agricultural engineering.eu 79(2), 2024, 64–79
DOI:10.15150/ae.2024.3309

agricultural
engineering.eu

Economic effects and profitability of investing in automated bedding, feeding and manure removal processes on dairy farms in Baden-Württemberg

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Daily routine tasks take up a lot of working time on dairy farms, placing a heavy burden on labour costs. One solution is to automate relevant routine tasks. This study involved recording working hours in 13 new or renovated barns on dairy farms of different sizes in Baden-Württemberg. Processes relating to bedding, feeding and manure removal with and without automation were compared for ten of these farms. In addition, break-even point analyses were used to determine the wage rate needed to make an investment in automation profitable. Robotic feed pushers and manure robots were found to be profitable even at wage rates of less than €21.5/MH (man-hour), while investment in bedding automation was calculated at over €40/MH and in feed belts at just under €27/MH. The results offer guide values for practical application, whereby exclusively considering labour savings did not take into account essential qualitative and structural aspects that can be decisive for purchasing decisions.

Keywords
automation, farm building management, dairy farming, barn construction

Agriculture is a labour-intensive sector that has the highest weekly working hours of all occupations in Germany (German Federal Statistical Office 2020). Farm managers in dairy farming work around 63 hours per week, and 38% of the family workforce have no days off (Lassen et al. 2014). In addition to field management and administrative tasks, dairy farmers invest a lot of time in daily routine tasks in the barn such as feeding, milking, cubicle maintenance and calf rearing (Baden-Württemberg Regional Statistical Office 2022a).

There are around 5478 dairy farms in Baden-Württemberg (Baden-Württemberg Regional Statistical Office 2022b). The medium-sized farm categories (20–49 and 50–99 dairy cows per farm) make up over 60% of the farms, while small farms with fewer than 20 cows account for almost a quarter of all farms. The number of dairy farms in Baden-Württemberg is steadily declining, with 10% of farms leaving dairy farming since 2020.

Profits per farm vary depending on the size of the farm (Baden-Württemberg Regional Statistical Office 2021). Farms with fewer than 50 cows reported a profit of €30,254 , while larger farms with more than 50 cows made a profit of €99,370 (Baden-Württemberg Regional Statistical Office 2021). The farms with fewer than 50 cows have an average man-power (MP) of 1.39 workers, 95% of whom are unpaid. Conventional farms with over 50 cows have 2.29 labourers at their disposal, 78% of whom are unpaid (LEL Schwäbisch Gmünd 2023). The number of people employed in agri-

received 17 October 2023 | accepted16 February 2024| published 17 May 2024

culture is falling, while the use of automated systems is increasing. Around 22 % of dairy producers in Baden-Württemberg use automatic milking systems (LKV Baden-Württemberg 2022), while slatted-floor manure removal robots and robotic feed pushers are used on around 16 % and 12 % of Bavarian dairy farms respectively (Gabriel et al. 2021).

Milking accounts for more than a quarter of all labour time, followed by 21 % for feeding. Calf rearing, bedding tasks and manure removal each make up just 6 % of the labour time (Schick 2022). When it comes to cleaning cubicles, manual procedures are common practice in which, as described by Schrade et al. (2008), heavy soiling is removed twice a day and the lying surface is levelled at the same time. The authors indicate the labour time requirement for procedure (including collecting a new supply of bedding 14 days) as one minute per animal and day for farms with 45 cows and a straw-manure mattress (6 MP/A/year); for elevated cubicles with a comfort mat, the values are around 30 % lower. When management and extra tasks are added, the result is a total requirement of 43 man-hours per cow per year (Schick 2022).

For routine bedding, feeding and cubicle maintenance tasks, the KTBL (2022a) gives the following values for herds with 41 to 240 cows (Table 1).

Table 1: Reference values for routine bedding, feeding and cubicle cleaning tasks (amended according to KTBL 2022)

Task	**Bedding[1)]**	**Cubicle cleaning[2)]**	**Feeding[3),4)]**
Herd size	**MH/A/year**	**MH/A/year**	**MH/A/year**
41 to 60	0.40	2.19	8.33
61 to 80	0.37	2.01	8.33
81 to 120	0.35	2.01	7.24
121 to 180	0.34	2.01	6.02
181 to 240	0.32	2.01	5.90
Average	0.36	2.04	7.17

[1)] Reference value used for suckler cows, deep-bedded cubicles, bedding equipment.
[2)] Cubicle maintenance with pitchfork has been adjusted from twice a week to 6 times a week.
[3)] Set-up work before and after feeding; loading and distributing silage, hay/straw and concentrated feed with milling mixer wagon.
[4)] For herd sizes below 80, a milling mixer wagon was already used in a deviation from the KTBL planning figures.

Efficient organisation, clear processes and qualified staff are crucial for minimising man-hours and production costs (DLG Info Sheet 460). Implementing automated process can also improve work efficiency (Harms et al. 2015). Automation can not only reduce labour time and workload, but also increase flexibility for farm management, as Grothmann et al. (2010) show using the example of automated feeding systems.

