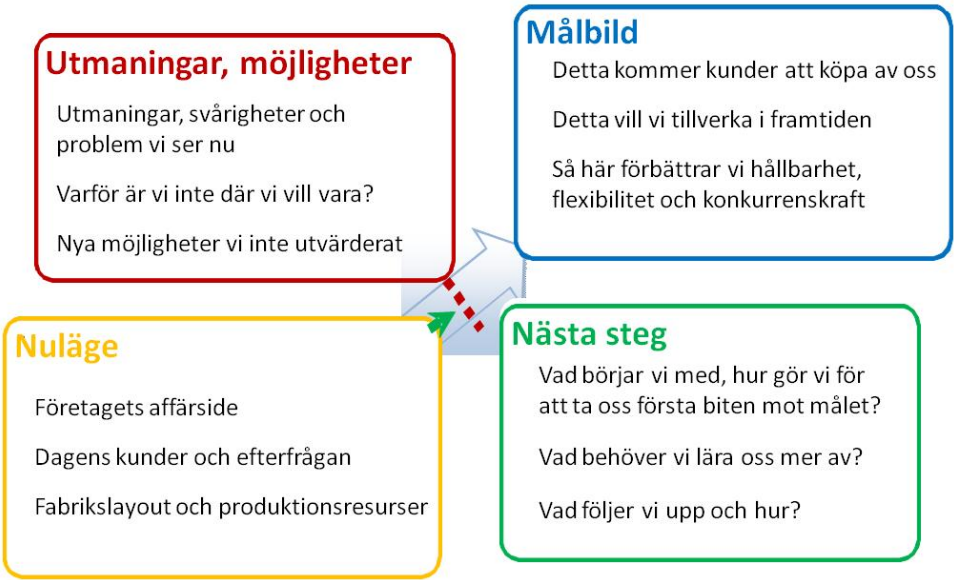

Guide to the

Flexible Automation of Low-volume Production

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Produced within Swedprod by:
Peter Almström, Chalmers University of Technology
Johan Frisk, Opiflex AB
Caroline Jarebrant, RISE IVF
Malin Löfving, Träcentrum
Boel Wadman, RISE IVF
Magnus Widfeldt, RISE IVF

The purpose of this guide is to describe a work method in order to map out opportunities in manufacturing companies to automate flexible low-volume production. The guide includes tools for analysis in respect of efficiency, ergonomics and economy.

The work method in the guide has been developed by the "Produce in Sweden" project (Swedprod), financed by Vinnova and with contributions from participating companies.

The structure of the guide is based on the Production Leap's model for guides.

Knowledge from the Swedprod project was integrated into the Robot Leap's pilot project PILAR in 2018 through synergies in the production of guides and analysis material.

Contents

Guide to the Flexible Automation of Low-volume Production

Introduction

Sweden has been a pioneer when regarding automation and rationalising the production process for large production volumes. But the situation is different in the group of small and medium-sized enterprises (SMEs). These companies mostly have a low degree of automation: 10 robots for 10,000 employees, according to the International Federation of Robotics. Sweden has been falling behind the rest of the world when it comes to automation, hence the government's initiative in automation and robotisation by such means as "The Robot Leap".

In the past it has been very difficult to automate small-series manufacturing, which is common in Swedish SMEs. This has resulted in there being an extremely low degree of automation, and some SMEs find it difficult to attract employees to perform heavy, monotonous tasks, and at the same time they are not competitive.

Many companies want to automate, but this is difficult for many reasons, see below:

Situation	Automation challenge	Need
Wide variation in volume, low machine utilisation	Long pay-off time with fixed robot	Share robot cell with several machines
Small series, new products every day	High programming costs for specialists, long changeover time	Simple robot programming, quick changeovers, flexible gripping devices
Need to be able to operate the machines manually	A fixed robot and fence blocks machines for manual operation	Full manual operation, no fences

The trends of "increased global competition" and "high mix and low volume" are pushing strongly towards increased automation with a need for greater flexibility. This also applies in companies that manufacture high volumes, where customers are able to make more and more individual choices. New technology is opening up new opportunities for automation such as mobile robots, collaboration between human and robot, and additive manufacturing of gripping devices and fixtures with 3D printers.

How to use the guide

The aim of this guide is to offer guidance to manufacturing companies in achieving increased competitiveness through flexible automation of low-volume production.

The guide is divided into three sections:

- Guiding principles for automation
- Work method for the analysis of conditions and choice of automation
- Facts about production and automation

The guide can be used to:

- Create and update a production development strategy based on what the company's customers are buying at present and will buy in the future
- Build in-house competence to develop using automation and robotisation.

Guiding principles for automation

Automation is a tool for work and expansion

It is a basic rule that companies that automate need – and retain – employees who are engaged, develop their skills and grow into the tasks created through increased automation.

Automation increases competitive strength and profitability, removes monotonous and heavy tasks and instead creates stimulating tasks.

The driving forces for investments in automation include the opportunities for improved efficiency, ergonomics, learning and economy.

Efficiency	Don't automate waste in the business, do something about the waste first. Then the investments in automation will have a greater impact and increase productivity.
Ergonomics	Automation in the right way can minimise or eliminate heavy lifting and short-cycle, repetitive tasks.
Learning	Automation and robotisation require learning and competence. The level of difficulty in applications should therefore increase in time.
Economy	Investing in automation is a decision about money. Calculate increased efficiency and also try to put a value on improved ergonomics and the value of enhanced competence.

Remove waste before automation

One principle for automation and robotisation is first of all to map out the current state for the materials flow, and then to identify and reduce or eliminate all that does not create value, i.e. "waste", Figure 1. An efficient automation solution can then be built based on the perspectives of efficiency, economy and ergonomics.

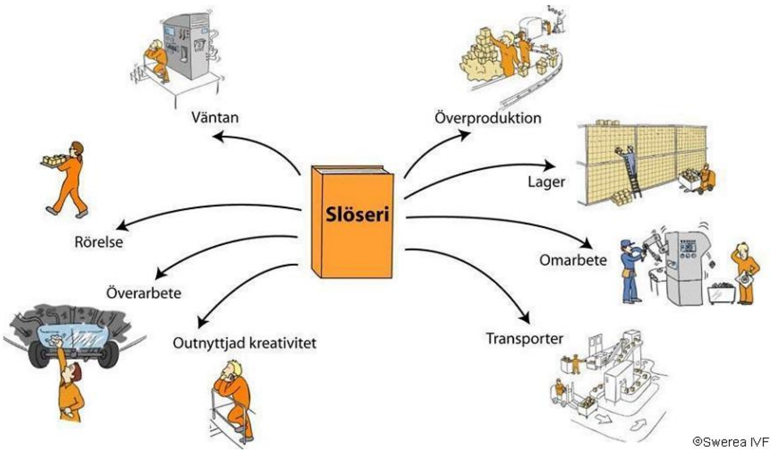

Figure 1. Don't automate waste, do something about it first! Time that creates value is often minimal compared with the time throughout the whole production flow.

Put safety first

Safety is very important for automation and robots. To be allowed to use a robot, the robot cell including gripping devices and connection with the machine must be CE-marked. Reference: EU Machinery Directive 2006/42/EC, Annex II 1. A.

Please note that risk assessments must be conducted in connection with all changes in production. Reference: Systematic Work Environment Management (SAM), AFS 2001:1, Swedish Work Environment Authority.

Start simply, then increase the level of difficulty

Tasks are various easy or difficult to automate. One piece of advice is not to choose the most difficult task first. A suggested sequence for automation is:

1. Handling and machine operation
2. Manufacturing processes, such as welding, gluing, grinding, painting
3. Assembly processes

Maintain the position orientation, it's expensive

Putting a not oriented part on a pallet with a collar is expensive, as the part has to be identified, separated and its location defined for the next manufacturing stage. People are good at doing this additional work, but it may be very complicated combined with automation.

So create automation with material handling that maintains the position orientation of parts and products, as this enables smart, efficient flows between different manufacturing steps.

Understand the handling requirements in the manufacturing process

Handling requirements are specified in the manufacturing process:

- before different manufacturing stages, such as pick one part at a time from a pallet
- when placing parts in a fixture or in a machine
- after a manufacturing step that has joined together several parts or created a completely new form in a part
- when positioning several parts after a manufacturing step
- when transporting parts between different manufacturing steps.

Parts or components that have been changed and placed on a pallet may become entangled with each other in a way that was not the case before processing or forming.

Adapt the products for production

Use design for assembly and design for manufacturing principles. There are major questions, such as modularisation and assembly sequences, and important details, such as correctly selected radii and surface finishes that should be considered. Work with the customer if your company is a subcontractor to achieve important product design changes.

