. For example, the eligibility of CBM investment is heavily dependent on the wind farm availability percentage. All the financial metrics indicate that the investment should be undertaken, even though the payback period is relatively long. A reason for this contradiction is the discount rate. With a few percent higher discount rate, NPV and IRR would turn the investment totally ineligible. From these points of view, this investment seems risky. However, as the wind energy becomes more and more favored due to its renewability and environment-friendliness, more and more wind turbines and remote monitoring and analysis systems are produced. This enables reduction of prices and facilitates the investments to the wind farm CBM systems.

As the sensitivity analysis in fleet management case indicated, definitely the most significant factor for the investment profitability is fuel saving. For example, if fuel saving is only 1 percent and the average kilometers per truck in a month are slightly lower than average, the payback time can be over 40 years. However, as research proves, there is potential for even larger fuel savings than assumed in this case and thereby a shorter payback time for the investment.

Another potential risk is a combination of low fuel price and low fuel saving. In the worst case, this could raise the payback time close to 45 years. This case will not be very likely as there is rising trend in fuel price. The third risk realizes if the fuel consumption per kilometer decreases significantly from the expected and fuel saving is only close to 1 percent. The fuel consumption per truck is likely to decrease during the forthcoming years as there is growing pressure toward environmental issues. The automotive manufacturers are pushed to develop fuel-efficient engines. On the other hand, this risk is not assumable as the effect of the fuel consumption is dramatically decreased when the fuel saving percentage is at least few percent. For example, with fuel saving of 4 percent, the payback time is less than five years even with low fuel consumption.

The created decision support system is a comprehensive tool for any manager involved in investment planning. The system contains several methods which can be used to assess the eligibility and profitability of an investment. The system was tested with two practical cases from different M2M domains and no large weaknesses were found. The methods are easy to use and the data needed in calculations are relatively easy to collect. However, there is no system that provides the understanding of the application domain. The user of the decision support system still has to be familiar with the most important factors that affect the results that the methods in the system produce.

Some factors concerning to the validity of the results can be designated. In the decision support system, payback period and ROI calculations do not take the time value of money into account and may produce slightly more optimistic values compared to the situation in which the time value of money is taken into account. However, the other methods contain the time value of money in the calculations and thereby make the overall judgment from the decision support system more realistic.

Even though a lot of effort and concentration was put in this study, there are still a lot of opportunities left for further research. All the presented cases are based on material from scientific articles, web-pages of numerous companies, books and the writer's own understanding. Much more additional understanding and expertise could be gained by interviewing managers and staff from companies in different M2M domains. The most reliable insights to the prominent factors in different businesses can be obtained only by working several years in the business in practice. In addition, the research could be extended to entirely new area to cover also the eligibility and profitability of service provider investments.

References

Alvarez, J.A., Fernandez-Montes, A., Moreno, J., Ortega, J.A., Gonzalez-Abril, L. and Velasco, F. (2008), "Delivery improvement for transport companies", *Composition-Based Software Systems, Seventh International Conference in Madrid, February 25-29*, pp. 217-219.

Asif, S.Z. (2011), *Next Generation Mobile Communications Ecosystem: Technology Management for Mobile Communications*, John Wiley & Sons Ltd, Chichester.

Berk, J. and DeMarzo, P. (2011), *Corporate Finance: The Core*, 2nd ed., Pearson Education Limited, Harlow.

Business Wire (2012), "Werner enterprises reports fourth quarter and annual 2010 revenues and earnings", available at: www.businesswire.com/news/home/20110126006835/en/Werner-Enterprises-Reports-Fourth-Quarter-Annual-2010 (accessed March 3, 2012).

Brealey, R., Myers, S. and Allen, F. (2011), *Principles of Corporate Finance*, 10th ed., McGraw-Hill/Irwin, New York, NY.

DeFusco, R.A., McLeavey, D.W., Pinto, J.E. and Runkle, D.E. (2007), *Quantitative Investment Analysis*, 2nd ed., John Wiley & Sonc Inc., Hoboken, NJ.

Delehaye, M., Hubaux, D., Guedria, L., Legat, J.D., Delvaulx, T. and Goffard, B. (2007), "Smart adaptable network device for fleet management and driver coaching", *Telecommunications, 2007. ITST '07. 7th International Conference on ITS, Sophia Antipolis, June 6-8*, pp. 1-5.

Eaton, J.W. (2012), "GNU Octave", available at: www.gnu.org/software/octave/ (accessed April 15, 2012).

Eto, H., Matsuo, H., Kurokawa, F. and Fukuda, M. (2003), "Network of plant remote monitoring system using web for windfarms", *Telecommunications Energy Conference, 2003. INTELEC '03. The 25th International in Yokohama, October, 23-23*, pp. 857-863.

Foschini, L., Taleb, T., Corradi, A. and Bottazzi, D. (2011), "M2M-based metropolitan platform for IMS-enabled road traffic management in IoT", *IEEE Communications Magazine*, Vol. 49 No. 11, pp. 50-57.

Hau, E. (2006), *Wind Turbines: Fundamentals, Technologies, Application, Economics*, 2nd ed., Springer-Verlag, Berlin.

Horngren, C., Datar, S. and Foster, G. (2007), *Cost Accounting*, 12th ed., Pearson Education Inc., Upper Saddle River, NJ.

iTrak (2012), "iTRAK GPS wireless vehicle tracking system", available at: www.itrak.com/EN/index.html (accessed January 29, 2012).