Construction costs in dairy farming are influenced by various factors, including the economic situation, interest rates, subsidy schemes and farm-specific conditions (Rasche 2017). The costs for the barn building are largely determined by the design, the area per animal and the size of the functional areas. Multi-housing barn systems can save around 30% of the costs. The total costs for free-stall barn housing increase with the number of lying spaces, while technical equipment such as milking technology have cost degression effects. The costs per space decrease as the number of animals increases (Bavarian State Research Centre for Agriculture (LfL) 2015). 2020/21 and 2021/22 saw an inflation-related increase in barn construction costs of around 16 % due to increased demand and supply bottlenecks during the Covid-19 pandemic (Hoffmann 2022). Future price increases cannot be ruled out, although construction costs are unlikely to fall (Hofmann 2022). The investment sum is mainly divided between the foundations, barn shell, fitting out the barn and milking equipment. Flat bottom silos, slurry stores and ancillary construction costs are also relevant cost factors, which can fluctuate due to farm-specific factors (Eilers et al. 2008, KTBL 2019, Hofmann 2022). In Baden-Württemberg, the fixed costs (capital costs for interest and capital recovery) for the barn and stationary equipment amount to an average of ten euro cents per kilogram of milk produced (Gräter 2021).

The aim of the study presented here is to develop benchmarks for the profitability of investments in automation technology for dairy farms on the basis of empirical data collected on working farms.

Material and method

The study included 13 dairy farms that had carried out barn construction projects between 2018 and 2021 and were involved in the Baden-Württemberg EIP-AGRI Construction in Cattle Farming working group. Nine farms (A, D, E, F, G, H, K, L, M) built new barns and four farms (B, C, I, J) renovated and extended their existing barns. All the farms included construction-related measures to reduce ammonia emissions in their construction projects and focussed in particular on measures to structure and improve animal welfare. Grazing was practised on five of the participating farms (B, C, G, I, J), while the others had exercise yards. Four of the farms (B, C, G, J) operated in compliance with organic farming standards. The farms kept herds of between 44 and 206 cows. The study farms H and J used an auger system to automate the bedding process (Strohmatic, Schauer, Austria), while farms E and F used a rail-mounted system (MiniStrø , JH Agro, Denmark). Manure robots used were the Discovery Collector (Lely, the Netherlands), Barn E (JOZ, the Netherlands) and SRone (Gea). Robotic feed pushers used were the OptiDuo (DeLaval, Sweden), Dairyfeed (GEA, Germany), Juno (Lely, the Netherlands) and Moov (JOZ, the Netherlands). All four renovated barns had installed a feeding belt manufactured by Eder, Germany (farms B and J), Köhler, Germany (farm C), and Scherfler, Austria (farm I) (Table 2).

Table 2: Key figures and process details of the 13 study farms (AMS = Automatic milking system)

Farm	MH	Number of animals	Building	Milking technology	Feeding technology			Manure removal technology		Bedding technology	
					feed mixing wagon	fobotic pusher	feeding belt	stationary pusher	manure robot	tractor	bedding automation
A[1]	3.5	123	New build[3]	AMS	x	x		x		x	
B[2]	2.2	72	Renovation/ extension	AMS			x[4]	x	x		
C[2]	4.5	200	Renovation/ extension	AMS	x		x	x	x	x	
D[1]	2.5	128	New build	AMS	x	x			x	x	
E[1]	2.5	150	New build	AMS	x	x		x			x[7]
F[1]	2.6	144	New build	AMS	x	x		x			x[7]
G[2]	3	75	New build	Milking parlour	x	x		x	x	x[8]	
H[1]	4.3	206	New build[3]	Milking carousel	x	x		x			x
I[1]	1.8	44	Renovation/ extension	Milking parlour	x[5]		x	x		x	
J[2]	3.5	58	Renovation/ extension	Milking parlour	x		x	x			x
K[1]	4.3	180	New build	AMS	x	x				x	
L[1]	2.5	170	Extension	Milking parlour	x			x		x	
M[1]	2.7	178	New build	AMS	x	x		x	x[6]		

[1] Conventional. [2] Eco. [3] Multi-housing. [4] hay crane. [5] Stationary m ixer. [6] Slatted floor. [7] Slurry solids. [8] Compost-bedded barn.

Surveys on labour time

All 13 farms were surveyed to determine the amount of labour required for the routine tasks of bedding, manure removal and feeding. The routine tasks were divided according to preparation, main time and ancillary time (Table 3). The labour time was recorded once directly on site by a surveyor using a smartphone stopwatch function (iPhone 8). The procedure for self-documentation of labour time was then agreed with the farms. The data was supplemented by a farm work log and the arithmetic mean was calculated from three morning and three evening barn times. On average, the data provided by the farms differed only slightly from our own surveys (bedding/cubicle maintenance +2 %, manure removal +1 %, feeding -9 %). On two farms with summer grazing (farms B and I), two surveys were carried out, one in summer and one in winter, and the results were averaged. At farm J, data on labour time spent on manure removal was only available from one evening barn time.