Work method for the analysis of conditions and choice of automation

Work method in the guide

Are there prerequisites for automation? The guide offers guidance through the following process:

- Start with how the company wants to develop.
- Perform an automation analysis of the whole company.
- Identify appropriate automation candidates.
- Analyse the opportunities for automation based on each automation candidate.
- Next steps

Development map, the company's road map

The tools in the guide make it possible to follow up on changes and investments for learning and improvement work. The guide can be used both in the company's production planning and for individual investment processes. The initial steps in the work method are described as a strategic development map, Figure 2. The method of visualising the company's development is based on different perspectives, e.g. the customers' and the company's.

The development map with its four defined boxes is in many cases an adequate tool to create structure and driving force in a development process.

The principle for using the development map in an automation context is to:

- Describe the company's **current state** based on:
    - products, customers and production resources.
- Define an **objective** for the whole company, focusing:
    - what customers will be demanding and what the company wants to manufacture.
- Describe **challenges and opportunities** in continued production development:
    - automation candidates to proceed with
    - clarify effects and consequences through analyses and calculations.
- Prioritise "to do lists" in the **next steps**. Set a deadline, e.g. six months from now.

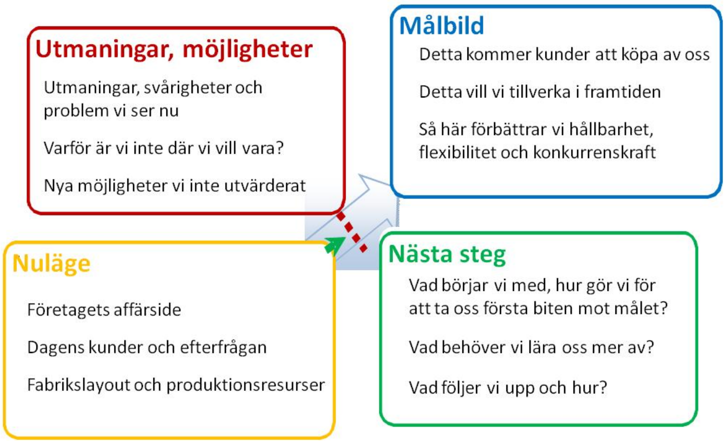

Figure 2.

The company's strategic development map

Define a summary of the current status

Define an objective

Describe challenges and opportunities

Prioritise and decide the next steps

Questions in the work on the development map, primarily current state andobjective:

The customer perspective

- Why do customers choose you?
- What demands do you foresee customers specifying in 3–5 years?
- If you lose an order today, why?

The company's own perspective

- Your vision? Your goals?
- What is most important for increased competitiveness?
- What requirements does this impose on automation?

The development map can be used for the whole company, for a factory, a part of the production or a production cell. Figure 3.

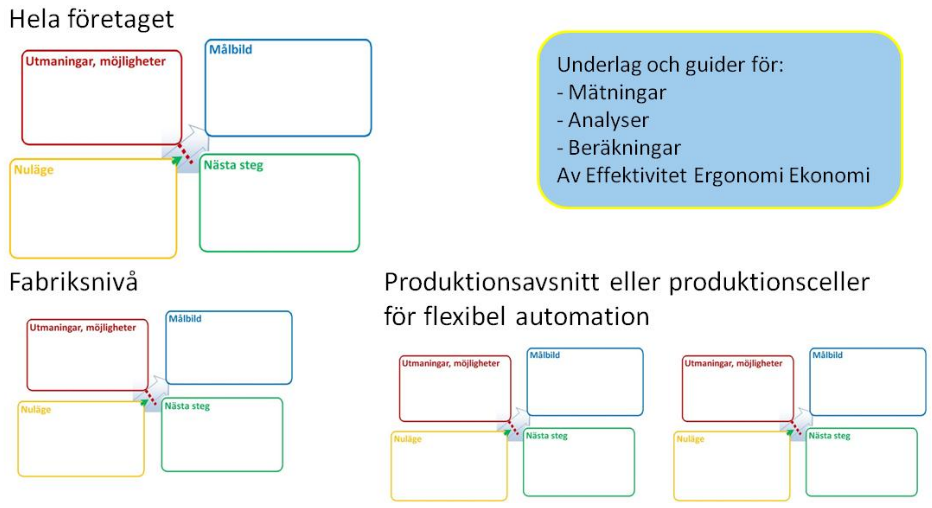

Figure 3. The development map can be used in several steps, so that the objective for the whole company corresponds with changes and investments at factory level, for part of the production and for production cells.

Development map at factory level based on manufacturing by subcontractors or in-house products

The conditions are different for subcontractors compared with companies that manufacture their own products. The mega trend is high mix and low volumes, which creates greater dynamics for subcontractors and challenges the objective of swift and even flows. A flow should be interpreted as a pre-defined set of production activities linked together by transportation and storages for one specific product or a family of products.

- Do you have obvious flows, in which machines or groups can be linked together to rationalise and clarify the flow?
- Do you have more dynamic flows, in which it must be possible to regularly change the flows and machines?
- Are you more focused on optimising machine utilization and the opportunity for flexibility (more clearly in subcontracted manufacturing)?

From development map to investment decision for automation

The development map for the whole company's development needs to be synchronised with the investments in automation that are planned and will be implemented. Figure 4.

After the development map, the guide continues with a work method to map out the opportunities to automate and which automation candidates should proceed to investment.

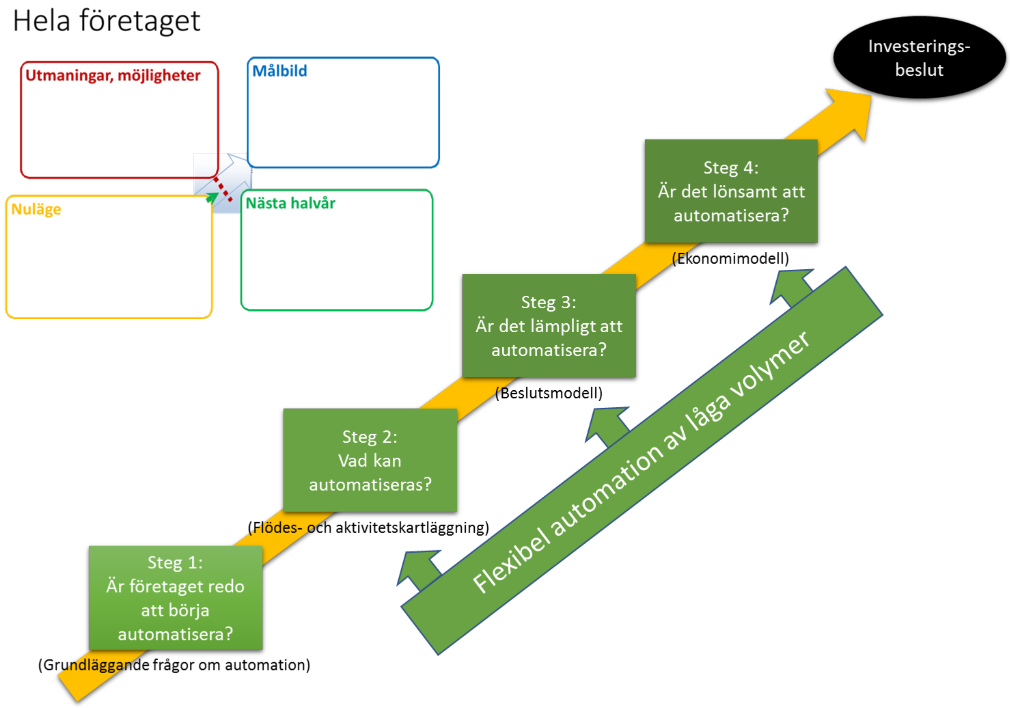

Figure 4. The development map visualises the way for the whole company and can be used to highlight needs for development in production. In four steps, the company is guided to a decision on investment. The guide highlights in particular opportunities for flexible automation of low volumes.

The work method follows four steps:

1. Is the company ready to start automating?
2. What can be automated?
3. Is it appropriate to automate?
4. Is it profitable to automate?

Do the conditions exist to automate?

