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Autonomous Equipment in the Public City Setting - An Economic Consideration

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Summary

Autonomous systems seem to be the future in various domains. Actually, nobody knows if it is a suitable solution for city cleaning. The economic consideration gives approach to calculate the total cost of ownership of a cleaning system, shows a first implementation and first results. Final and detailed results will be available at the EVS30. Secondary it focuses on the additional requirements for an autonomous city cleaning system and suggests how to deal with some of them.

Keywords: autonomous, case-study, infrastructure, state government

1 Motivation

Autonomous systems is a topic that is on everyone's lips – from intelligent homes and self-optimizing factories to automatic driving vehicles in different settings. In agricultural engineering, for example, autonomous driving machines are already being used on the land, while autonomous passenger cars are still some years off as there are obviously more challenging traffic situations and legal hurdles that must be heeded. The combination of autonomous participation in street traffic and the autonomous performance of tasks in the public urban environment therefore poses a particular challenge. Nevertheless, this combination also bears enormous economic opportunities for the sustainability of community management.

Actually, nobody knows exactly which autonomous system and which level of autonomy will lead to success in the context of public city cleaning. Therefore, a consortium of different stakeholders decided to consider the economic side of the challenge. The consortium consists of: the city of Karlsruhe and its communal business development division, the automotive engineering network (AEN), ITK Engineering GmbH and the University of Karlsruhe. This work is described in the following chapters.

2 Levels of autonomy for street cleaners

2.1 Categories of autonomy for autonomous working systems

Autonomous work systems can approximately be categorized according to two main factors:

- Kind of tasks the system must fulfil
- The work environment for the autonomous working system

The kind of tasks can be classified into systems which get defined tasks at the time of development. These systems can only carry out these predefined tasks. The other type of systems are able to carry out tasks assigned to the system during operation. These systems are quite more flexible but also more complex to design and operate.

The second factor is the work environment. Here it is fundamental to distinguish between the usage of the system in a protected or a public area. Another constraint that must be considered is if the operating environment is static and known at the time of development or dynamic and unknown when the system is developed.

2.2 Levels of autonomy for city cleaning systems

These two factors can be adapted to the special task city cleaning system or street cleaners. Fig. 1 shows four levels which can be used to describe the level of autonomy of a city cleaning system. Some more characteristics are listed and taken into consideration.

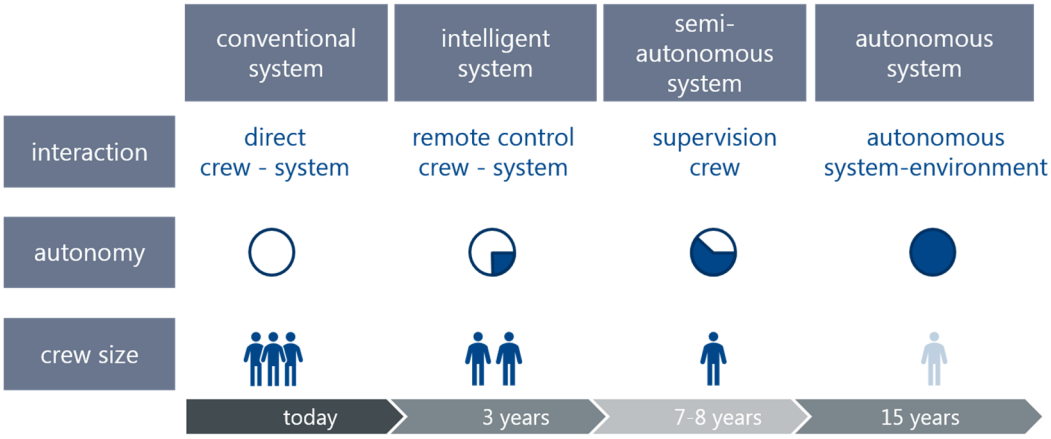

Figure1: Levels of autonomy for city cleaning systems

These levels can be mapped to actual or future systems:

- Conventional systems – systems that are state of the art now, e.g. a street cleaner with one driver and two additional persons walking behind it and doing the work the machine isn't able to do with brooms.
- Intelligent systems – systems that would extend the state of the art by using a remote control for the street cleaner. This would offer the possibility to reduce the crew of a city cleaning system without adding to much intelligence or autonomy into a street cleaner. Although this solution seems to be very easy and cheap it isn't available right now.
- Semi-autonomous systems – systems that are able to carry out tasks in a specified and protected area. The functionality of these systems can be compared to the actual available automatic vacuum cleaners or lawn mowers. On scenario would be to bring such a semi-autonomous system to a large fairground and let it clean automatically only under supervision of one worker.
- Autonomous systems – systems that are able to go autonomous to the place to clean and do the job without any help of a worker. Only supervision by specialized stuff is needed.