Table 3: Breakdown and description of the routine tasks studied

Work processes	Division of the work processes		
	preparation	main time	ancillary time
Bedding	Filling the bedding device	Distributing the bedding material	
Cubicle maintenance	Creating an animal-friendly lying area in accordance with good practice		Treating the cubicles with lime etc.
Manure removal	Manual removal of soiling from cubicle areas that cannot be reached by stationary or mobile manure removal equipment		
Feeding	Preparing rations	Feed supply at feed fence or belt	Feed pushing, removing leftover feed

The labour time for bedding tasks and cubicle maintenance was recorded separately, but analysed as the sum of both tasks. Exceptions were farms G (compost-bedded barn) and K (elevated cubicles, no separate recording of bedding tasks and cubicle maintenance). If there was no bedding process involving filling up a larger supply of bedding for several days during the survey period, then only the value stated by the farmers was used, the same as for the cubicle maintenance at farm D. The methods for automated bedding differed fundamentally, as the Strohmatic system required an additional bedding bin to be filled, which was not necessary with the MiniStrø system in combination with slurry separation. Filling the bedding bins was recorded as a preparation task. The routine task of manure removal only included those barn areas that were not cleaned by stationary manure removal systems, such as alleyways, waiting areas and exercise yards. In terms of feeding technology, none of the processes analysed included automatic feed removal, so this aspect was not taken into account.

Procedure for creating the process comparisons

For ten farms, calculations were also made relating to the profitability of investments in automation technology (net prices, 30 % AFP subsidy on a maximum eligible investment volume of € 1.5 million taken into account) on the basis of average annual costs. In the process comparisons, the annual costs were made up of technology and labour cost blocks.

The annual costs for technology (K_t) included depreciation expenses (AfA), maintenance (u) and interest rate (i). A useful life of ten years was used as the basis of the depreciation of the machines as current assets (Federal Ministry of Finance 2023), without taking into account the different farm sizes and the associated usage of the machines. It was assumed that the variance of the farms in question led to a representative average. The variable individual costs such as work materials and repairs were included in the maintenance costs (u) and were estimated at 3 %, as a budgeted figure was only available for the robotic feed pushers. In addition, the daily operating hours of the machines were not known. The interest rate was set at 3 %.

The calculation formula was:

$$K_t = \frac{investment\ amount}{useful\ life} + \frac{investment\ amount}{2} * interest\ rate\ i + \ investment\ amount * u \qquad \text{(Eq. 1)}$$

The calculation of the annual costs for labour was based on a wage rate of € 21.50/MH in accordance with KTBL (2022b). In the case of the automated process variants, this was multiplied by the empirically determined hours required to complete the work. The comparative calculation of the non-automated variants for the bedding, cubicle maintenance and feeding processes was based on labour requirement values from KTBL (2022a) for comparable barn systems and herd sizes respectively. No comparable value from the literature could be used for areas cleaned with mobile robots, so the measured average value of the eight farms without manure robots was used as a reference value in this process. The annual costs of the processes were calculated from the sum of the annual costs for technology and for labour, and alternative processes without automation were compared with the automated variants.

For the bedding process without automation, a mechanical bedding device was assumed, for which machine costs were estimated according to KTBL (2023). A pro rata use of the yard loader was assumed for bedding with a total utilisation of 900 h per year based on the depreciation threshold (KTBL 2023). No costs for technology were estimated for the feed pushing, feeding belt and manure removal processes in the non-automated variant. In the case of the feeding belt, it was assumed that there was no difference in feed collection, mixing and unloading between the automated and non-automated processes. This did not take into account the once-daily journey along the feed fence for unloading, which led to a sight underestimation of the costs for technology in the non-automated process.

Using the example farms, the break-even point was determined for the three areas of bedding, manure removal and feed pushing automation to shed some light on the wage rate above which the respective investments become profitable.

Due to the practical conditions, this empirical study provided descriptive data that was presented descriptively.

Results

Labour time

The sum of the three tasks – bedding, manure removal and feeding – gave on average a labour time of 8.21 man-hours per animal space (A) and year (minimum = 4.42 MH/A/year, maximum = 17.42 MH/A/year, standard deviation SD = 3.18 MH/A/year, coefficient of variation CV = 0.39) (Figure 1).

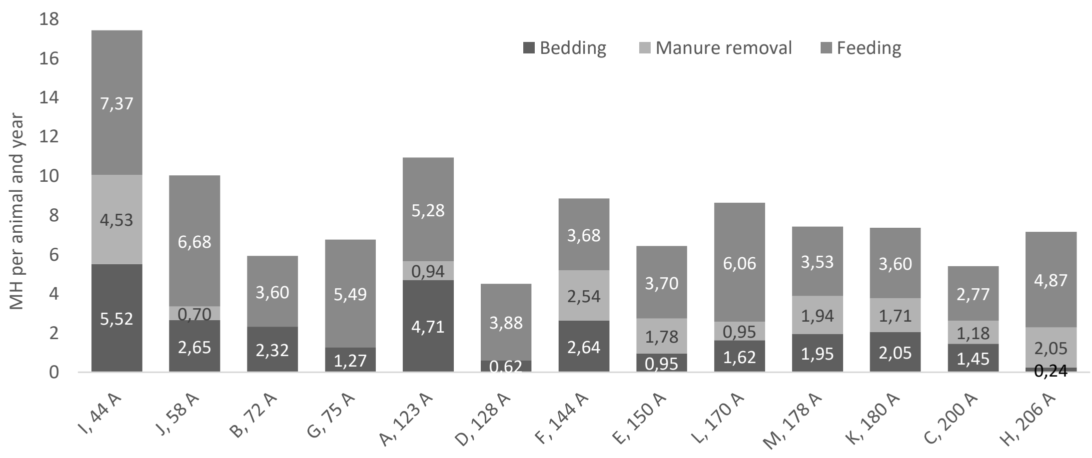

Figure 1: Sum of the labour time for the three categories bedding, manure removal and feeding, farms ordered by number of animal places in ascending order from left to right