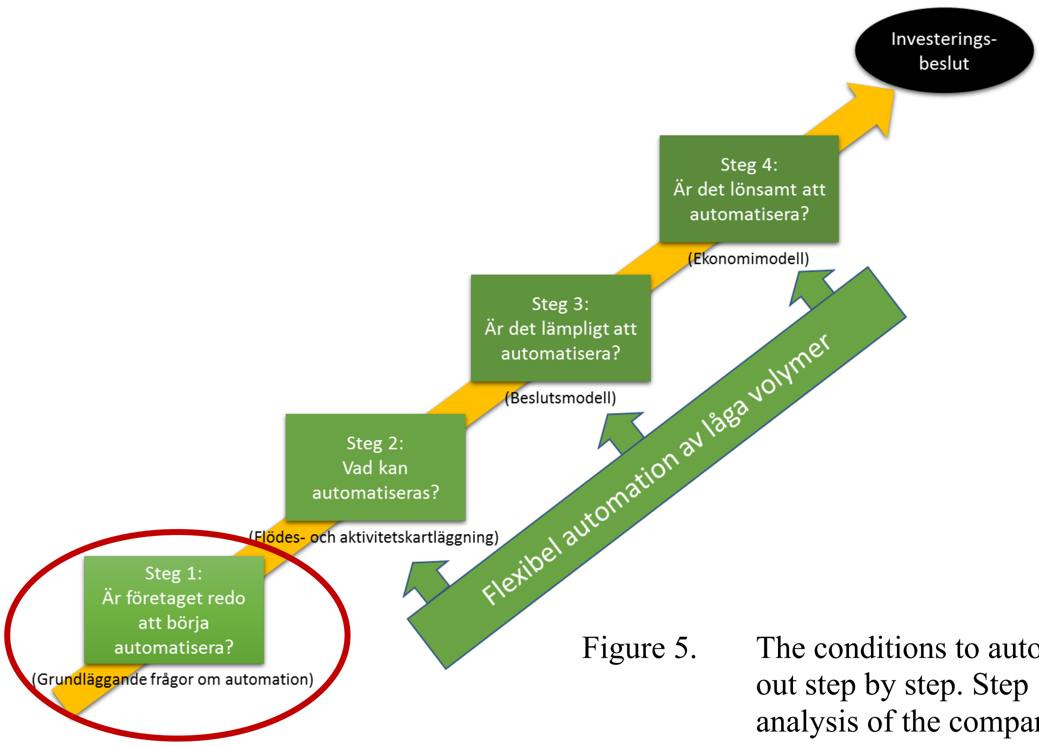

Figure 5. The conditions to automate are mapped out step by step. Step 1 involves an analysis of the company's automation maturity.

Step 1: Is the company ready to start automating?

An initial assessment of the opportunities for automation based on the whole company is performed using six basic questions (Figure 6). If the response to any question is "No", an in-depth analysis is performed of the challenges and opportunities to change the response to a "Yes".

		Ja	Nej	Utred
1.	Är produkterna lämpliga att hantera automatiskt överhuvudtaget eller kan man anpassa dem för automation?	☐	☐	☐
2.	Finns det möjlighet att finansiera en automationsinvestering? (Alltså finns sparat kapital, möjlighet till lån eller leasinglösning?)	☐	☐	☐
3.	Har företaget kompetens eller kan skaffa kompetens för att hantera automatisk utrustning?	☐	☐	☐
4.	Är den egenskapsmässiga variationen (geometri, vikt, yta, mm) hos produkterna tillräckligt liten (eller inte allt för stor)?	☐	☐	☐
5.	Utförs aktiviteter tillräckligt ofta för att automation ska vara realistiskt? (Aktiviteter såsom omställningsarbete eller kvalitetskontroller utförs troligtvis inte tillräckligt ofta.)	☐	☐	☐
6.	Är det sannolikt att det finns kunder till befintliga eller liknande produkter om två - tre år?	☐	☐	☐

Figure 6. Basic questions for automation based on the whole company.

What can be automated?

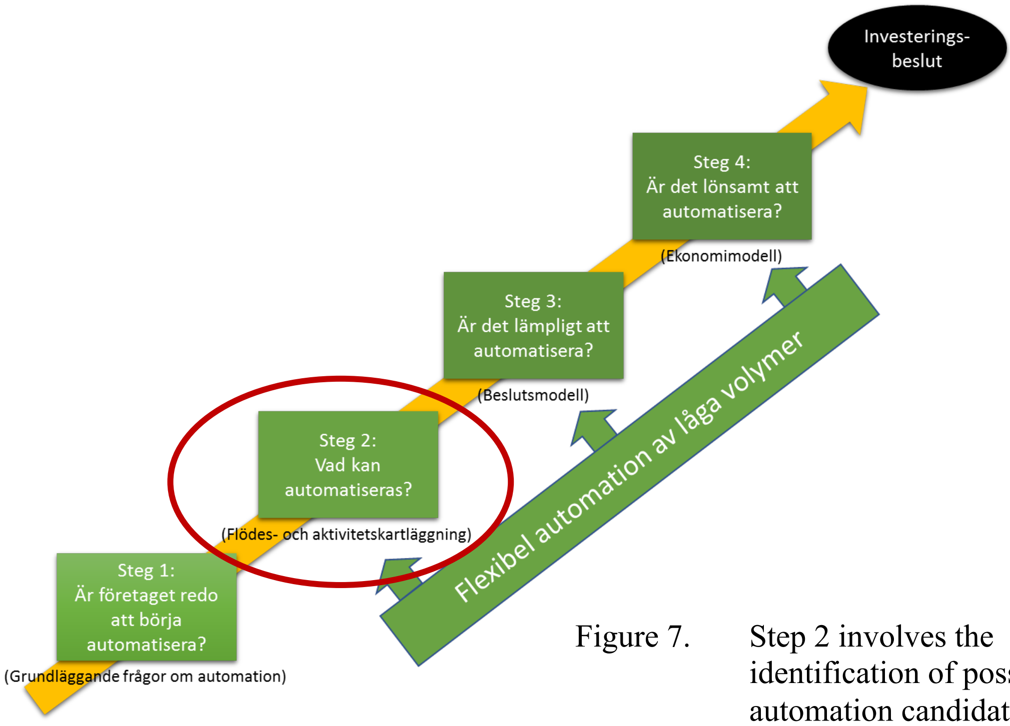

Figure 7. Step 2 involves the identification of possible automation candidates.

Step 2: What can be automated?

The basis for being able to assess what can be automated is to view the actual production with your own eyes. This method is known as a linewalk, which means walking through and reviewing the materials flows throughout the whole chain, from incoming material to outbound delivery.

The purpose of a linewalk is to identify automation candidates, i.e. steps within the materials flow that can be automated on the basis of efficiency and ergonomics. Figure 7.

It is also during this phase that a picture is formed of which products or product families that are suitable for automation.

Guidelines for a linewalk

- Scope: Walk through the whole factory, at least the most important materials flows, and take photos or videos of areas of interest for automation.
- Look for conditions for automation/robotisation in:
  - Manufacturing operations: in separate machines, for manufacturing operations, in handling in and out of machines
  - Flow: Machines that can be linked/connected together by automation
  - Products that are suitable for automation: quantity, variants, design.
- Identify tasks with poor ergonomics such as:
  - repeated heavy lifting/manual handling
  - Short-cycle, repetitive tasks
  - Inappropriate working postures

Map out individual automation candidates

Produce a general description of possible automation candidates, in which the following are described for each automation candidate:

- manufacturing operation before and transport to
- manufacturing operation that is performed
    - total capacity utilization/shift in production at present
    - time for a manufacturing cycle
- handling and transport from
- next step in manufacturing process.

Describe relevant products

Produce a general description of products for each automation candidate:

- total number and number of variants
- sizes
- weights
- complexity
- ease of handling
- product requirements
- delimitations

The purpose of this step is to achieve a clear picture, based on facts about opportunities and challenges for automation with an efficient flow, before the next step.

Analysis of automation candidates

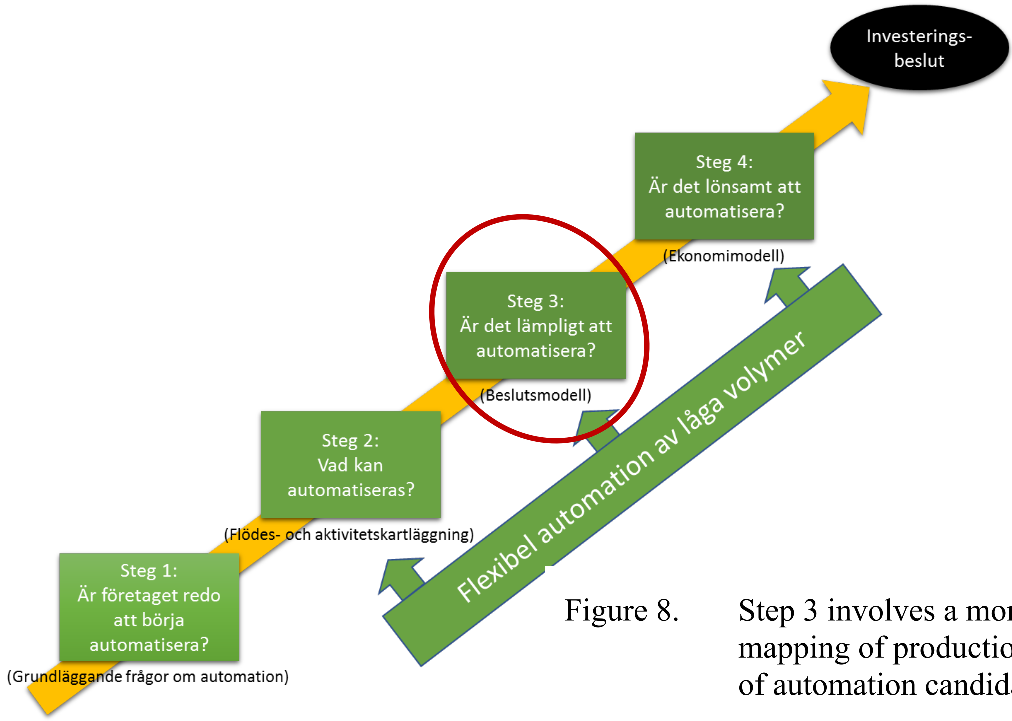

Figure 8. Step 3 involves a more detailed mapping of production and analysis of automation candidates identified.

