REMODEL - Robotic tEchnologies for the Manipulation of cOmplex DeformablE Linear objects

Deliverable 2.5 - First assessment of system performance

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1 Introduction

This deliverable will report the system performance from the point of view of the impact Imp1, Imp2 and Imp3 measured through periodic measurements and surveys carried out at different project development stages.

This first release of the deliverable will establish the comparison basis for the evaluation of the project impact that will be assessed during the next releases of this deliverable planned at M32 and M48.

2 Evaluation of project impact

The following table summarizes the REMODEL project expected impact with respect to the call topic:

Expected impact from the topic	Expected REMODEL impact
Imp1 Demonstrating the potential to bring back production to Europe	To achieve competitive and sustainable manufacturing in high-labor costs regions like Europe, performance must be radically increased by smart manufacturing systems. To this end, the REMODEL project will: • Reduce time to market from 10% to 27% depending on the use case; • Increase customization capabilities; • Introduce product documentation and traceability for better quality assessment.
Imp2 15% increase in OECD Job Quality Index through work environment and safety improvement	The REMODEL project will impact on job demands: • Reducing time pressure, which encompasses long working hours, high work intensity and working time inflexibility by assigning to the robot time-consuming tasks; • Reducing physical health risks through augmented ergonomics, by reducing exposition to hard work, e.g. painful/tiring positions, awkward postures, low-load high-frequency manual material handling and tool usage, by exploiting the robot DLOs manipulation. The REMODEL project will impact on job resources: • Release workers from repetitive and stressful tasks execution and move them to more qualified and decision-making activities; • Improving workers' self-efficacy in their job through a better exploitation of their competences in close relationship with robots' capabilities. The impact will be verified by quantitative risk assessment techniques that are required by regulations and standards on occupational safety (e.g. NIOSH LI, OCRA method, Strain Index, TACOs) and reduction of absenteeism rates.
Imp3 20% increase in productivity	Manufacturing tasks documentation and planning from product design results in: • From 10% to 30% of the manufacturing reduction time; • Possibility of robotized products pre-processing during nighttime, potentially triple the production of partially assembled products to be reprocessed by workers during the working hours.

Imp1 and Imp3 will be evaluated taking into account the data about the production of industrial partners and underline how they will be affected by the technologies introduced along the project.

On the other hand, Imp2 will be evaluted through a preliminary analysis of the OECD Job Quality Index. The analysis will be here presented for the actual state of production at the industrial partners on the basis of the data collected in D2.3 adopting one of the method reported in literature, e.g. the Strain Index method. The following tables summarize the way of measuring the quality of the working environment.

Measuring and Assessing Quality of Working Environment (Imp2)

Dimensions	Description	Indicators	How the contribution will be measured
Job Demands - Time pressure at work - Physical health risk factors **Job Resources** - Work autonomy and learning opportunities - Workplace relationships	Non-economic aspects of employment. They include the nature and content of the work performed, working-time arrangements, workplace relationships as well as opportunities for training and self-improvement.	Incidence of job strain (more job demands than the number of available resources) among employees	The project will increase the work environment and improve the safety records of the organizations. In specific, the project will reduce the incidence of Job Strain. In WP2, Job strain for the selected scenarios will be assessed at the beginning of the project. New assessment will be repeated in WP2 to evaluate the project impact at M32 and M48 considering the worker supporting the development of REMODEL technologies and the robotic platforms validated at TRL5 and demonstrated at TRL6 in WP7.

The project will reduce the incidence of job strain (Imp2) through:

Reducing Job Demands	Increasing Job Resources
Reduction of time pressure - less tendency to work at very high speed and to tight deadlines - reduce the need of repetitive manual tasks	Increase of work autonomy and learning opportunities - more freedom to change the order of tasks - more opportunities to change methods of work - new skills to acquire attending training on effective HRC - informal learning opportunities at work on development of HRC
Reduction of physical health risk factors - reduction of tiring and painful positions - decreased crouch down and arm stretch up	Improvement of workplace relationships - better relationship with colleagues and leaders due to less time pressure, more orientation to safety and new learning opportunities - more social support and positive organizational climate - improvement in work-life balance
Reduction of ergonomic risk factors - awkward postures (static and dynamic) - low-load high-frequency manual handling	Improved working conditions and performances of workers - Increased work ability and stay at work for aged workers on high-quality jobs - Increased employers' ability to prevent early exit of skilled and trained workers from labor market and employment on highly qualified positions

3 Production of industrial partners in 2019

The data reported in the following tables represent the actual production capability of hte REMODEL industrial partners. These data are used as basis to evaluate the impact of the REDEMOL technology from the point of view of Imp1 and Imp3.