The labour time of the farms with mechanical or manual bedding processes was 0.50 MH/A/year, with a wide variation between the farms (minimum = 0.21 MH/A/year, maximum = 1.19 MH/A/year, SD = 0.36 MH/A/year, CV = 0.72). The farm with the highest labour time for bedding is the one with the fewest animals.

The labour time for bedding including cubicle maintenance on the farms with automatic bedding systems was on average 1.62 MH/A/year (minimum = 0.24 MH/A/year, maximum = 2.65 MH/A/year, SD = 1.06 MH/A/year, CV = 0.65), with cubicle maintenance accounting for the majority of the labour time invested. Farm H, with the most animals, had the lowest total labour time, while of the farms with automatic bedding systems, farm J had the fewest animals and the highest labour time (Table 4).

Table 4: Labour time for bedding and cubicle maintenance on farms with mechanical or manual bedding processes (farms A, B, C, D, I, K, L, M) and with automatic bedding systems (farms H, J, F, E); farm G with compost-bedded barn excluded

Farm	Bedding (MH/A/year)	Cubicle maintenance (MH/A/year)	Total (MH/A/year)
Mechanical and manual bedding processes			
A	0.21	4.50	4.71
B	-	2.32	2.32
C	0.27	1.18	1.45
D	0.31	0.31	0.62
I	1.19	4.33	5.52
K	0.26	1.79	2.05
L	0.75	0.88	1.63
M[1)]			1.95
Ø	**0.50**	**2.19**	**2.53**
Automated bedding systems			
H	0.15	0.09	0.24
J	0.73	1.92	2.65
F	0.00	2.64	2.64
E	0.00	0.95	0.95
Ø	**0.22**	**1.40**	**1.62**

[1)] Aggregated data available, division into bedding and cubicle maintenance not possible.

When considering bedding and cubicle maintenance together, the automation of bedding achieved average savings of 0.91 MH/A/year compared to farms with mechanical or manual processes.

Labour time for manure removal from areas not subject to stationary cleaning

The highest labour time for the manure removal procedure (stationary, mechanical, manual) was on farm I which had the fewest animals (4.53 MH/A/year). On average, manure removal took 1.90 MH/A/year (SD = 1.09 MH/A/year, CV = 0.57). Farm J had the lowest value with 0.70 MH/A/year. The farms with manure robots needed an average of 0.62 MH/A/year for manure removal (minimum = 0.0 MH/A/year, maximum = 1.94 MH/A/year, SD = 0.80 MH/A/year, CV = 1.28), i.e. they spent only 33 % of the labour time of farms with manual manure removal (Table 5).

Table 5: Labour time for manure removal on farms with stationary, mechanical and manual manure removal (farms A, E, F, H, I, J, K, L) and with manure robots (farms B, C, D, G, M)

Farm	Stationary, mechanical and manual manure removal (MH/A/year)	Farm	Manure robot (MH/A/year)
A	0.94	B	0.00
E	1.78	C	1.18
F	2.54	D	0.00
H	2.05	G	0.00
I	4.53	M	1.94
J	0.70		
K	1.71		
L	0.95		
Ø	**1.90**	**Ø**	**0.62**

Labour time for feeding

On farms with feed mixer wagons and robotic pushers, the labour requirement for feeding was on average 4.45 MH/A/year (minimum = 3.53 MH/A/year, maximum = 6.06 MH/A/year, SD = 0.92 MH/A/year, CV = 0.21) and in farms with a feeding belt 5.11 MH/A/year (minimum = 2.77 MH/A/year, maximum = 7.37 MH/A/year, SD = 1.96 MH/A/year, CV = 0.38) (Tab. 6).

Table 6: Labour times for feeding on farms with mixer wagons and robotic pushers (farms A, D, E, F, G, H, K, L, M) and those with feed mixer wagons and feeding belts (farms B, C, I, J)

Farm	Feed mixer wagons and robotic feed pushers (MH/A/year)	Farm	Feed mixer wagons and feeding belt (MH/A/year)
A	5.28	B	3.60
D	3.88	C	2.77
E	3.70	I	7.37
F	3.68	J	6.68
G	5.49		
H	4.87		
K	3.60		
L	6.06		
M	3.53		
Ø	**4.45**	**Ø**	**5.11**

On the study farms, feeding with a feeding belt took slightly longer on average (13 %) than feeding with feed mixer wagons and robotic pushers.