Step 3: Is it appropriate to automate?

Automation candidates that have been identified in step 2 are evaluated in step 3, Figure 8, with:

- mapping of the materials flow, Figure 9 (also available as Excel document)
- mapping of operator activities, Figure 10
- ergonomic analysis, Figure 11
- work content analysis, Figure 12
- decision-making model for assessment of a specific activity, Figure 13.

Mapping of the materials flow for flexible automation of machine resources

Individual machine resources in the materials flow are mapped. See table below and Figure 9 for a grouping of questions and examples:

Machines	Name, model, flexibility, level of automation
Utilization	On annual basis, number of people per shift, bottleneck?
Products manufactured	Order length, total quantity, series sizes, small batches for manual machine operation, form of automatic handling
Material handling and materials flow	Structure of incoming material, size, weight, structure of material transport operations
Ergonomics	Heavy lifting, bending, inappropriate working postures, repetitive tasks
Summary	Loading, programming times for automation/robots, flexibility requirements

Produktionskartläggning för flexibel automation av maskinresurser

Maskiner			
		Maskin 1	Maskin 2
Maskinbenämning		Skivkap	kap
Maskintyp		Skivkap	kap
Fabrikat		Schelling	Weining
Modell			Opikap S50 ny
Tillverkningsår			
Är maskinen flyttbar?	ja/nej	nej	nej
Har maskinen förberetts för automation:			
finns automatläge?	ja/nej	ja	ja
krävs manuell fastsättning av detaljer med verktyg idag?	ja/nej	nej	nej
Beläggning			
Snitt beläggning över året (antal skift)	antal skift	2,25	2
Antal personer per maskin/skift		1	1
Flaskhals ibland	andel av tid (%)	ja	ja
Planeringshorisont	veckor	4	4
Snitt arbetstimmar/skift ((*ingår i bedömning av ergonomi*))			
Produkter som tillverkas			
Orderlängd (snitt)	månader		
Uppsägningstid order (snitt)	månader		
Antal artiklar totalt	st		
Antal nya artiklar per år	st/år		
Seriestorlek		100%	100%
Viktigt att kunna köra maskin manuellt för korta order eller komplexa detaljer?	ja/nej	ja	ja
< 100 st	andel av total voym (%)	30%	30%
100-500 st	andel av total voym (%)	70%	70%
500 - 1000 st	andel av total voym (%)		
1000 - 10 000 st	andel av total voym (%)		
> 10 000 st	andel av total voym (%)		
Normal maskin cykeltid (enbart maskin)	s	2	15
Normal total cykeltid (maskin + in/ut)	s	25	25
Normalt antal omställningar / vecka			
Form på detaljer inpall (för robot att greppa)		100%	100%
två dimensionella, enklare former, enkla att positionera	andel av total voym (%)	100%	100%
tredimensionella detaljer, med enklare former	andel av total voym (%)		
två dimensionella, gemotrier som är svår att orientera och kräver precision	andel av total voym (%)		
tredimensionella detaljer, med komplexa former	andel av total voym (%)		
mjuka detaljer	andel av total voym (%)		
annat som komplicerar grepp av robot	andel av total voym (%)		
Förändrad form på detaljer efter maskin (för robot att greppa)		100%	100%
samma/liknande form som innan maskin	andel av total voym (%)		
två dimensionella, enklare former, enkla att positionera	andel av total voym (%)	100%	100%
tredimensionella detaljer, med enklare former	andel av total voym (%)		
tredimensionella detaljer, med komplexa former svåra att greppa	andel av total voym (%)		
operatör måste göra något speciellt ibland t ex inspektion	andel av total voym (%)		
kvalitetsbrist från maskinen	andel defekta av totalt antal (%)		
Materialhantering och produktionsflöde			
Struktur på inkommande material		100%	100%
strukturerat i pall (tydliga högar, staplar, positioner)	andel av total voym (%)	100%	100%
rack	andel av total voym (%)		
magasin	andel av total voym (%)		
inbana	andel av total voym (%)		
icke orienterat i pall (huller om buller)	andel av total voym (%)		
risk att detaljer krokar i varandra	andel av total voym (%)		
annat	andel av total voym (%)		
storlek, min	mm		
storlek, max	mm	1200x3000	4000
Vikt, min	kg		
Vikt, max	kg	30	30
Struktur på materialtransporter			
Normal ordningsföljd mellan maskiner (1 första, 2 andra etc)			
Maskiner som i mycket hög grad används efter varandra	andel av tid (%)		
Annan operation görs direkt före maskinen (bearbetning, häftsvetsning, avsyning)	ja/nej		
Annan operation görs direkt efter maskinen	ja/nej		
Ergonomi			
Tunga lyft / hantering (> x kg, y timmar)	andel av total volym (%)	100%	100%
Böjd/vriden arbetsställning	andel av total volym (%)	100%	100%
Arbete i/över axelhöjd	andel av total volym (%)		
Arbete under knähöjd	andel av total volym (%)	40%	40%
Axel-, hand-, armbelastning	andel av total volym (%)	50%	50%
Repetitiv arbetscykel (ersätter *"Monotont..*))	andel av total volym (%)	100%	100%
Tillbud och olyckor (ersätter *Säkerhetsproblem)*	antal senaste året		
Organisering av arbetet (rotation, adm uppgifter etc ev fler rader)			
Sammanställning - automation			
Beläggning automation (grov uppskattning)	antal skift	1,6	1,4
Beläggning manuellt (grov uppskattning)	antal skift	0,7	0,6
Uppskattad programmeringstid (snabb & enkel robotprogrammering, ca 10 min/artikel)	timmar	0	0
Uppskattad programmeringstid (traditonell robotprogrammering, ca 3,5 tim/artikel)	timmar	0	0
Behov av flyttbarhet - Manuell betjäning viktig	Bedömt behov av flyttbarhet (ja/nej)	ja	ja
viktigt med manuell access		ja	ja
låg beläggning (< 1,5 skift med automation)		ja	ja
många olika artiklar			
låga seriestorlekar ibland		ja	ja
detaljer svåra att greppa inpall ibland			
detaljer svåra att greppa efter maskin ibland			
operatör måste göra något speciellt ibland t ex inspektion			
svår struktur på detaljer ibland			
Automationslämplighet med snabb & enkel robotprogrammering (negativt tal visar mycket stor programeringsinsats)		229	204
Automationslämplighet med traditonell robotprogrammering (negativt tal visar mycket stor programeringsinsats)		229	204
Ergonomi	index (ju högre destå värre)	390	390

Figure 9. Mapping of the manufacturing steps for flexible automation of machine resources. Available as Excel document.

Focus on safety

Safety is of central importance in connection with automation in order to avoid accidents, other injuries and near-accidents. In addition to directives and standards, the Swedish Work Environment Authority has special regulations with regard to machines, AFS 2008:3 Machinery (ref. no. 7 that must be observed). Prevent has a checklist for machines, "Maskiner – Användning" (*"Machines – Use"*), http://checklists.prevent.se/checklist/answer/70, which also covers other applicable regulations (reference no. 8).

Map out operator activities and ergonomics, safety and risks

Map out operator activities for each automation candidate

LoHi:	Operatör A	Operatör B	Maskin	
Aktiviteter per cykel				
Ladda				minuter/produkt
Tillföra värde				minuter/produkt
Lossa				minuter/produkt
Placera i färdigläge				minuter/produkt
Aktiviteter per batch eller order				
Ställ maskin				minuter/batch
Hämta pall				minuter/batch
Transport från platsen i pall				minuter/batch
Kvalitetskontroll				minuter/batch
Rapportering				minuter/batch
Aktiviteter per ny produkt i maskinen				
Antal nya produkter per år				
Beredning utanför maskin av operatör				minuter/produkt
Beredning i maskin av operatör				minuter/produkt
Övriga aktiviteter (facility activities) för alla produktkategorier				Gemensamma för båda kategorierna
Rast då maskin står stilla				minuter/dag
Rast då maskin går				minuter/dag
Personlig tid				minuter/dag
Störning maskin				minuter/dag
Operatör arbetar i annan maskin				minuter/dag
Planerat underhåll maskin				minuter/dag
Skiftöverlapp eller möten				minuter/dag
Annat				minuter/dag

Figure 10. Tool for mapping operator activities.

