VLAIO-TETRA
Machine Vision for Quality Control
Economic Validation

Contents

1 Introduction

The aim of this report is to provide an economical point of view on the cases covered in the VLAIO TETRA project on Machine Vision for Quality Control. For companies looking at integrating machine vision in their applications, it is often unclear what costs will emerge from adopting a vision system. This report provides a short economical evaluation for each case that covers the economic analysis of the case before adopting a machine vision system, the cost of a machine vision system, and a possible Return on Investment when a company decides to adopt the machine vision technology. For the economical evaluation of a case before adopting a machine vision solution, information is obtained from the company where the case is situated. For the cost evaluation of a machine vision solution, information is obtained from the system integrators that performed a feasibility study for the case.

2 Case 1 - Detection of surface damage on flat sheets

2.1 Current situation

In the current situation at Decospan, a machine operator assesses the quality of veneer panels during the sanding operation. The sanding operation is the last step of the production process and it serves as the final quality check before shipping to customers. As shown in Figure 1, an image is captured of both sides of the veneer panel after sanding. These images are then presented to the operator for quality monitoring. As a result, Decospan already has a database of veneer panels images containing various defects. Data from the 2022 and 2023 financial year show that there is an average annual failure of 4627 panels.

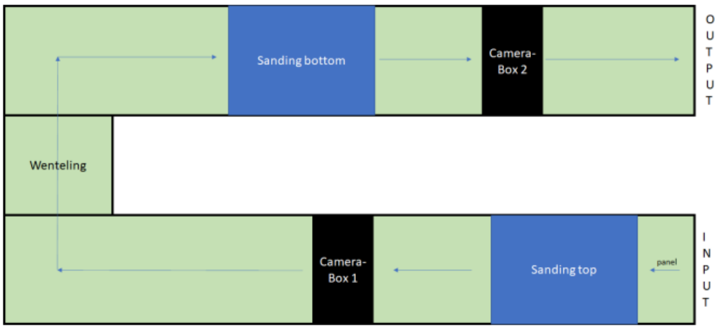

Figure 1: Schematic overview of the sanding operation.

2.2 Cost of a machine vision setup

The machine vision solution for this case was developed in the Master's thesis of Karel Debedts. At the moment of writing, a proof-of-concept was developed where he deployed his defect detection model on a Jetson Nano module. Table 1 provides the costs that are related to the hardware and software of this proof-of-concept. This data is provided by Captic.

Category	**Subcategory**	**Cost**
Hardware	Camera	€950
	Illumination	€700
	Mounting parts	€450
	Jetson Nano	€680
Software	Machine vision model	€49.500
	Modification machine lay-out and PLC programming	€12.000
Total:		€64.255

Table 1: Machine vision setup costs case 1

2.3 Return on Investment

Currently, the operator is able to detect 71% of the defective veneer panels. On an annual basis, this results in 1.352 defective panels being shipped to the customers. The purpose of implementing a machine vision system is not to replace the operator but to assist him. With the developed machine vision system, it would be possible to improve the detection rate of defective veneer panels to 90%, which would mean that only 463 defective panels would reach customers. When a customer receives a defective panel, they have two options: a replacement or a refund. Typically, at Decospan, approximately 10% of customers opt for a refund. The cost for replacing a batch of 10 panels is €390, while the cost for refunding a batch of 10 panels is €870. The additional benefit gained from using a machine vision system is summarized in Table 2.

System	Defective panels to customer	Costs
Operator	1.352	€59.457
Machine vision	463	€20.348
Difference	**889**	**€39.109**

Table 2: Comparison costs operator vs machine vision.

The ROI is determined using an IRR calculation. This starts with the total investment cost, then processes the annual gains and also takes into account the annual costs for maintenance and electricity. These are estimated at €3.600. Taxes (34%) will also be charged. The analysis is carried out over 5 years, based on the tax legislation. Machines must be depreciated over 10 years according to Belgian law and IT over 3 years. The middle-ground of 5 years is used. Table 3 shows the results of the IRR analysis.