Process comparisons and break-even point analysis of the wage rate

The evaluation of the annual costs and labour times of ten farms with automated processes compared to alternative processes without automation based on reference values from the KTBL (2022a) showed that the automation did not always lead to savings in the annual costs or the labour time. The automated bedding and cubicle maintenance process proved to be more cost-effective in terms of the annual costs on two of the four farms (on average -€25.0/A/year), with the labour time also being lower in these cases (on average -1.7 MH/A/year). For the robotic feed pushing process, the annual costs on all farms with the automation were lower than the alternatives without automation (on average -€18.9/A/year), with a labour time saving of 1.9 MH/A/year. The feeding belt was only economically advantageous for two of the four farms in terms of the annual costs (-€23.7/A/year), but led to an average labour time saving of -2.6 MH/A/year for all farms. The manure robots reduced annual costs by an average of €5.0 /A/year, with an average reduction in labour time of 1.6 MH/A/year (Table 7).

Table 7: Comparisons of the automated processes and alternatives without automation using data from ten working farms; data basis for automated processes based on our own surveys; for the alternatives without automation based on reference values (KTBL 2022), except for labour times for manure removal (average values from our own surveys)

	Automated							Alternative without automation				Annual costs difference	Labour time difference
Farm	Investment sum	Fixed costs for technology	Annual costs for technology	Labour time	Annual labour costs	labour completion costs	Total annual process costs	Annual costs for technology	Labour time	Annual labour costs	Total annual process costs		
	€/A	€/A/year	€/A/year	MH/A/year	€/A/year	€/A/year	€/A/year	€/A/Year	Akh/A/Year	€/A/Year	€/A/Year	€/A/Year	Akh/A/Year
Bedding and cubicle maintenance													
H	195.00	22.43	28.28	0.24	5.16	10.53	**33.44**	22.73	2.33	50.10	69.33	**-35.90**	**-2.09**
J	628.00	72.22	91.06	2.65	56.98	71.84	**148.04**	38.80	2.59	55.69	90.82	**57.22**	**0.06**
F	448.00	51.52	64.96	2.64	56.76	66.24	**121.72**	9.02	2.35	50.53	56.03	**65.69**	**0.29**
E	258.00	29.67	37.41	0.95	20.43	26.74	**57.84**	24.83	2.35	50.53	71.98	**-14.15**	-1.40
Ø	**382.25**	**43.96**	**55.43**	**1.62**	**34.83**	**43.84**	90.26	**23.84**	**2.41**	**51.71**	**72.04**	18.22	-0.79
Robotic feed pusher													
A	68.00	7.82	9.86	5.28	113.52	107.64	**123.38**	0.00	6.02	129.43	120.40	**2.98**	-0.74
D	124.00	14.26	17.98	3.88	83.42	81.32	**101.40**	0.00	6.02	129.43	120.40	**-19.00**	**-2.14**
E	59.00	6.79	8.56	3.70	79.55	75.77	**88.11**	0.00	6.02	129.43	120.40	**-32.30**	**-2.32**
F	71.00	8.17	10.30	3.68	79.12	75.73	**89.42**	0.00	6.02	129.43	120.40	**-30.99**	**-2.34**
G	173.00	19.90	25.09	5.49	118.04	114.99	**143.12**	0.00	8.33	179.10	166.60	**-23.48**	**-2.84**
H	19.00	2.19	2.76	4.87	104.71	97.97	**107.46**	0.00	5.90	126.85	118.00	**-10.54**	**-1.03**
Ø	**85.67**	**9.85**	**12.42**	**4.48**	**96.39**	**92.24**	108.81	**0.00**	**6.39**	**137.28**	**127.70**	-18.89	-1.90
Feeding belt													
B	454.00	52.21	65.83	3.60	77.40	69.02	**143.23**	0.00	8.33	179.10	166.60	**-23.37**	**-4.73**
C	237.00	27.26	34.37	2.77	59.56	79.11	**93.92**	0.00	5.90	126.85	118.00	**-24.08**	**-3.13**
I	636.00	73.14	92.22	7.37	158.46	166.48	**250.68**	0.00	8.33	179.10	166.60	**84.08**	**-0.96**
J	603.00	69.35	87.44	6.68	143.56	151.49	**230.99**	0.00	8.33	179.10	166.60	**64.39**	**-1.65**
Ø	**482.50**	**55.49**	**69.96**	**5.10**	**109.74**	**116.53**	179.70	**0.00**	**7.72**	**166.03**	**154.45**	25.25	-2.62
Manure removal													
B	238.00	27.37	34.51	0.00	0.00	7.14	**34.51**	0.00	1.90	40.85	40.85	**-6.34**	**-1.90**
C	74.00	8.51	10.73	1.18	25.26	26.22	**35.99**	0.00	1.90	40.85	40.85	**-4.86**	**-0.73**
D	273.00	31.40	39.59	0.00	0.00	8.19	**39.59**	0.00	1.90	40.85	40.85	**-1.27**	**-1.90**
G	229.00	26.34	33.21	0.00	0.00	6.87	**33.21**	0.00	1.90	40.85	40.85	**-7.65**	**-1.90**
Ø	**203.50**	**23.40**	**29.51**	**0.29**	**6.32**	**12.11**	35.82	**0.00**	**1.90**	**40.85**	**40.85**	-5.03	-1.61

The average values of the farms showed that investment in bedding automation can be worthwhile from a wage rate of approx. €40/h. For the robotic feed pusher, the break-even point was at a wage rate of approx. €7/h and for the feeding belt €26.7/h. For manure removal, investment would be worthwhile from a wage of approx. €18/h (Figure 2).

