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Robots On the Move from the Production Line to the Service Sector: The Grand Challenges for Contractors, Workers, and Management

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Abstract: This paper presents a study on robot vacuum cleaning within the Danish public sector. Contrasting conventional images of robots as ineffective and technologically immature, we put forward the proposition that vacuum cleaning robots are at par with or better cleaning quality achieved by conventional vacuuming. Although the financial cost-benefit analysis provides inconclusive results, the case study reported here indicates that robots are mature enough to be adopted in the cleaning of the office environment. In the adoption of robots, we identify key challenges for management, contractors, and workers.

1. Introduction

The introduction of robots into the service sector provides a potential solution to a multi-faceted dilemma caused by a shrinking work force and financial deficits within the public sector. In the 1970s and 1980s, robots became part of the manufacturing landscape, raising societal concerns while creating new opportunities for individuals and organizations [1-4]. Recent advances have ushered in an era in which robots offer a real and pragmatic alternative to traditional labour for providing routinized services. The computerized devices are cost-effective and sophisticated enough to perform basic tasks. The technology advances rapidly and becomes increasingly affordable, so research at this nascent stage can provide key insights into the advantages and the challenges that will become increasingly important as robots move from the production line to the service sector.

Despite unemployment resulting from the lingering financial crisis, manpower is still in short supply because of a growing imbalance of population in which there are fewer people of working age to provide services in the economy. The economic crisis and the shrinking labor force present an immediate demand for alternatives to the traditional workforce. Additionally, as the population retires, the tax base will shrink; therefore, budget constraints will continue beyond the Great Recession. Cost-effective and ready for work, robot technology provides a solution for this dilemma. At present, the robotic vacuum cleaner offers an affordable and widely available alternative to traditional employees and it can serve as a gateway technology for the introduction of robots to the mainstream service sector.

This study offers an alternative to robotic vacuum research, which typically focuses on consumer home use rather than on use within an office context [5-8]. Office settings provide a materially different environment, offering standard surfaces, large rooms, and

established daily cleaning times. This paper provides an overview of the study setting, and details an experiment conducted to determine the effectiveness of robot vacuum cleaners. A comparison between human and robotic vacuuming follows, both looking at service quality and providing a cost-benefit analysis. In the concluding section, the paper provides a discussion of the challenges that will be faced by contractors, workers, and management.

2. Objectives

Many images of the future include robots aiding humanity by shouldering the burden of manual tasks. While experimental technology such as Honda's Asimo appear in the headlines, more practical robots are widely available for immediate use. By understanding the acceptance and use of these devices, researchers and practitioners can better understand the process by which people decide to incorporate robots into the daily routine; an understanding that will become more important as robots become more capable and can perform more diverse roles.

The objective of this paper is to explore the maturity of vacuum cleaner robots by addressing the overall question: are robotic vacuums at a maturity level where they can be adopted within an office setting? Parallel to this interest, we explore the grand challenges for management, workers and contractors related to the adoption of a new generation of cleaning devices.

3. Methodology

This study investigates public sector organizations in Denmark because of the nation's shrinking labour force, high wages, and budget shortfalls. The state occupies a notable amount of real estate; and each week requires the cleaning of approximately six million square meters of floor space. A handful of departments control the majority of real estate: 36% Defense, 21% National Research and Education Buildings, 10% Palaces and Properties Agency, and 5% Prison Services [9]. The public sector in Denmark spends billions of kroner annually cleaning government facilities. Denmark spends over 1 billion kroner (€134 million) to clean hospitals alone.

Table 1: Floor area and estimated time consumption

Government area	*Area (m²)*	*Estimated time consumption on manual vacuum cleaning/week*
The Defence	2.2 mill.	22,000 hours
National Research and Education buildings	1.3 mill.	13,000 hours
Palaces and Properties Agency	0.6 mill.	6,000 hours
Detention facilities	0.3 mill.	3,000 hours
Other	1.6 mill.	16,000 hours
Total	6 mill.	60,000 hours

Source: National Audit Office (2005)

Our study was conducted in a government-owned education institution in Copenhagen. The test area consists of two floors. We conducted a controlled experiment in which current cleaning crew used a conventional vacuum cleaner on one floor and the other floor was cleaned with robot vacuums. Both floors contain a large open office area and a number of smaller offices in two different sizes. An internal staircase joins the second and third floor, and another staircase joins the third floor with a different department on the fourth floor. Each floor has two external entrances, one at each end that open to stairwells and elevators.