Map out operator ergonomics (physical exposure, work content, psychological strain) for each automation candidate

Based on selected product/product family/product mix and estimate the proportion of time as a % that the work involves (see Figure 11).

- heavy lifting / manual handling
- bent and/or twisted working posture
- work above shoulder height
- work below knee height
- physical strain on arms
- repetitive work, monotonous movements.

Guidelines for assessment of:

- Heavy lifting / manual handling:
    - There should not be any lifting/handling of weights of 25 kg or more.
    - Work involving the handling of weights of 15 kg to 25 kg should be evaluated in further detail. Frequency must also be taken into account.
    - Work involving the handling of weights of 7 kg to 25 kg within underarm distance (no more than approx. 30 cm from the body) should be evaluated in further detail. Frequency must also be taken into account.
    - Work that involves the handling of weights of 3–7 kg should be evaluated in further detail, depending on the distance from the focus of the load. Frequency must also be taken into account.

- Repetitive work
    - Repetitive work means similar work movements (monotonous movements) being performed time and time again, often at a high pace. If the work is controlled or tied to a location, for example work at a assembly line, the individual has less opportunity to influence. Consideration should be given to the time the work movements are carried out – the physical exposure is more varied if there are other kinds of tasks.

Note that that the total of the percentages can exceed 100%, as there can be several different kinds of physical exposure. For further guidance in assessing the ergonomic conditions, see the Swedish Work Environment Authority's regulations, AFS 2012:2 Ergonomics for the Prevention of Musculoskeletal Disorders, with assessment models (reference no. 5).

Automation candidate	**Heavy lifting/handling %**	**Bent/twisted working posture %**	**Work above shoulder height %**	**Work below knee height %**	**Physical strain on arms %**	**Repetitive work, monotonous movements %**

Figure 11. Screening tool for analysis of operators' ergonomics (physical exposure) in each automation candidate for low-volume production)

Work content

Variation of tasks

1. To what extent does the work provide *variation*?

1-------------------2-------------------3-------------------4-------------------5

Not at all | To some extent | To a very large extent

Identity of task

2. To what extent does the work result in an operator performing a "*whole, identifiable part of a job*"?

1-------------------2-------------------3-------------------4-------------------5

Not at all | To some extent | To a large extent

Importance of the work for others

3. How important is an operator's work to the customer or the end user?

1-------------------2-------------------3-------------------4-------------------5

Not at all important | Moderately important | Extremely important

4. How important is an operator's work to the next stage or process?

1-------------------2-------------------3-------------------4-------------------5

Not at all important | Moderately important | Extremely important

5. Is the operator aware of the importance of his/her own work to subsequent stages?

1-------------------2-------------------3-------------------4-------------------5

Not at all | To some extent | To a large extent

Psychological strain

22. To what extent does work take place under constant time pressure because of a high workload?

1-------------------2-------------------3-------------------4-------------------5

To a very large extent | To some extent | To a very small extent

23. Does the work tend to require overtime or cancellation of breaks?

1-------------------2-------------------3-------------------4-------------------5

Yes, often | Sometimes | No, not at all

Figure 12. Work content and psychological strain. Questions taken from "PPA-metoden, En metod för att bedöma produktivitetspotentialen i verkstadsindustrin" (*"The PPA method – a method of assessing productivity potential in the manufacturing industry"*) R 2006:17, Chalmers, published by NUTEK (reference no. 6)

Decision-making model for assessing the automation of a specific activity

This step involves continued work, after mapping and analysis, on a decision-making model (Figure 13) to determine whether activities identified are appropriate for automation.

- Conditions for using the decision-making model:
  - The products/product types being manufactured at present have been identified
  - The materials flow has been mapped out
  - Activities performed at present by operators have been identified
  - The activity to be analysed must be generally appropriate for automation (may not have requirements for creativity or problem-solving, not too much or random variation in how the activity needs to be performed, etc.).

- Work method with decision-making table in Figure 13:
  - Select activity for an automation candidate
  - Assess the activity on the basis of all points 1–8
    - If “Yes”, highlight “Yes” in different colour and go on to next point
    - If “Maybe”, investigate the issue with a more detailed analysis
    - If “No”, move on to next point.
  - If all 8 points are “No”, the activity is not appropriate for automation.

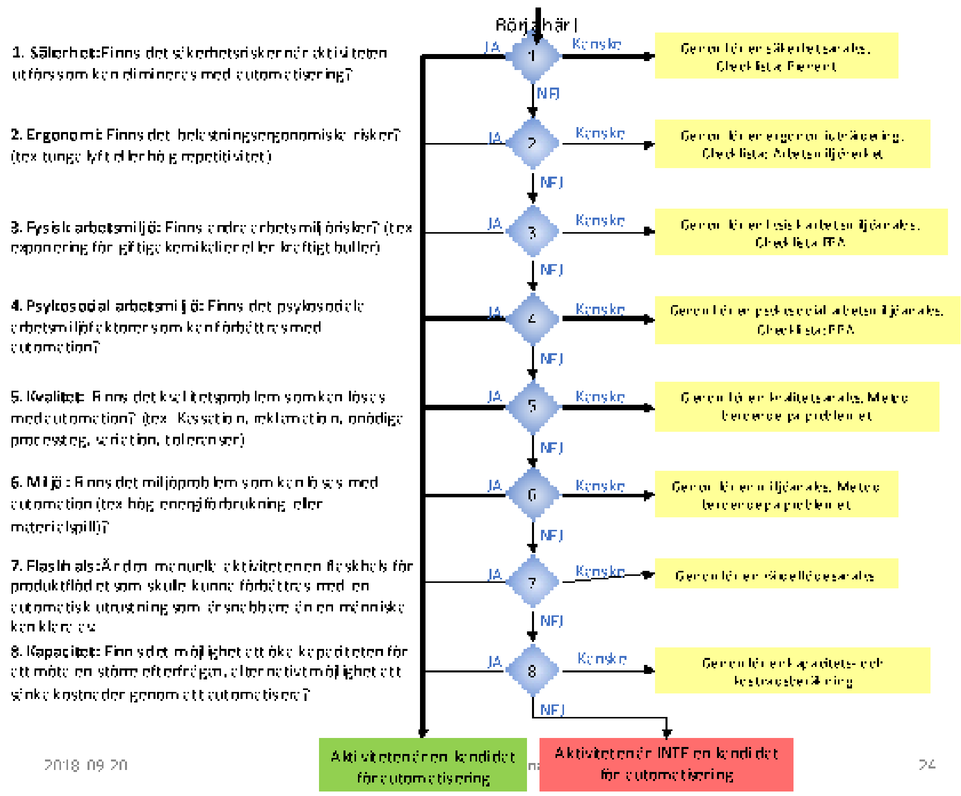

Figure 13. Decision-making model: Suitability for automating a specified activity.

Is it profitable to automate?

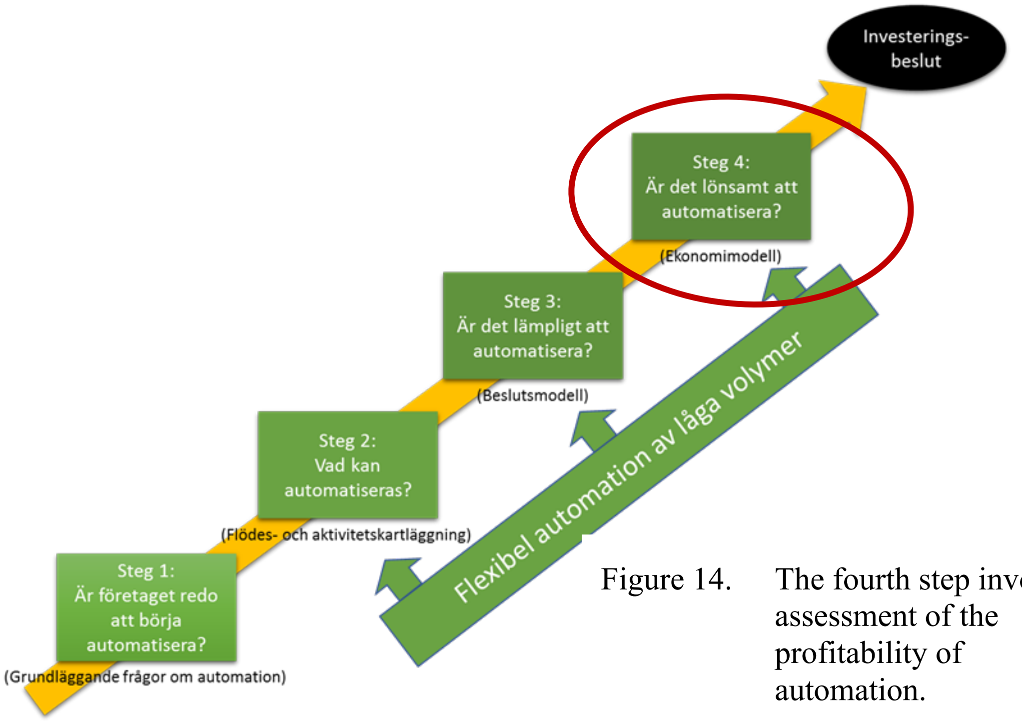

Figure 14. The fourth step involves assessment of the profitability of automation.