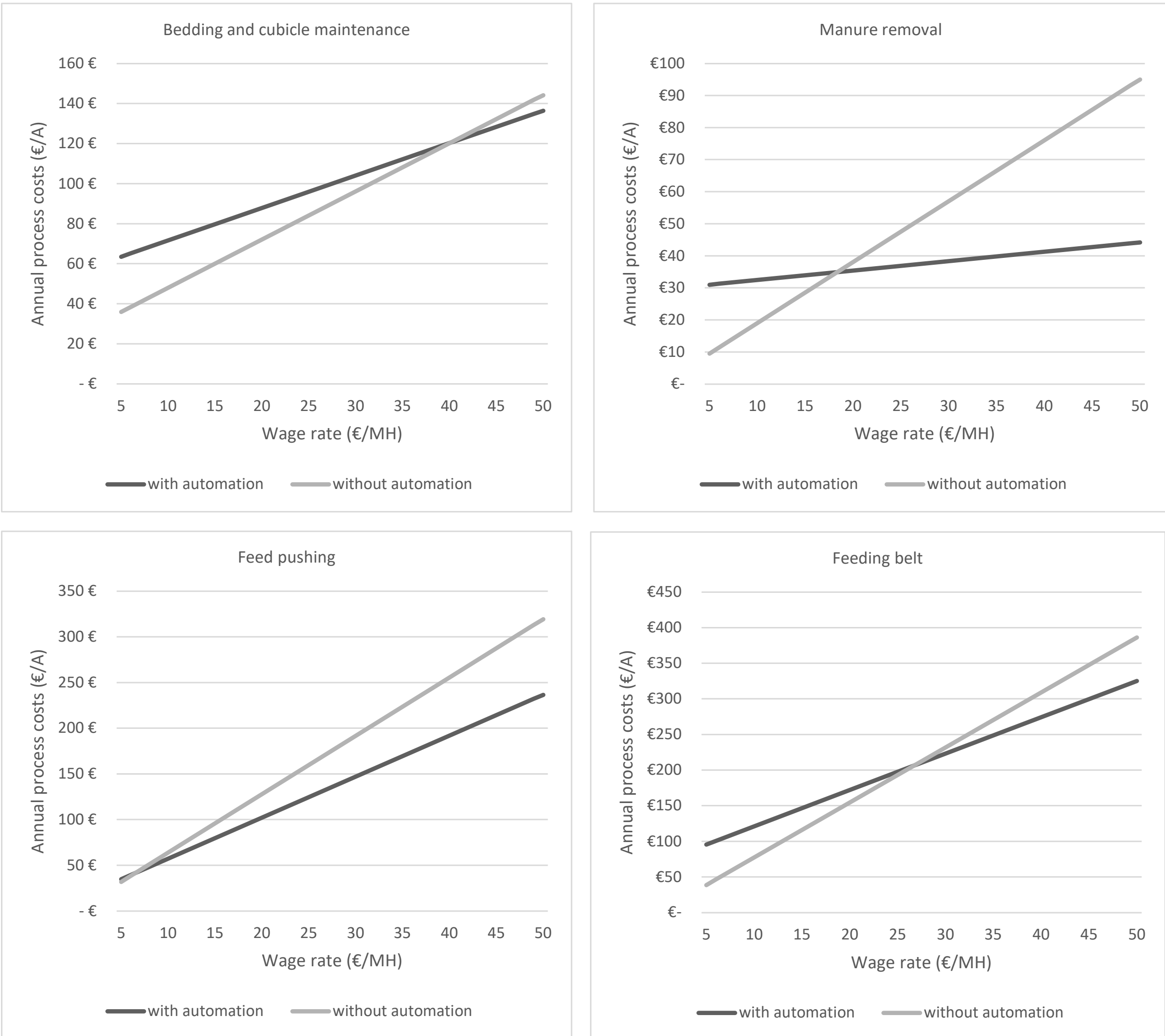

Figure 2: Illustration of the break-even point with regard to the wage rate for the bedding and cubicle maintenance, feed pushing, feeding belt and manure removal processes

These calculations were based on the additional costs for technology and the corresponding time savings. For bedding automation, additional costs for technology were €31.59 (€55.43 minus €23.84) divided by the time saving of 0.79 h (2.41 h minus 1.62 h). In the case of robotic feed pushers, the additional costs for technology were €12.42, divided by the time saving of 1.9 h. For the feeding belt, the additional costs for technology were €69.96, divided by the time saving of 2.6 h. For manure removal, the additional costs for technology amounted to €29.51, divided by the time saving of 1.6 h.