Employees enter the floors using key cards that register when they enter the floor. There is no record of who leaves the office and no direct data about how long individuals have been there. The internal staircases between the floors enable undocumented movement between floors. While all activity cannot be measured, it is reasonably assumed only that there is a certain relationship between the number of passengers entering a floor from outside and the collected amount of dust on the floor.

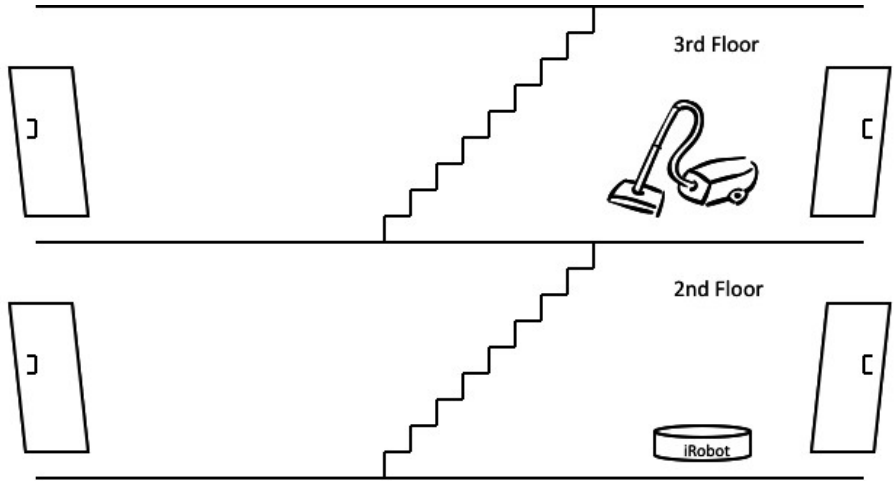

Figure 1: Sketch of the office experiment setting: test and control areas

We analyzed logs from the entrance doors that require access cards in order to account and possibly adjust for any differences in traffic on the two floors. While steps were taken to control for measurable variables, such as the number of security swipes at the doors (see table 2), we could not account for all environmental variables that could impact the area to be cleaned.

Table 2: Personnel traffic on the test and control areas, spring and fall 2009

Number of log-ins with card reader at entry door	Robot test area		Conventional vacuuming (control area)	
	Spring	Fall	Spring	Fall
People with office in the test floor	377 (13 unique)	164 (9 unique)	418 (13 unique)	433 (13 unique)
People from other floor	33 (6 unique)	47 (8 unique)	78 (12 unique)	12 (7 unique)
External visitors	23 (9 unique)	8 (3 unique)	56 (12 unique)	33 (7 unique)
Cleaning company personnel	11	16	15	32
Total / sum	453 (29 unique)	235 (21 unique)	567 (38 unique)	497 (28 unique)

As for electricity consumption, we measured the power consumption of the conventional vacuum cleaner by measuring a 20-minute vacuuming process. As for the robots, we monitored the use of power throughout the process. This different electricity monitoring was used because several times during a cleaning shift the robotic vacuum cleaners return to their docks for recharging. We assumed that the charging station continuously uses electricity because an LED remains illuminated when the robot is performing work. Cleaning quality was measured by weighing the quantity of collected dust and dirt. A new vacuum bag was placed in the person-operated machine at the beginning of the experiment.

The study measured labor hours required for both standard vacuuming and for servicing the robots. Maintaining the robot vacuums included emptying the vacuum bags, manually resetting the machines, and performing scheduled maintenance as recommended by the manufacturer. In addition, manufacturer representatives answered queries about total cost of ownership, providing statistics on battery and engine lifecycles. Data and information about the cleaning employees (prices, time, contracts, etc.) were gathered from the campus services department and from other people who interact with the test environment (such as the cleaning personnel assigned to third floor). The methods for qualitative data collection include email correspondence and qualitative interviews using predefined interview guides.