	Year 1	Year 2	Year 3	Year 4	Year 5
Savings	39.108,81	39.108,81	39.108,81	39.108,81	39.108,81
Maintenance	3.000,00	3.000,00	3.000,00	3.000,00	3.000,00
Electricity	600,00	600,00	600,00	600,00	600,00
Depreciation	12.851,00	12.851,00	12.851,00	12.851,00	12.851,00
Net before tax	22.657,81	22.657,81	22.657,81	22.657,81	22.657,81
Tax	7.703,66	7.703,66	7.703,66	7.703,66	7.703,66
Net after tax	14.954,14	14.954,14	14.954,14	14.954,14	14.954,14
Cash flow	27.805,15	27.805,15	27.805,15	27.805,15	27.805,15
Actual value	20.938,40	15.767,46	11.873,54	8.941,25	6.733,12

Table 3: IRR analysis case 1

This shows that an investment in a machine vision solution has an annual IRR of 32.8% with a payback period of less than two years. This assumes that that production remains the same and inflation does not change, which is not realistic in practice.

2.4 Conclusion

The benefits of implementing a machine vision solution in this use case are manifold. Firstly, it will reduce the number of defective panels received by customers, thereby enhancing the company's reliability and image. Secondly, the operator's stress level will decrease due to the assistance provided by the machine vision system. Lastly, as demonstrated in this report, there is also a significant financial gain associated with using such a system. The investment in this machine vision solution is justified because it pays for itself within a period of less than 2 years.

3 Case 2 - Detection of the optimal cut line for chicory

3.1 Current situation

In the current situation, growers of chicory separate the loaf from the root using a rotating saw blade that is operated by one operator. The setup can be seen in Figure 2. The operator takes chicory form a bin and places them one by one on the saw blade to cut the root from the loaf. The loaf falls on a conveyor belt where four operators are checking the loaf if it is cut properly. If not, they further clean the loaf until it satisfies the requirements. This process requires a lot of manual effort and is also a dirty job as there is a lot of water and dirt coming from the chicory. The five operators result in high operator costs and make this manual process rather expensive.

Figure 2: Current setup for root removal of chicory.

3.2 Cost of a machine vision setup

The machine vision solution for this case was developed by Captic. They did a data collection at three growers and developed software that is able to segment the loaf from the root and to obtain a cutting line for a subsequent automated cutting process. During the project, no real deployment was done and only a proof-of-concept was made. Table 8 provides the costs that are related to the hardware and software if this proof-of-concept would be deployed in practice. The mentioned cost for the software covers continuous data collection, data labelling, professional IT/IOT security measures, development/training/evaluation of AI models, local deployment, dashboards, flexibility to the future, integration with PLC/robot/MES, etc.

3.3 Return on Investment

During the project, only a feasibility study and a proof-of-concept were made and no real integration was done. In general, it was unclear how the further automation of the process would be instantiated.

Category	Subcategory	Specification	Cost
Hardware	Camera	Basler 8MP	€1200
	Lens	None	€650
	Illumination	IP69K illumination	€700
	Safety measures food		€1200-2400
	Mounting parts		€300-600
	Industrial PC		€3000-4500
Software			€40.000-55.000
Total:			€46.000-65.000

Table 4: Machine vision setup costs case 2

A machine vision that obtains a cutting line was developed, but how the cutting line information from the vision system could be used to really cut the chicory was not explored and even automation solutions that do not even need a vision system could exist. As things are unclear about the actual automation of the cutting process, no real ROI was calculated.

3.4 Conclusion

The benefits of automating the cutting process of chicory is clear to the growers as it is a tedious and expensive process. However, how this process can be automated in the future is still unclear and several options are currently being explored. Also, it is not completely clear if a vision system would be necessary as there could be other options that do not require vision to do the job. Anyway, this project explored the possibilities of using a machine vision system to obtain the cutting line of chicory based on images and enables to provide an insight in the costs that emerge when a vision system could be necessary in the further automation of the process.

4 Case 3 - Inline determination of the length distribution of fish by category

4.1 Current situation

In this case, there is not really an economical motivation to adopt a machine vision system but rather an ecological motivation. For ecological purposes, knowing the length distribution of fish in the sea may be of value to organizations to evaluate the health of fish over time. Hence, there is not really an economical cost that can be related to this case.

4.2 Cost of a machine vision setup

During the project, ILVO developed a mobile machine vision system that can be deployed on board a fishing vessel to capture images of the fish being caught at that moment. The different costs related to this machine vision setup is shown in Table 5.