Besides the autonomy levels the work environment of city cleaning systems is another important factor. Here we can distinguish between blocked-off areas like huge fairgrounds or big public spaces and public areas like pedestrian zones where the cleaning systems have to interact with much more objects.

This shows that a large number of variations of city cleaning systems is possible and it isn't clear which will be the future system solving all requirements.

3 Economic Consideration

The strongest argument for switching from conventional to semi-autonomous or autonomous city cleaning systems is a reduction in the total cost of ownership. Because of that reason an economic consideration for some variants of cleaning systems is made. The big questions it should address are: Are the expected savings in operating costs for a municipality justified for the development of the needed autonomous work equipment through the manufacturer?

Since a calculation of all variants would be complex and time-consuming the consideration is restricted to the following variants and frame conditions:

- Only one working area with an area of 50.000 m²
- Two levels of autonomy:
  - semi-autonomous systems
  - autonomous systems
- Two periods under consideration
  - medium term (state in 7-8 years)
  - long term (state in 15 years)

The economic consideration tries to deal with most of the known parameters influencing the total cost of ownership of a city cleaning system. All factors are matched to different parameters in the calculations. The study uses the five big factors which can be seen in Fig. 2.

The economic factor includes all costs and developments which are associated with the operating of the system (e.g. operating supplies, oil, gas, labour costs,….), the purchasing and running costs like taxes and insurances. The climatic development, the pollution of the environment and the ecological awareness of the people are the main inputs for the factor ecological factor. One example is the change in mind of the people regarding the use of paper cups for coffee to go. Some cities and many single persons decided to use reusable cups or bring their own cup to get a coffee to go. This shows a change in mind and is a good example for a factor the influences the costs of operating a cleaning system. Another factor is the trend of the technological costs for the next years. It is probably that the costs for the technologies used in autonomous vehicles will reduce in the next years. This is a factor that decreases the investment and helps the autonomous systems to get in the lead. The social factors are more soft factors like the demographic change of the human population, the urban development and the acceptance of autonomous systems. Last but not least it is important to consider factors like permissions and liability. These factors can push or stop projects with the objective autonomous systems very easy with one new law.

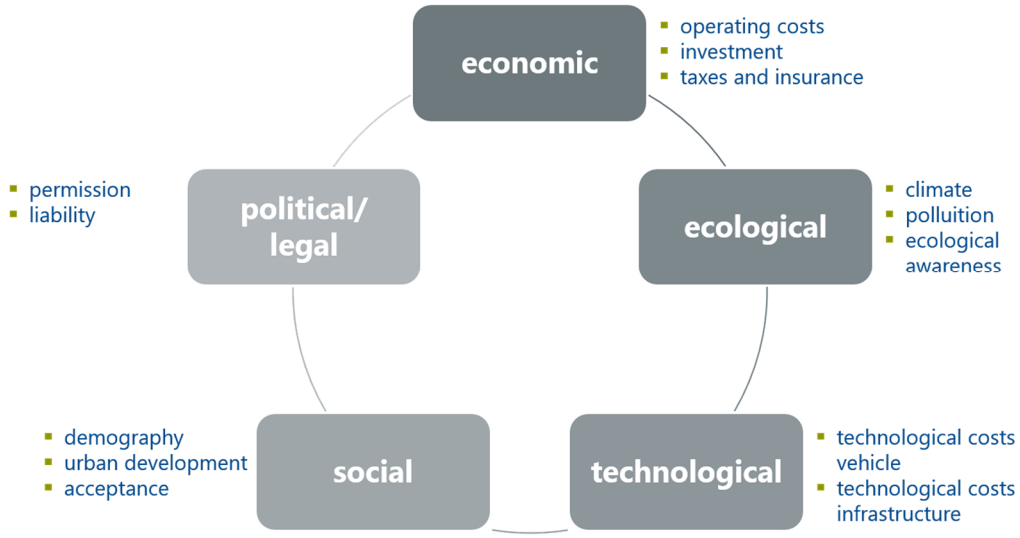

Figure2: Factors in the economic consideration

All of these factors can vary in a special bandwidth, which would lead to thousands of permutations. To get to a result a subset of three scenarios for the future is fixed. The scenarios are called: positive, trend and negative scenario.

In Fig. 3 the three future scenarios are shown. The trend scenario shows the development of the factors for an extrapolation of the actual trends and the mindset of the people. The negative and positive scenarios show the extreme values of all factors in their direction. With these three scenarios, it is possible to predict the actually assumed trend and both the positive and the negative border of the economic consideration.

The calculation needed for the consideration was implemented using a spreadsheet analysis and first results have been produced. These first calculations give a first hint that a change in the operating costs has the biggest influence while many other factors have only a very little influence. Another first result is that autonomous systems seem to have huge advantages against all other systems with the objective of total cost of ownership.