Discussion

The labour time saved and the monetary valuation of this time play an essential role in the profitability of investments in automated technology. The greater the time saving, the better the farms studied had a chance of achieving a financial advantage. In the examples, the wage rate was set at €21.5/MH in line with KTBL (2022b). If the hourly rate is estimated to be higher, the effect of time saved increases, and vice versa. The labour time for the four routine tasks considered was recorded exclusively in this study on the basis of the daily barn routine without any disruptive interruption times. This means that the labour time for monitoring the automated technology was not taken into account. On farms B, D and G, for example, a collecting manure robot cleaned all the areas, so that no manual labour was involved in the alleyways. The actual labour time needed was underestimated due to this approach, as labour time was also invested in malfunctions, adjustments and optimising the robot's route. The same applies to monitoring the automated bedding technology in combination with slurry separation. In both farms, malfunctions occurred, for example in the pumping equipment, which were not recorded as part of the labour time, meaning that the actual labour time was underestimated. Moreover, if the entire process were to be considered, the labour time for straw removal would also have to be factored in, which is not necessary when using slurry solids for bedding. Bedding and cubicle maintenance were recorded separately where possible, but this was not possible on all farms. Farm F had the third highest labour time for cubicle maintenance. This can be explained by the combination of automated milking with automated bedding, as there were always animals lying down in the cubicles during the bedding process, creating heaps of bedding between the animals. In addition, bedding material fell over the animals' backs and into the head space whenever they stood up. Levelling the cubicles was therefore associated with increased work. The study could not explain why this effect did not occur on comparable farm E, or why less labour time was needed on this farm for the cubicle maintenance. In general, the quality of the data from the labour time records limits the informative value of the data, as only one barn period was surveyed, this then being supplemented by labour time logs from the farms themselves. However, the break-even point analyses are based on average values from at least four to six farms, which improves their quality compared to merely considering individual case studies.

Classification and evaluation of the results of the labour time surveys

The labour times determined for the chosen routine tasks were judged to be plausible overall in comparison with literature values. For example, the study farms without automation used on average 2.19 MH/A/year for cubicle maintenance; the reference value is 2.04 MH/A/year (KTBL 2022a). The KTBL (2022a) also specifies 7.17 MH/A/year for feeding. If we subtract the potential savings of 3.5 MH/A/year estimated by the DLG (2013) made through automation measures in feeding from this value, the result is similar to that of the study farms (average 4.45 MH/A/year for feed provision with feed mixer wagon and robotic pusher).

Underestimating the labour times would have greatly influenced the result for the process with a higher share of labour costs in the process costs. For the robotic pusher, the share of the labour costs in the annual costs was the highest at 89 %, meaning that an overestimation or underestimation of labour time would have had a large influence on this process. In this process, the coefficient of variation of the labour times recorded on the nine farms was 0.21 and therefore only showed a slight variation in the values. For manure removal, on the other hand, the share of the labour costs accounted for only 18 % of the annual costs, meaning that an overestimation or underestimation of the labour time required on the nine farms (CV = 0.57) would only have a minor effect here. For bedding including cubicle maintenance, however, the share of the labour costs was 39 % of the annual costs and only four farms were considered at the same time (CV = 0.66). Here, an over- or underestimation would significantly change the result. The labour time for bedding and cubicle maintenance determined for the eight farms without automation was, at 2.53 MH/A/year, very close to the KTBL reference values (2022a). It also seemed plausible that the labour time for the automated process was slightly lower on average (0.91 MH/A/year) than that of the non-automated process. For the feeding belt, the labour costs accounted for the majority of the annual costs (61 %), while the technology only accounted for 39 %. However, the average labour time recorded on the four farms with a mean variation (CV = 0.38) was higher than on the farms without feeding belts, which would suggest that the labour time was overestimated rather than underestimated.

The results suggest that scale degression effects could be at play and that more labour time was spent per animal place on smaller farms, as Grothmann et al. (2010) also found using the example of automatic feeding systems. However, within the 13 analysed working farms, individual construction-related solutions were developed for a wide range of operational and site-specific conditions. As a result, the study included very different farms, which led to a wide variation in the processes and the associated labour time. For investment costs in milking technology, scale degression effects are described in the literature (Bayerische Landesanstalt for Landwirtschaft 2015), which are likely to be transferable to other areas. Using farm C as an example of feeding technology, it can be seen how the farm's initial set-up led to a comparatively low labour time for feeding. Feeding with a feeding belt took longer on average on the four study farms with renovated barns than feeding with feed mixer wagons and robotic feed pushers on the nine other farms (eight new barns, one extension). However, farm C with a feeding belt and a herd size of 200 cows had the lowest labour time requirement of all the farms studied. A total of three feeding belts were installed on this farm (Figure 3).