Category	**Subcategory**	**Specification**	**Cost**
Hardware	Camera	3D Camera with polarization filter	€599
	Illumination	None	/
	Capture card		€399
	SSD 4TB		€331
	Mounting parts		€250
	Mini PC		€2199
Research		Wages	€350.000
Total:			€353780

Table 5: Machine vision setup costs case 3

4.3 Return on Investment

As there is no real economical motivation in this case, no real ROI can be calculated.

4.4 Conclusion

Whereas no ROI was calculated in this case, an overview of the costs of the vision system for the inline length determination of fish is provided.

5 Case 4 - Determination of the proper functioning of a LED display

The implementation of a machine vision application significantly impacts various aspects of a company. Here, we examine the economic implications of using machine vision to test CAN-Displays, based on data provided by TVH. It is essential to note that the solution was developed using a single type of CAN-Display as a testing base for the techniques. However, the ultimate end-goal is to test every display in the TVH assortment. Therefore, we will base our analysis not on the numbers of a single display but on the combined statistics of multiple displays.

5.1 Current situation

The determination of the proper functioning of an LED display is currently carried out by a technician who possesses knowledge of its correct operation. Each display undergoes testing before being sold to a client. This is done using a Functional Testing Bench (FTB), which enables a user to activate different components of the CAN-Display, simulating its integration into a forklift truck. This testing process takes about 10 minutes each and must be performed by a knowledgeable technician who possesses knowledge about and has the motivation to rigorously test each part. This entails activating components and visually inspecting their functionality, there's a risk of monotony leading to lapses in attention. Therefore, technicians must remain dedicated to seeing the entire process through and maintaining close attention throughout the full 10-minute testing procedure. The price for testing a display is determined by the time needed to test × the wage per hour (€55 /h), resulting in €9.17 for each test. If we then consider the total number of displays sold, which is 320, the calculation becomes: 320 × 9.17, resulting in €2,934.4 spent on testing alone. Additionally, we have also received information on the number of returns, totaling 16 returns or $\frac{1}{20}$ of the displays being returned to TVH for further inspection due to errors. The average time needed to find and fix the problem is 1 hour and 30 minutes, costing €82.5. Factoring in the need for a test and the number of returns, we calculate: 16 × (82.5 + 9.17) = €1,466.72 that TVH has lost in repairs alone. This disregards the reputation damage and costs related to selling a broken part.

5.2 Cost of a machine vision setup

To solve the need for a skilled and willing tester, TVH will establish a new testing bench responsible for the machine vision implementation. The original FTB will however not be discarded and still be used in other situations ensuring no loss from its discontinuation. This new machine vision testing bench will consist of a a box-shaped structure with a door for installing the hardware and blocking out stray light. At the bottom, there is a slot where the display can be inserted and connected to a Beckhoff CX-2043 PLC, which will control and execute the Twincat vision tests. Positioned above the display is an IDS camera used for inspection. Paired with this hardware and thanks to previously done research, the Beckhoff corporation has already begun developing the software solution paired with this hardware. The software, build using the Twincat Vision framework is based on insights gained from case 4 and has already been presented as a proof-of-concept to the TVH upper management. Table 6 shows the costs and specifications of the aforementioned parts. With the drastically reduced testing time and the elimination of manual validation, the goodwill of the tester no longer factors into the testing process. All displays will undergo thorough testing and will be held to the same standard. Consequently, the number of faulty tests, returns, and repairs is expected to decrease significantly, possibly by around 50%.

Category	Subcategory	Specification	Cost
Hardware	Camera	GV-50C0CP Rev.2.2	€575
	Lens	ricoh-fl-cc1618-5mx	€240
	Lighting	2 X LBRX-00-160-3-W-24V and ST-1000-D1	€943.80
	Beckhoff PLC	CX-2043 with additional modules	€2.100
	Mounting parts and cables	/	€50
	Enclosure	/	€101
Development costs	Machine vision software	Beckhoff Twincat Vision base TF7100	€2850
	Software license	GigE vision connector TF 7000	€271.90
Total:			€7131.7