4. The Technology

iRobot, Electrolux, Texas, Samsung, and Yujin are the major robot vacuum suppliers. The experimental study detailed in this paper used two Roomba 580 models from iRobot. The robot is equipped with sensors and can learn from the environment to optimize its cleaning pattern. So-called Virtual Walls can be used to maintain the robot vacuum cleaner in a particular room or to keep it away from wires or delicate objects.

The manufacturer recommends that the filters, storage tank, brushes, sensors and battery terminals must be kept clean so that robot vacuum cleaner can continue to deliver optimal performance. The robot vacuum usually takes about three hours to charge, but occasionally, to extend long-term battery life, the device will charge for sixteen continuous hours. This happens automatically when the robot vacuum cleaner's power has been drained entirely and it has not returned to its charging station. On a full charge the battery capacity from 60 to 90 per minute charging depending on floor type.

5. Results

The data from the experiment indicate that the robotic vacuum cleaner outperformed the human-operated device. Using the robot vacuum cleaner, a total of 57.6 gram were collected whereas using the conventional vacuuming approach, 36.44 gram were collected.

Table 3: Dust and dirt collection (gram)

	Robot vacuum cleaner	Conventional vacuuming (control area)
Spring / early summer	32.93	20.72
Fall / late summer	24.7	15.72
Total	57.6	36.44

Contrary to expectations, huge savings were not realized in this experiment. In fact, it was actually 14% more expensive to use the two robot vacuums on the second floor than the manual vacuum cleaner on the third floor. The robot vacuum cleaners required maintenance that incurred labor costs equal to 87% of what it would have cost for

conventional cleaning personnel to vacuum the floor. Additionally, the robot uses more power. Furthermore, implementing robot vacuum cleaning requires a marginal cash outlay, whereas the standard vacuum cleaner is a sunk cost that has already been paid. Accruing for replacement devices must also be considered, because the expected lifespan of a Roomba 580 is only half as long as that of a manual vacuum and the batteries need periodic replacement. Table 4 provides a cost comparison.

Table 4: Summary of cost breakdown: electricity, time, acquisition, and maintenance (DKK per year)

Cost	Robot vacuum cleaner	Conventional vacuum cleaning (control area)
Electricity consumption (economic value)	189.49	57.15
Time consumption (labour costs)	5,970.8	6,832.1
Acquisition and maintenance	1,960.48	251.8
Total	8,120.77	7,141.05

6. Conclusion and challenges for contractors, workers, and management

This paper has reported the results of an experiment measuring the performance and costs of robot vacuum cleaners in a public sector setting. The preliminary findings are somewhat surprising, as they show that the adoption of the robot technology does not translate in cost savings from a public sector point of view. Robot vacuums may increase cleaning costs. While cost savings may not be realized, the cleaning quality is superior to that of human agents.

In this paper we have had a focus on robot vacuum cleaners, but there are also robot technologies for floor washing, cleaning of stairs, etc. Compared to the prospective work of the pilot testing and implementation of the robot vacuum cleaning, there will naturally also be a debate about how far the state itself must go directly to instruct the cleaning companies to use robots in the tendering of the cleaning tasks. A classic market argument would be that it is not for the state to buy robot vacuum cleaners, but for contractors bidding on public cleaning tasks. Our key proposition it that government should much more actively pursue the adoption of robot vacuum cleaning and not just leave it to the long-term market competition. This can be done, for example, by tender requirements and by launching a supplier forum where there is a dialogue and direct signal to suppliers of active initiation of the robot vacuum cleaning.

Based on the findings of the experiment, we have created a list of public sector contexts and ranked their potential for robot vacuums. The list includes potential drivers and barriers for the spread of robot vacuum cleaners within each context. We have divided the public sector in a number of subcategories. The number of stars (*) indicate how large we view the potential to be in office environments, training areas and other non-residential common floors and residential institutions (elderly centers, prisons, etc.). Distinction between residential and non-residential premises is essential for deployment, since size, degree of standardization, and the ability to implement consistent adjustments are significantly higher for non-residential floors.