Step 4: Is it profitable to automate?

The ultimate requirement for the flexible automation solution is that it must be economically profitable, in both a short-term and a longer-term perspective. Step 4, Figure 14 describes how an economic production model can be used as base data for the investment in the flexible automation solution. The model can also be used as base data for capacity decisions on the flexible automation solution. The model and the instructions are in Figure 15.

- The manufacturing operation before an automation candidate
- Handling and transport to and from
- Next step in manufacturing process after the automation candidate.

The purpose is to achieve a clear picture of opportunities and challenges for automation with an efficient flow before the next step.

Calculating the actual level of economic profitability is a challenge when the automation solution is part of a value chain and when the ergonomic benefits can be difficult to calculate. The model applies only to a specific activity (typically Load/Unload a machine) that has been identified in an earlier step in the guide.

A simple, flexible model has been chosen for a machine. The model can be reused, depending on conditions and needs. If you want to calculate for several machines, save the model with a new name and perform a new calculation.

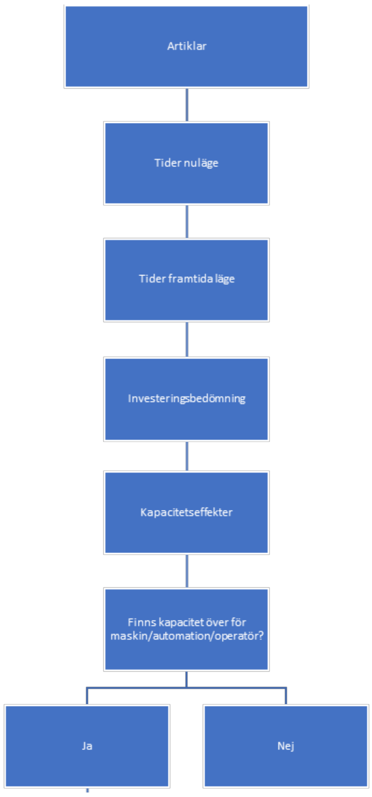

Figure 15. The economic production model for flexible, low-volume production.

The model is based on analysing the current state based on articles running in the machine, and the future situation with a flexible automation solution is then analysed in the same way. The result indicates capacity effects together with cost, contribution margin and payback time for the flexible automation solution. The model also analyses the setup times for the current state and the future with flexible automation.

When you start to analyse data, it is natural to look for improvements in the workplace layout and the structure of the operators' work. To get a clear picture of the current state and future state, improvements are not analysed in the model, as this changes the basic conditions for production, but not for the automation investment. Improvement is always a positive thing. If production is improved together with an investment in flexible automation, the effect is even greater. This is a new analysis in itself. If you see opportunities for improvement while you are using the model, return to the analysis of the current state and enter the improvements both there and in the future state in order to achieve a fair picture of capacity effects and economic profitability.

Next steps

The guide assists the company to make strategic and better decisions about the next step in its development of automation.

The guide's work method involves working step by step to describe, analyse and consciously choose appropriate candidates and activities for the flexible automation of low-volume production.

Facts about production and automation

Robot safety – to bear in mind

A robot is not CE-marked, but complies with the EU Machinery Directive 2006/42/EC, Annex II 1. B for a partly completed machine. A robot is not a completed machine until it is fitted with a clamp device and integrated into a robot cell. It is therefore the party that assembles the robot, clamp device, safety solution and machine/station to create a robot cell that must CE-mark the robot cell in accordance with the EU Machinery Directive 2006/42/EC, Annex II 1. A

For collaborative robots there is a special ISO standard, ISO/TS 15066:2016. When the work area is shared with a person there are tougher demands, with force, speed and risks being considered carefully. A collaborative robot with a teddy bear in the gripper is safe, but as soon as you have something sharper in it the risks increase significantly, as these robots normally stop at a force limiter when the robot comes into contact with an object or person, e.g. a sheet of metal, metal object against the head, soft tissue or other sensitive area. For more information, here is something to read:
https://www.robotics.org/userAssets/riaUploads/file/6-Pat.pdf

The Swedish Work Environment Authority has special regulations with regard to machines, AFS 2008:3 Machinery, the Swedish Work Environment Authority's regulations on machinery and general advice on the application of the regulations. If changes are made in the production, a risk assessment must also be performed in accordance with the regulations on Systematic Work Environment Management, AFS 2001:1. A robot installation is also subject to other regulations that apply to, for example, the layout of the workplace.

Ergonomics

Work in production may involve various kinds of physical exposure. Risk factors are, for example: inappropriate working postures, heavy manual handling, repetitive work (monotonous movements).

When assessing the ergonomic conditions, consideration should be given to both the individual tasks and the employees' total work content (the sum of the tasks performed by each employee). The time for the different tasks is also an important factor in making an assessment.

When identifying the ergonomic risks, it is important not to have too narrow perspective, as the source of the risk may be in a different production step than the actual risk itself. People sometimes talk in terms of "residual work tasks", often at the beginning or end of a production flow, that may arise in connection with changes to production – one example of this is manual packing.

Work content and the psychological strain should also be considered, including for example:

- Demands (work pace, time pressure, etc.)
- Control (degree of opportunity to have an influence on what, when and how something is produced)
- Information, instructions and signals that may require action
- Communication (with other employees, management, information flow, etc.).

Skills and skills development

Focusing strongly on both individual and team development is a successful work method in companies to build the future industrial work. Flexibility increases, and for each individual employee there is a greater opportunity to have an influence, and at the same time the individual's skills are highlighted. Figure 16. A distinctive feature is an increased focus on closeness, with:

- Leadership that is present in day-to-day work

- New forms and means of communication.

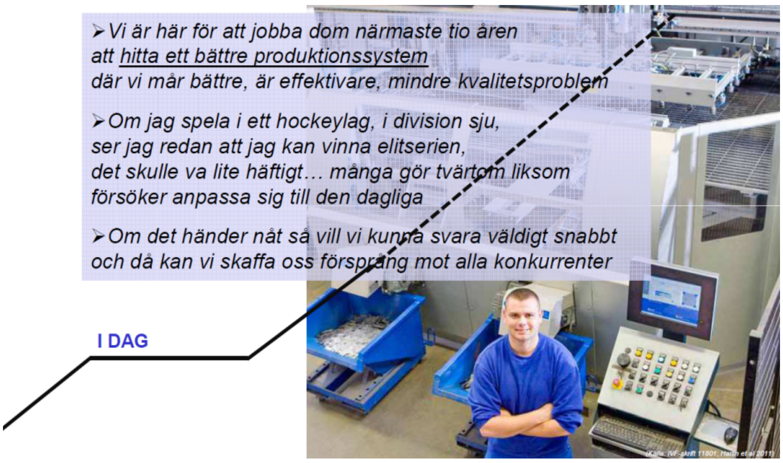

Figure 16. Developing industrial work and employees' skills is a competitive factor, especially in flexible, low-volume production.

The significance of engagement

A method of systematically analysing and improving the conditions for engagement among employees in companies has been produced by Swerea IVF (now RISE IVF). Figure 17 describes ten thematic areas in the method. Read more at http://res.ivf.se/survey/

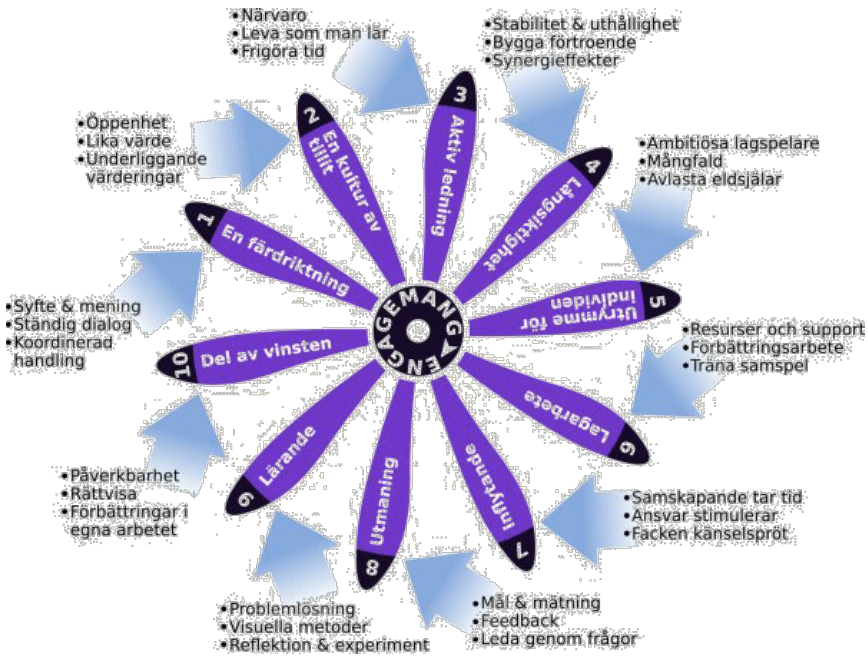

Figure 17. Ten thematic areas that build engagement.