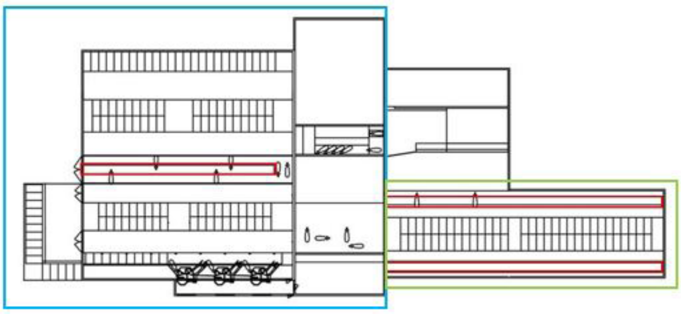

Figure 3: Barn floor plan of farm C with three feeding belts (framed in red); the old building is on the left (framed in blue); the extension is on the right (framed in green)

The results of the study presented here are of practical interest and provide a good benchmark with regard to the profitability of investments in automated technology, particularly due to the real-life conditions and the combination of new and renovated farms with innovative construction-related solutions. Additional benefits such as a possible qualitative improvement in the feeding and feed intake, or structural advantages in terms of repurposing existing buildings and saving space when using automated feeding technology, were not taken into account in the study. However, these are influencing factors that ultimately determine the benefits of automation investments for working farms.

Profitability of investments in automated technology

Variable costs for the operation of the automated technology including maintenance costs were estimated at a flat rate of 3 %. Depending on each farm's situation, the costs might have been overestimated for electricity generated on the premises and underestimated for purchased electricity. It should also be noted that a depreciation period of ten years was assumed for the automated technology, although the actual service life of this technology is likely to be longer. This means that the determined annual costs were relatively high and, consequently, the determined break-even point of the wage rate for the cost balancing was also set high from the perspective of a working farm. Overall, it can be assumed that the results of the process comparisons and also the break-even point analysis did not always favour the investments in automation.

Of the study farms with mechanical bedding processes, bedding accounted for only 20 % of the total process including cubicle maintenance, compared to 14 % on the farms with automated bedding. Therefore, the potential savings from automating the bedding process were generally low only for the cubicles of dairy cows. This resulted in a break-even point of the wage rate of €40 /MH, which would barely justify investment in automation in general. However, other, farm-specific reasons could drive the decision to install an automated bedding system. For example, for the two farms with rail-mounted automated bedding systems, the combination with slurry separation to produce slurry solids on the premises was likely a decisive factor for the investment, rather than the time saved on the bedding process. It can also be assumed that the farms had previously underestimated the labour time required for the deep-bedded cubicle maintenance when automatically using slurry solids as bedding.

With regard to the profitability of manure robots, the study shows that the investment makes economic sense, since 1.6 MH/A/year can be saved compared to the alternative process without automation. This means that the investment in a manure robot pays for itself from a wage rate of just over €18 /MH. For three farms, however, a labour time of zero hours for the manure robot was applied within the study, whereby the outlay for maintenance and monitoring was obviously not taken into account. However, it can be assumed that the amount of time spent monitoring the robot during the study period, i.e. immediately after installing it in the barn, was higher than during later routine operation. In two other farms, the labour time was of the order of one to two MH/A/year, which could be explained by the fact that not all areas of the barn were reached by the robot due to structural factors. The profitability was therefore not given for these two farms.

A robotic feed pusher becomes profitable from a wage rate of approx. €7/MH, while a wage rate of just under €27/MH would be needed to make the feeding belt profitable. When considering the profitability of investments in feeding automation, however, it should be borne in mind that neither a possible improvement in the feed supply to the animals due to frequent pushing or feed presentation could be taken into account, nor savings in barn construction costs due to the elimination of the feed fence.

The break-even point determined for a wage rate, which makes investment in automated technology economically viable, was used as a guide, as other farm-specific influencing factors are likely to play a part in the investment decision. The availability of skilled and unskilled labour poses an increasing challenge for farms, so that in addition to the comparatively high workload involved in dairy farming (Lassen et al. 2014), the decision to invest in automated technology can also be influenced by whether a farm relies on contracted labour (LEL Schwäbisch Gmünd 2023). If the investment costs are below average, profitability can be achieved even with lower labour savings.

Conclusions

The labour time for bedding and cubicle maintenance, manure removal and feeding can be reduced considerably in some cases by investing in automation. On average, the highest investment per animal per hour of labour saved was for bedding (€484), followed by €184 for the feeding belt and €126 for manure removal. The lowest investment required was in the area of feed pushing, where one hour of labour per animal and year was saved at €45 per animal. This study provides benchmarks for the break-even point of the wage rate for the profitability of investment in automation on the basis of data determined empirically on real working farms and thus sheds some light on the wage rate above which automation can become profitable for a farm. Investments in robotic feed pushers and manure robots can be profitable even below a wage rate of €21.5 /MH, while investments in bedding automation would have to be over €40/MH and feeding belts just under €26 /MH. However, in practice, in addition to profitability, other factors such as the possibility of using old buildings, improving feed intake or optimising bedding management play a key role in purchasing decisions.

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Notes and acknowledgements

The project was funded as part of the European Innovation Partnership “Agricultural Productivity and Sustainability” (EIP-AGRI). The funding initiative was part of the Rural Development Plan for Baden-Württemberg 2014-2020 (MEPL III). The project was funded by the State of Baden-Württemberg and the European Agricultural Fund for Rural Development (ELER).