Table 6: Machine vision setup costs case 4

5.3 Return on Investment

As we can see in table 7, the total cost to create the Vision implementation is €7131.7, representing the initial loss. However, this loss is offset by several advantages that the solution brings. Firstly implementing a machine vision solution would significantly reduce the cost of the testing process, decreasing it from 10 minutes to an estimated 3 minutes per test. Secondly, a machine vision solution ensures objectivity, with the same tests performed consistently every time. This eliminates the need for a trained technician and opens the door for someone like a job student to perform the tests, reducing the cost of a tester to around €25 per hour. Consequently, the overall cost of a test would decrease to €1.25 for each test. Finally, as stated all displays will undergo thorough testing and will be held to the same standard each test. Meaning the number of faulty tests, returns, and repairs is expected to decrease significantly, possibly by around 50%. If we incorporate these estimates into our formula, we get the following calculation: $8 \times (82.5 + 1.25) =$ €670 as the cost for all the testing. We can then compare this result with the previously calculated values. While there is an initial loss due to the cost of the machine vision testing bench this is quickly regained by the profit margins created by the use of the machine vision application. The immediate gain on the tests alone is a drop of 85%, and while the values may seem small, if we factor in the fact that we have to test all displays before selling them, we can observe that we have a €2,534 profit margin.

Category	Without machine vision	With machine vision	Difference
Single test cost	9.17	1.25	€7,92
Yearly total test costs	2934.4	400	€2534
(Estimated) retours	16	8	8
Yearly total retour cost	1.466,72	670	€796.72
Yearly total test + retours	4.401,12	1070	€3.331,12

Table 7: Return on investment case 4

5.4 Conclusion

In conclusion, implementing a machine vision solution for LED display testing offers TVH numerous advantages, enhancing efficiency and economics. The current manual testing process, reliant on experienced technicians, is labor-intensive, subjective, and prone to errors. Introducing machine vision reduces testing time, eliminates the need for highly skilled personnel, streamlines testing, improves objectivity, and cuts testing costs. Despite initial investments in hardware, software, and development, long-term benefits outweigh these costs. Reduced testing expenses, minimized returns, and increased operational efficiency demonstrate a clear return on investment. Economic analysis indicates significant overall cost savings for TVH, with reduced testing and return counts offsetting the initial machine vision setup costs. Enhanced testing accuracy and efficiency contribute to increased profitability. In summary, adopting machine vision for LED display testing offers a favorable ROI while also opening the door for more machine vision applications in other areas of TVH's workflow.

6 Case 5 - Inline determination of the fat absorption of donuts after frying

6.1 Current situation

Vandemoortele produces donuts on a series of continuous, large-scale production processes, consisting of the preparation, proofing, frying, cooling, and post-processing stages. The deviating and varying fat absorption values in the donuts have a negative effects on product quality. This is two-fold; Firstly, the product weight is critical for customer (retailers); and secondly, the variations in the fat quantity and type result in a different end user experience. The multistage manufacturing process is highly susceptible to initial process parameters and environmental changes. A quality control system with the following requirements is necessary:

1. Non-destructive
2. Non-contact
3. Large-volume
4. Accurate
5. Fast

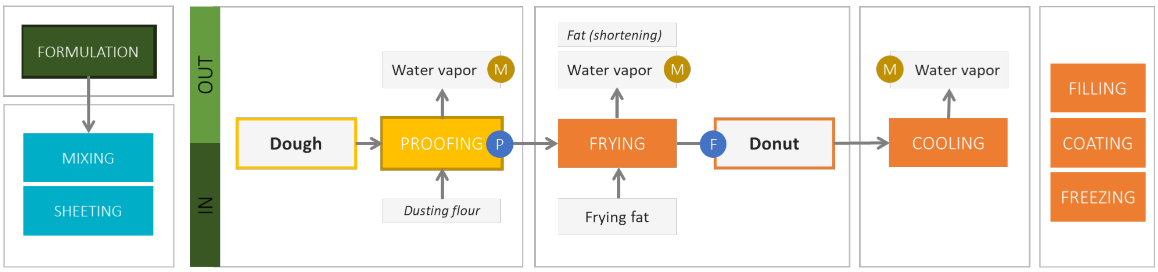

Figure 3: In- and outflow diagram of the current donut production setup.