Lead time: Value creation and waste

The materials flow in manufacturing companies can be followed relatively easily from incoming delivery to outbound delivery from the company. The time required to add value to the material is often negligible compared with the time the material is in the factory, Figure 18.

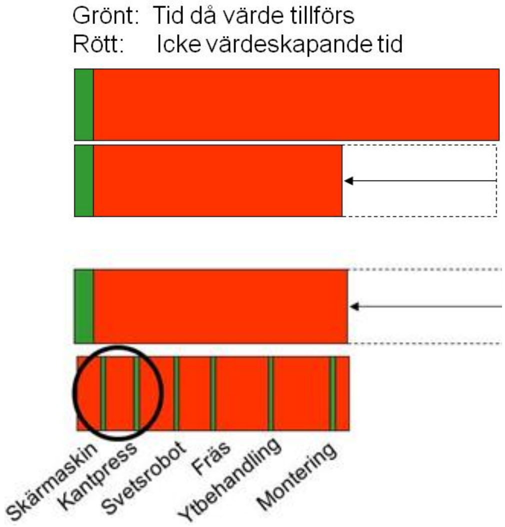

Figure 18. Material flows that take a week to pass through a factory (red) can have a value-adding time for cutting, jointing, surface treatment and assembly of 15 minutes in total (green). The greatest effect is to reduce the time that does not create value (red).

In a factory, value (green) is created in production cells in different places. Special challenges for flexible production are to create efficient material flows and quick changeovers.

Profitable series size and manual operations

For flexible, low-volume production to be profitable, there must be quick changeovers. Be careful to differentiate between series size and batch size.

- Series size is the quantity for an article over its known useful life.
- Batch size is the volume manufactured on each occasion.

If you are a subcontracted manufacturer, you may not even know whether the same article will reappear at all.

Profitable series size for robots depends on:

1. The time it takes to program the robot
2. The time and cost of making sure that the part can be run using a robot, e.g. that there is a gripper device and that the part can be grasped and presented to the robot.
3. Anything else that might be a challenge for a robot.

Profitable series size can easily be estimated as the series size that you can run manually during the time for the three points above with flexible gripper devices. **Example:** With simple programming that normally takes 10–20 minutes and for traditional programming approx. 3–4 hours or more.

Profitable batch size is determined by how much extra time it takes to load a product in the robot and to convert the gripper device, for example, plus the time that is feels reasonable for the operator to do something else. **Example:** It normally takes approx. 2–5 minutes for most robots, plus the time that feels reasonable for the operator to do something else, by estimating, for example, more than 10–15 minutes if the changeover is not done automatically.

Manual access important Experience tells us to expect a flexible robot to be able to perform, for example, 70–90% of manufacturing, while manual operation of the machine is needed, for example, for 10–30%. The reason for manual operation is short/small batches and parts that cannot be gripped by the robot. Having the opportunity for manual operation is one of the most important reasons for using a flexible robot.

Changeover efficiency

One principle for efficient materials flows through a factory is to achieve quick changeovers for the manufacturing of different products without needing to tie up capital in large batch sizes. **Being able to achieve quick changeovers is absolutely fundamental for flexible, low-volume production.**

Improved work methods and new technical solutions make it possible to move gradually towards profitable industrial small-batch manufacturing or even single-unit manufacturing.

With quick changeovers, customers can be offered deliveries in small batches, based on needs. This means that one large customer delivery does not lock the whole factory for other customers. With quick changeovers, customers can be offered a lower price if they do not order the same number of similar articles each time.

SMED

This stands for Single Minute Exchange of Die, to replace a tool in no more than 9 minutes, the number 9 being the highest single-digit number. In general terms, SMED means doing quicker changeovers. The focus is on preparing the changeovers before production stops, so-called external setup.

Flexible robotics – to consider

A robot is very good at repeating, performing monotonous tasks without stopping. Even if it is now possible to program a robot quickly with new technology, the challenge is to be able to present the parts to the robot and for the robot to be able to grip the part. It is therefore usually important to be able to supplement this with a human being when the brain and dexterity are needed or in connection with, for example, single-unit or small-batch manufacturing.

Make sure you keep the material in order to make it easy for the robot. The robot prefers structure, which is usually easy to create. If you have structure and order in your material, you must not lose the structure, e.g. let a robot or a machine release a part down into a pallet or box where the parts are not lying in order.

Vision systems exists, but there are still technical challenges to be met, such as fine-tuning of shadows and reflections, to enable these vision systems to see and perceive the parts correctly in order to avoid stoppages. Vision is a challenge in high-volume production, but a much bigger problem in small series as even more fine-tuning is needed. Picking from a pallet of parts not lying in order is possible with a robot, but it is a major challenge and may only work for certain kinds of parts.

Automate the low-hanging fruits. There are often many simple and very good robot jobs that can be easily automated. Examples of this are most kinds of machine handling and material handling, as well as palletizing in all industries.

It is easy to want too much and to create very complex automation that both costs a lot of money and also has problems with robustness.

Monotonous, heavy and risky tasks make it difficult to find staff, and result in low productivity, which results in losing out in global competition. SMEs make up more than 90% of the engineering industry in Sweden and are often important workplaces in sparsely populated areas.

Read more in reference no. 3, Löfving, M., Almström, P., Jarebrant, C., Wadman, B. and Widfeldt, M. (2018), Evaluation of flexible automation for small batch production.

Robot trends

The International Federation of Robotics (the industry organisation for all robot manufacturers) emphasises that the drivers for flexible automation are more important now than ever before, as we are moving quickly towards high mix and low volume (i.e. small series and several variants). This affects not only smaller subcontractors but also large OEMs (Original Equipment Manufacturers) with their own products, and Tier 1 subcontractors, where quick changeovers and flexible lines have become important. The major OEM and Tier 1 suppliers want to be able to combine production as much as possible and be able to optimise manufacturing.

Figure 19. Drivers for automation Source: IFR

This means that the trend among large OEMs and Tier 1 suppliers is to create flexible lines that can be set up quickly. This often means that lines are broken up into smaller sections to increase flexibility and flow. This means in turn that tougher and tougher demands are being placed on all subcontractors, especially those further down the chain. Bottlenecks are now dynamic rather than static.

The Tier 1 subcontractors that have previously been used to being able to manufacture a product on three-shift setup for three years are now facing serious challenges when they have to change over to increased flexibility, with more products having to be combined with quick changeovers, varying volumes and shorter order runs.

More information about trends can be downloaded from the International Federation of Robotics at https://ifr.org/free-downloads

The four revolutions in the field of robotics

KUKA describes the different robotic revolutions according to the figure below.

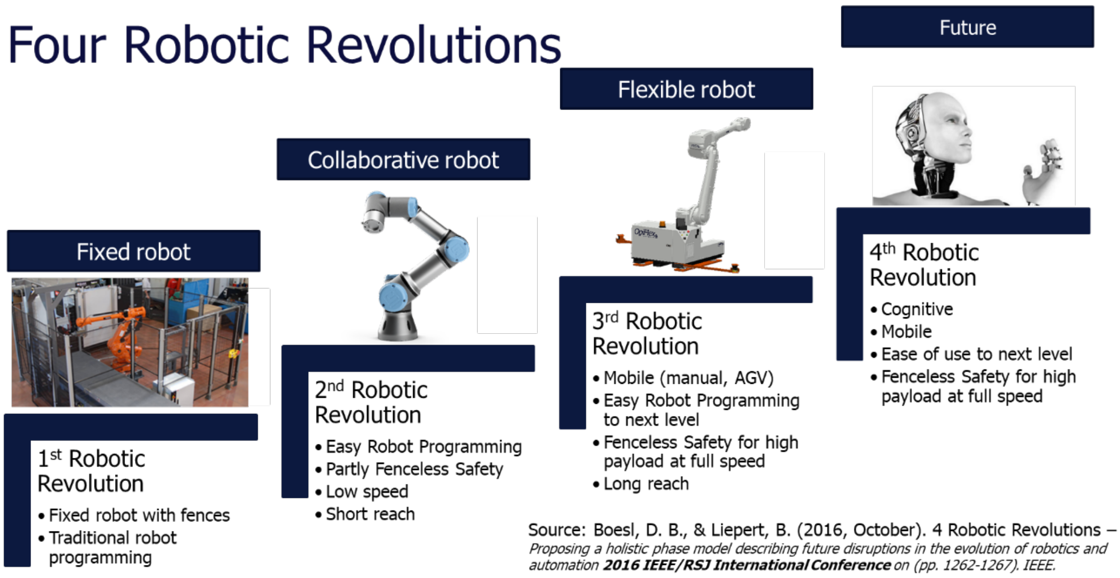

Figure 20. The four robotic revolutions. Source: KUKA.
Original Source: Boesl, D. B., & Liepert, B. (2016, October). 4 Robotic Revolutions – Proposing a holistic phase model describing future disruptions in the evolution of robotics and automation 2016 IEEE/RSJ International Conference on (pp. 1262-1267). IEEE.