Table 5: Robot vacuum cleaning in the public sector: drivers and inhibitors

Public Sector Buildings	*Driving forces*	*Inhibitors*
Office environments and other non-residential areas *** (classrooms, etc.)	Uniform surfaces Possibility of adapting furniture	Theft Absence of monitoring during nighttime crash problems, technical challenges
Residential institutions (prisons, etc.) *	Need for constant optimization of work routines	Heterogenous surfaces High start-up costs Noise disturbance for residents
Hospitals **	Need for constant optimization of work routines	Failure to meet minimum quality cleaning standards
Schools ***	Need for constant optimization of work routines	Absence of monitoring during nighttime crash problems, technical challenges
Elder centres** Home care*	Need for constant optimization of work routines	Heterogenous surfaces High start-up costs Noise disturbance of residents

Note. *) lower relative potential, but benefits may still be realized; **) moderate potential; ***) extremely high potential

The opportunity to introduce robot vacuums in the organizational environment is not simply a technical choice or purely a rational cost-benefit decision. Many challenges will arise during the process of introducing robots into an environment accustomed to long-established practices This study provides a basis for investigating emerging challenges regarding a range of actors in public sector organizations, including management, contractors, and workers.

6.1 Management Challenges

Cost savings are often used as the main argument for managerial decision-making, and such arguments have increasing relevance given the budget restrictions in the public sector. While the findings of this study challenge any easy assumptions that robot vacuum cleaning will be a straightforward cost saver, managers may consider other advantages from the adoption of robots in cleaning such as reducing the difficulty of finding/staffing positions because robots make it possible to have fewer cleaning personnel for large buildings. On the other hand, the novelty of the technology poses risks related to equipment failure (as it is easier to replace an absent cleaning worker from an established labour market than a failed robot system). Managers also face the risks related to being a first mover. The career damage and blame if the technology does not pay off will likely be more impactful and have greater consequences than if the manager misses an opportunity through inaction.

The public nature of the setting also poses managerial challenges related to conflict with labor unions and with public (political) legitimacy of management decisions. A manager introducing a new technology that apparently results in eliminating jobs is likely to face criticism from public opinion and press, while the impact resulting from discord with workers' unions may take a political toll and may impact future negotiations about unrelated issues.

6.2 Contractor Challenges

Contractors working with public sector agencies compete with each other on service levels and prices. In a market that experiences relatively low levels of innovation in cleaning services, the provision of robot-enhanced services could represent a potential competitive advantage in the tendering process. Businesses competing for contracts with public sector agencies could use the innovative nature of the robotic vacuum cleaning as a showcase for

service improvement and innovation, and try to market the novelty and efficacy of this new feature to increasingly budget-conscious public agencies. On the other hand, there are negative potential impacts associated to the adoption of robot vacuum cleaning from a contractor point of view: when introducing a potentially disruptive technology that is outside the mainstream, the potential advantages can be harder and more costly to communicate to customers, especially considering that the technology cannot deliver immediate cost savings. Also, contractors face increased quality of service risk because of the uncertainties of utilizing a new technology.

6.3 Worker Challenges

Obvious positive impacts on workers of introducing robot vacuum cleaning include the possibility of freeing workers' time so they can focus on less mundane and more meaningful work. At the same time, potential downsides can represent a challenge – if not the main challenge – to robot adoption in a public sector environment.

The people who are in charge of manual cleaning could feel threatened by the thought that they could be replaced by a machine; therefore, they may see the introduction of robots as a threat to their job security and their sense of accomplishment. While some may welcome reassignment to more complex tasks, others may perceive such a move as raising the level of difficulty and work stress. Similarly, it could be viewed as an increase in responsibility without a raise in wages.

While cleaning personnel may be affected directly, many other workers may be indirectly affected if they have to change their environment or workflow to accommodate the new vacuums. Robots could be perceived as a disturbance to employees' working routine (e.g. from noise produced by the robots in working hours), an inconvenience to performing their duties (e.g. if they are required to make special arrangements of their workplaces, such as arranging cables and other objects on the floor so that they do not interfere with the robot operations), or hindered work routines (e.g. being unable to use office spaces during specific hours because of robot operations -- something that could impact heavily the work routines of particular settings, such as the university department in our study).

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