Currently, two methods exist to evaluate the fat and moisture content of the product. The first method is an offline, lab NIR-analysis that can produce highly accurate results of a batch of product. This method has the disadvantages that the volume is very small and it requires a large time investment. A second online system exist that extrapolates the fat absorption based on the weight change before and after the frying step. This is annotated by P and F respectively on Figure 3. This method can evaluate large batches of continuous production in a semi-automatic manner. The downside of this method are:

1. The method produces a relative result, measuring the difference in total weight between batches.
2. The method is highly sensitive to operator execution.
3. The method does not incorporate additional (interaction) effects

The economical implications are the following:

1. Cost of scrap and defective accepted products
2. Lowering production efficiency (packaging)
3. Poorer customer perception of product quality and increased complaints (weight, quality)
4. Invested time of different departments in finding root cause for (fat absorption related) problems

6.2 Cost of a machine vision setup

The machine vision solution for this case was developed by Covicon. The data collection was performed by them in coorperation with KU Leuven. A custom software tool was developed and provided by Covicon to extract data from the used hyperspectral setup. During the project, no industrial integration was done and only a proof-of-concept was made. Table 8 provides the costs that are related to the hardware and software if this proof-of-concept would be deployed in practice. The mentioned cost for the software for continuous data collection, data labelling, professional IT/IOT security measures, development/training/evaluation of AI models, local deployment, dashboards, flexibility to the future, integration with PLC/robot/MES, etc. is not included.

Category	Subcategory	Specification	Cost
Hardware	Spectrometer Probe	Polytec Advanced Spectrometer (PAS)-2120 PAS-H-B01	€15000-25000
	Safety measures food		€1200-2400
	Mounting parts		€300-600
	Industrial PC		€3000-4500

Table 8: Machine vision setup costs case 5

6.3 Conclusion

Based on the results of the POC, Vandemoortele plan an integration around fat absorption control in production NET beginning of 2025. Determining 'benefits' is a significant challenge for Vandemoortele since such an installation does not yield direct profit. There would be a positive impact on operator satisfaction and the chance of placing defective products in the market would decrease, but the impact of this is difficult to budget. When the installation is functional, it would be an enabler to look at process control (i.e., your doctoral theme) whereby variation (in positive and negative sense) can be reduced. The profit here will, in addition to the above-mentioned items, come from limited losses and better predictable/controllable costs.

7 Case 6 - Detection of a sufficient presence of nuts and sauce on Cornettos

7.1 Current situation

In the current situation, the quality of Cornettos is assessed based on the presence of sauce and nuts by a machine operator. The production line is equipped to produce multiple variants of ice cream, sauce, and nuts. Due to the high production speed of 36.000 Cornettos/hour, it is challenging to evaluate each Cornetto individually. Additionally, there is limited time-frame when this control can be done because of the subsequent packaging. As a consequence, many bad quality Cornettos reach costumers, leading to complaints and financial losses. Currently, the quality control is carried out every hour by an operator of the production line.

7.2 Cost of a machine vision setup

The machine vision solution for this case was developed by Captic. They did a comprehensive data collection inline and developed a data-driven quality control framework using an object detection model to enhance robustness. At the moment of writing, a proof-of-concept was made and plans are made for real deployment. Table 9 provides the costs that are related to the hardware and software of this proof-of-concept.

Category	**Subcategory**	**Specification**	**Cost**
Hardware	Camera	Area scan camera (2-8 MP)	€650-1.200
	Illumination	Standard IP69	€700
	Safety measures	Hygienic camera enclosure	€1.200-2.400
	Mounting parts	/	€200-400
	Industrial PC	/	€2.100-3.500
Software	Machine vision model	Data collection, labeling, model training and evaluation, performance monitoring, ...	€30.000-55.000
	Software license	annual	€10.000
Total:			€44.850-73.200

Table 9: Machine vision setup costs case 6

7.3 Return on Investment

On an annual basis, 500 palettes of Cornettos are discarded due to soft horns. The primary reason is that Cornettos exceed their 6-month expiration date. Additionally, a poor sauce distribution leads to early softening, resulting in the loss of approximately 15 palettes on an annual basis. The cost of one palette is approximately €1.000. The total annual costs of Cornettos with a poor sauce distribution is €15.000. The ROI will be achieved after 3 years.

7.4 Conclusion

A machine vision solution to control the quality of Cornettos will offer several benefits. The first one is cost reduction. Implementing machine vision would lead to decreased financial costs. The ROI analysis indicates profitability over a 3-year period. Consider that additional machine vision solutions on other production lines may have lower costs due to reoccurring expenses. The next benefit is efficiency improvement. By implementing machine vision, the quality control time for operators can be reduced to 5 minutes. This allows operators to allocate more time to other essential tasks. The last benefit is quality enhancement. While not every customer reports quality issues, implementing machine vision would undoubtedly enhance product quality.