1. **The first robotic revolution: "Fixed robots"** – traditional robot solutions with fixed robot, fence and traditional robot programming. Has been used mostly for high-volume production with few variants. These robot solutions take time to install and can sometimes take up a lot of space because of the fence. Programming is undertaken by writing code in the relevant robot supplier's language, normally 3,000–4,000 lines of code. It often takes time to change program for a new article, as the code has to be changed. Can be difficult to achieve a flexible solution for high mix and low volume. Examples of manufacturers: all robot manufacturers.
2. **The second robotic revolution: "Collaborative robots"** – new kinds of robots that are easier to use, can be used partly without a fence, run slowly and stop when someone accesses them. If there is a risk that someone can come to harm from something in the gripper device, they need to be placed behind the fence. Programming is often easier than for traditional robots, but still requires all the logic and connection with the machine or equipment in order to work. These are intended for use primarily when people and robot need to collaborate. Examples of manufacturers: Universal Robots (UR3, UR5, UR10), KUKA (LBR iiwa); ABB (Yumi), Yashawa (HC10, SDA, SIA), Sawyer, Doosan.

3. **The third robotic revolution: "Flexible robots"** – large mobile robots without fences, at full speed and simple robot programming at a new level, with a new kind of flexibility. They can be moved manually or automatically, and can be operated at full speed without a fence, which means that they can be used on one machine or easily shared with several machines and provide full manual access to the machine. They have also taken easy robot programming to the next level in which the robot is already aware of how the machine and the robot cell work. The robot creates its own program by means of the operator showing in which order it has to operate the machines/stations, answering a few simple questions and showing, for example, how it wants to grip an object or insert it into the machine. Examples of manufacturers: OpiFlex (MRP10, MRP20, MRP60 with ABB robot)

Production finance

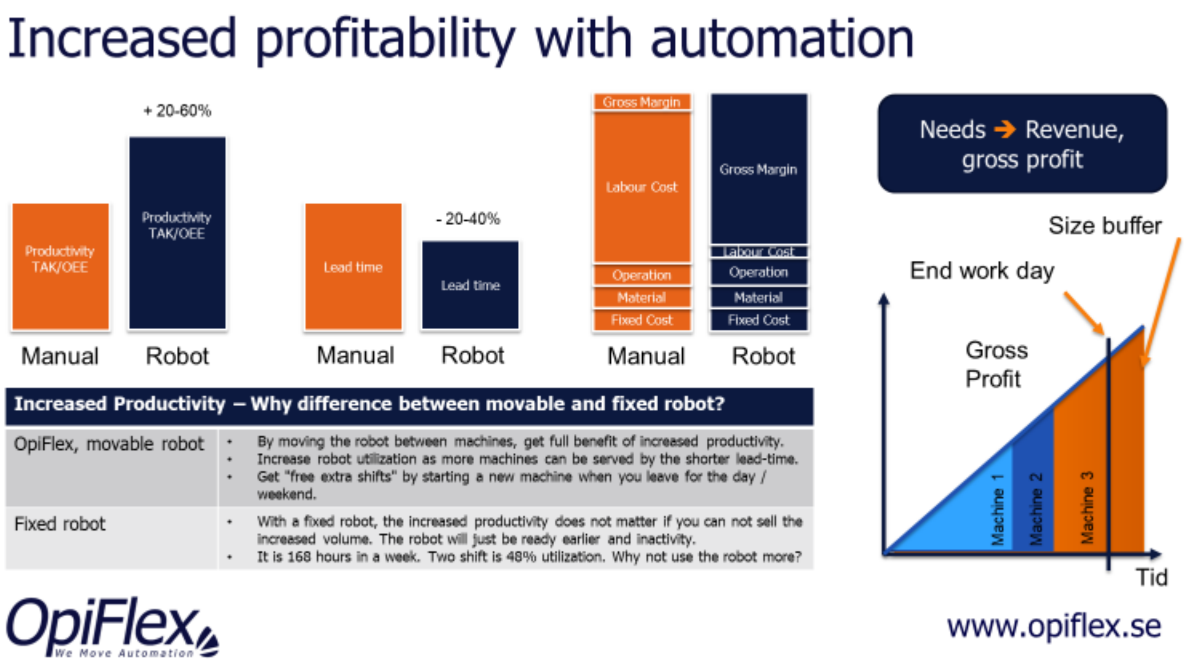

Figure 21. Effects of flexible robotics.

A robot can, for example, increase productivity by 20–60%, which means that lead times are reduced by 20–40%. The major benefit is that staff costs disappear. This means, in the example, above, that the contribution margin of SEK 0.8–1.2 million per shift of robot loading can be calculated at SEK 350/hour in payroll cost including social insurance and overheads.

Assume that a machine runs eight hours manually, in which case a robot has finished in approx. six hours, based on the example in the last paragraph. If the additional volume that can be produced in the machine with the robot cannot be sold, there is no benefit from the productivity increase with a fixed robot. But the however, the increase in productivity can benefit from a mobile robot, as this can now be moved more quickly to the next machine, see figure above.

By placing the robot where the production time (quantity*cycle time) is a little longer, and there is a large buffer, it can constitute one free extra shift.

If, for example, two shifts are operating somewhere in the factory, an operator can fill an input pallet or output pallet as required, and then when shutting down move the robot to the desired machines and let it run overnight.

One trend is to pick from a pallet instead of an input or output conveyor. Consider that if an input or output conveyor is used, someone has to pick from the pallet, which costs money and is ergonomically stressful, and usually provides a much shorter buffer for night operation.

Market situation for small and medium-sized enterprises

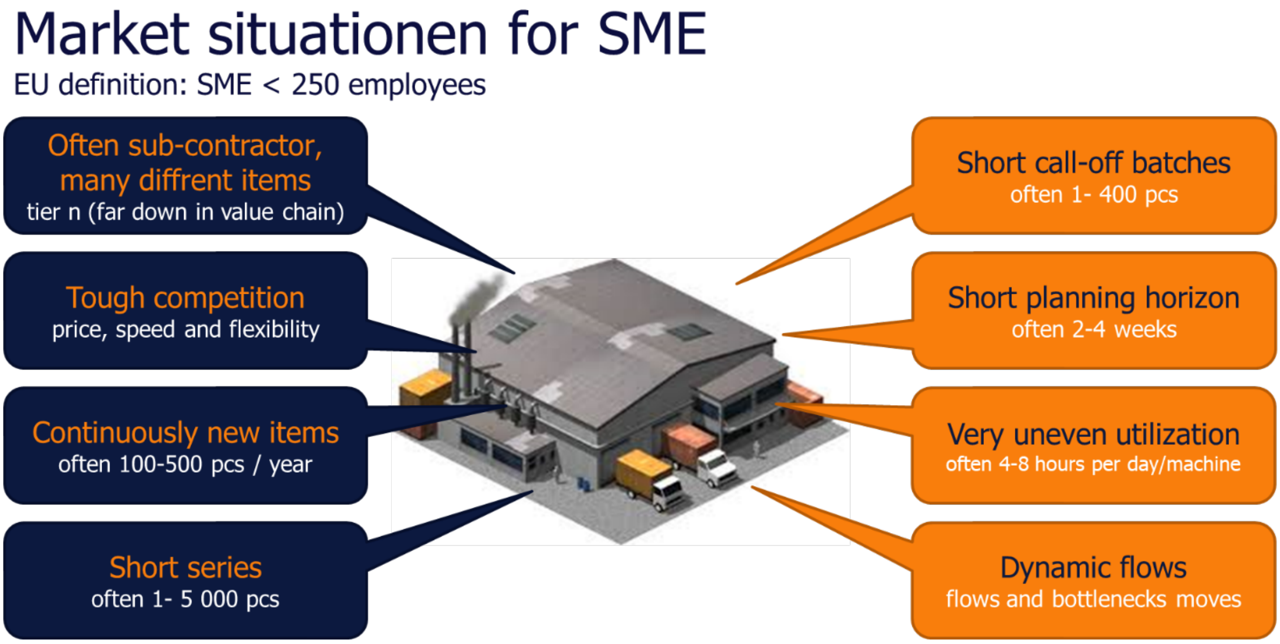

Figure 22. Market situation for small and medium-sized enterprises (SMEs).

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