Journal of Commerce (2012), "US diesel prices", available at: www.joc.com/economy/numbers-us-diesel-prices (accessed March 3, 2012).

Krug, F., Rasmussen, J.R., Bauer, R.F., Lemieux, D., Schram, C. and Ahmann, U. (2004), "Wind turbine/generator drivetrain condition based monitoring", available at: www.2004ewec.info/files/25_1100_floriankrug_01.pps (accessed February 28, 2012).

Lu, R., Li, X., Liang, X., Shen, X. and Lin, X. (2011), "GRS: the green, reliability, and security of emerging machine to machine communications", *IEEE Communications Magazine*, Vol. 49 No. 4, pp. 28-35.

Lucero, S. (2010), "Maximizing mobile operator opportunities in M2M: the benefits of an M2M-optimized network", available at: www.cisco.com/en/US/solutions/collateral/ns341/ns523/ABI-CISCO_M2M_Operator_Opportunity.pdf (accessed March 17, 2012).

Natural Resources Canada (2005), "Canadian Vehicle Survey 2005, summary report", available at: http://oee.nrcan.gc.ca/Publications/statistics/cvs05/appendix-a.cfm?graph = 24&attr = 0 (accessed March 3, 2012).

Nilsson, J. and Bertling, L. (2007), "Maintenance management of wind power systems using condition monitoring systems life cycle cost analysis for two case studies", *IEEE Transactions on Energy Conversion*, Vol. 22 No.1, pp. 223-229.

Orosa, J., Oliveira, A.C. and Costa, A. (2010), "New procedure for wind farm maintenance", *Industrial Management & Data Systems*, Vol. 110 No. 6, pp. 861-882.

Rodin, C. (1993), "EUTELTRACS: an innovative system for a changing industry", *Vehicle Location and Fleet Management Systems, IEE Colloquium*, IET, London, pp. 6/1-611, available at: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=243279&sortType%3Dasc_p_Sequence%26filter%3DAND%28p_IS_Number%3A6258%29

Schwanzer, G. (2013), "Getting more from wind turbines with condition monitoring systems", available at: www.renewableenergyworld.com/rea/news/article/2013/04/getting-more-from-wind-turbines-with-condition-monitoring-systems (accessed July 26, 2013).

Steklac, I. and Tram, H. (2005), "How to maximize the benefits of AMR enterprise-wide", *Rural Electric Power Conference, May, 8-10*, pp. C5/1-C5/7.

Stojanović, D., Predić, B., Antolović, I. and Đorđević-Kajan, S. (2009), "Web information system for transport telematics and fleet management", *Telecommunication in Modern Satellite, Cable, and Broadcasting Services, 2009. TELSIKS '09. 9th International Conference in Nis, October 7-9*, pp. 314-317.

Telogis (2012), "Telogis fleet. More than vehicle tracking", available at: www.telogis.com/solutions/fleet/ (accessed January 30, 2012).

The Wind Power (2013), "Vapon Tuulivoima Oy", available at: www.thewindpower.net/operator_en_103_vapon-tuulivoima-oy.php (accessed July 26, 2013).

TruckFLIX (2012), "Werner Enterprises Inc.", available at: www.truckflix.com/companies3/werner-enterprises.php (accessed March 4, 2012).

Vaasan Sähkö (2011), "Hinnat oma verkkoalue", available at: www.vaasansahko.fi/template_2006.asp?sua = 6&lang = 1&s = 402 (accessed February 15, 2012).

Vapo Group (2011), "Vapo vuosikertomus 2010", available at: www.vapo.fi/filebank/5213-vuosikertomus_2010_suomi.pdf (accessed February 2, 2012).

Vapo Group (2012), "VAPO", available at: www.vapo.fi/eng/main_page/?id = 563 (accessed February 29, 2012).

Verbruggen, T.W. (2003), "Wind turbine operation and maintenance based on condition monitoring WT-Ω – Final Report", available at: ftp://ecn.nl/pub/www/library/report/2003/c03047.pdf (accessed February 28, 2012).

Wiggelinkhuizen, E.J., Braam, H., Xiang, J., Watson, S., Giebel, G., Norton, E., Tipluica, M.C., Christensen, A.J., Becker, E. and Scheffler, D. (2007), "CONMOW – condition monitoring for offshore wind farms", *European Wind Energy Conference 2007 in Milan, May 7-10*, ECN Wind Energy, Petten.

Yang, W., Tavner, P.J., Crabtree, C.J. and Wilkinson, M. (2010), "Cost-effective condition monitoring for wind turbines", *Industrial Electronics, IEEE Transactions,* Vol. 57 No. 1, pp. 263-271.

Zhigang, T. and Tongdan, J. (2011), "Maintenance of wind turbine systems under continuous monitoring", *Reliability and Maintainability Symposium (RAMS), 2011 Proceedings – Annual in Lake Buena, Vista, FL, January 24-27*, pp. 1-6.

About the author

Tuomo Heikkilä is a Team Manager at the Wapice Ltd, Vaasa, Finland. He received his Master of Science Degree in Computer Science from the University of Helsinki, Finland in 2006 and Master of Science Degree in the Economics from the University of Vaasa, Finland in 2012. He has more than 15 years of experience from software industry. Tuomo Heikkilä can be contacted at: tpheikki@gmail.com