The next steps for the economic consideration are:

- calculate and compare the results for the scenarios and frame conditions mentioned above
- analysis of the sensitivity of the result relative to the single factors
- documentation of the results and precise information about the sensitivity and the total costs of ownership for each combination mentioned above

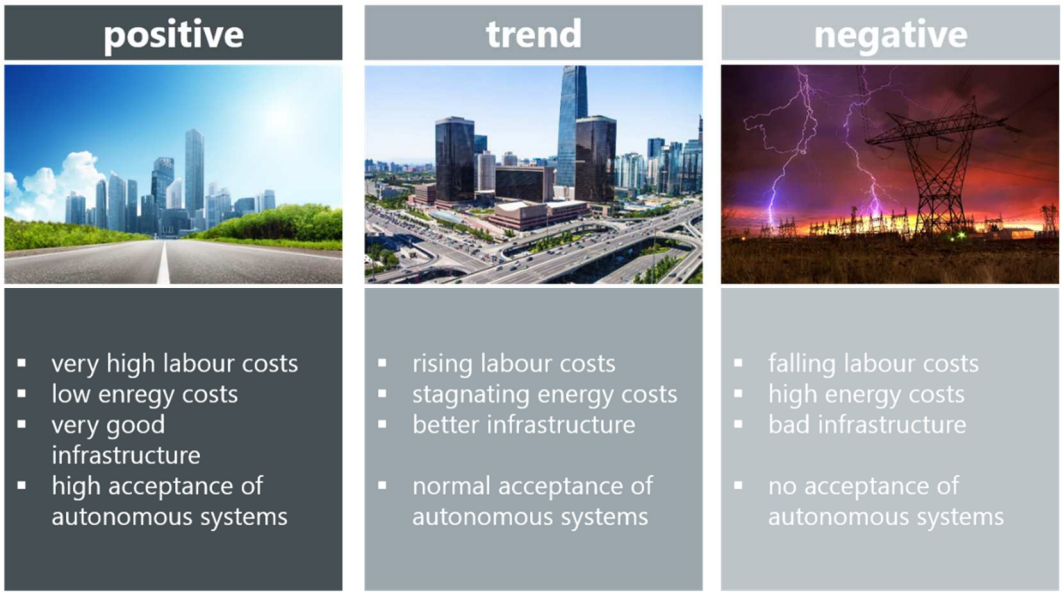

Figure3: Scenarios of the future

4 Technical Challenges and Solutions

A shown before the autonomous cleaning systems in all probability be the future of public city cleaning. Autonomous cleaning systems like a street cleaner have a big number of new requirements to deal with. Table 1 shows only the differences in the and the additional requirements for a conventional, a semi-autonomous and a fully autonomous street cleaner.

Table1: additional requirements for autonomous systems

requirement	conventional cleaning system	semi-autonomous cleaning system	autonomous cleaning system
no danger to the environment and people		+	++
Fulfilment of the tasks	+	++	++
independent route planning		++	+
recognition of the environment		+	++
interaction with operator		++	+
interaction with people			++
remote maintenance		+	++
protection against unauthorized access			++
independent planning and execution of drive to the work location			++

These additional requirements are all known in other autonomous systems too. It is possible to transfer the methods and solution used in other domains easily to the domain of autonomous cleaning systems.

One example is the avoidance of danger to environment or people. This is a topic for each autonomous system. The solution is to transfer the methods used in other domains like form autonomous floor-borne vehicles or autonomous trains. Another helpful thing is the usage of standards like the IEC61508, ISO26262, the ISO13849 or ISO25119 which all help to get safe products.

Another very critical requirement is the protection against unauthorized access. This aims to prohibit the violation of the security objectives like confidentiality, integrity, authenticity and availability. These goals are fundamental for each system that has a connection to the internet. They can be achieved by simple measures:

- only authorized operators should get access to the device
- reuse of proven in use solutions used in machine building or medical technology
- implementation of security requirements from the beginning of the development
- application of industry standards (e.g. CERT Coding guidelines, …)

These two examples show that several solution s for the additional requirements exist and can transferred to the new domain of autonomous cleaning systems.

5 Conclusion

The economic considerations shows first results and gives a good base for future development activities. They show that (semi-)autonomous city cleaning systems will be present in the future more and more, because the total cost of ownership is less than that of conventional city cleaning systems. Final and detailed results of the economic consideration are not available. They will be available on the EVS30 conference.

Autonomous city cleaning systems must face additional requirements. But based on experiences from other domains all technical requirements and risks can be identified and solutions can be transferred to create first solutions quickly.

Authors

Stephan Schreiber studied electrical engineering at the University of applied sciences in Esslingen. From 2002 to 2010 he worked in a research institution focused on control technology for machine tools, in a research institute with focus on assembly technology and a start-up with the focus on airships. Since 2011 he has been stationed at the Stuttgart branch of ITK Engineering GmbH. There he works on various projects regarding powertrain and control units in the automotive fields. Since 2014 he is team manager with a focus on processes, software quality, requirements engineering and functional safety