The data are collected according to the scheme reported in the following table:

KPIs	Unit	2019 production
Annual production	Items/year	X1
Mean cost per unit	Euro/item	X2
Mean production time	Person hours	X3
Overall production time for all products	Person hours	X1*X3
Mean time for the activity the REMODEL robot will carry out (X4)	Person hours	X4
X4 over total production time	%	100 * X4/X3
Mean salary of operators	Euro/hour	X5
Mean cost of X4	Euro/item	X5*X4
Mean X4 cost per unit	%	100 * X5*X4/X2
Mean time to market	Days	X6
Index of delivery delay / non-compliance at the final test	% Estimated time /Actual time	X7
Traceability of wiring and tests	--	Absent/Partial/Total
Sales volume	Euro/year	X8

3.1 IEMA

KPIs	Unit	2019 production
Annual production	Items/year	670
Mean cost per unit	Euro/item	18500
Mean production time	Person hours	190
Overall production time for all products	Person hours	127300
Mean time for the activity the REMODEL robot will carry out (X4)	Person hours	120
X4 over total production time	%	63
Mean salary of operators	Euro/hour	26
Mean cost of X4	Euro/item	3120
Mean X4 cost per unit	%	17
Mean time to market	Days	35

Index of delivery delay / non-compliance at the final test	% Estimated time /Actual time	6
Traceability of wiring and tests	--	Partial
Sales volume	Euro/year	13000000

3.2 ELVEZ

KPIs	Unit	2019 production
Annual production	Items/year	365.000
Mean cost per unit	Euro/item	2,8
Mean production time	Person hours	0,04818
Overall production time for all products	Person hours	17.585,9
Mean time for the activity the REMODEL robot will carry out (X4)	Person hours	10
X4 over total production time	%	10
Mean salary of operators	Euro/hour	11,50
Mean cost of X4	Euro/item	0,02
Mean X4 cost per unit	%	13.1
Mean time to market	Days	8
Index of delivery delay / non-compliance at the final test	% Estimated time /Actual time	7
Traceability of wiring and tests	--	Total
Sales volume	Euro/year	977.483

3.3 ELIMCO

KPIs	Unit	2019 production
Annual production	Items/year	2460
Mean cost per unit	Euro/item	1544.10
Mean production time	Person hours	16.5
Overall production time for all products	Person hours	40 359
Mean time for the activity the REMODEL robot will carry out (X4)	Person hours	9.2
X4 over total production time	%	80
Mean salary of operators	Euro/hour	22
Mean cost of X4	Euro/item	202.4
Mean X4 cost per unit	%	13.1
Mean time to market	Days	8
Index of delivery delay / non-compliance at the final test	% Estimated time /Actual time	7

Traceability of wiring and tests	--	Total
Sales volume	Euro/year	6 133 302,43

3.4 VW

KPIs	Unit	2019 production
Annual production Each car is equal one cockpit	Items/year	177 676
Mean cost per unit Regarding to overall cost of factory over **each vehicle, concerns the costs only on these work station (cockpit wiring harness)**	Euro/item	50,49
Mean production time Concerns the time needed to finalize cokpit assembly	Person hours/item	0,88
Overall production time for all products Annual production number multiply by a mean production time	Person hours	156 947
Mean time for the activity the REMODEL robot will carry out (X4) – Ø40,56 seconds/item, mean time concerns the activities involving only the wiring harness arrangment	Person hours/item	0,0113
X4 over total production time	%	1,284
Mean salary of operators **Concerns the mean salary on this specific work station (cockpit wiring harness)**	Euro/hour	20,15
Mean cost of X4	Euro/item	0,228
Mean X4 cost per unit	%	0,45
Mean time to market **Concerns the time to release complete built vehicle to the market (e.g. to the car dealers)**	Days	23
Index of delivery delay / non-compliance at the final test **the time spent to fix defective products in percentage over the whole production time**	% Estimated time /Actual time	0,312
Traceability of wiring and tests **e.g. ECOS Test - 100% of Inspection**	--	Total
Sales volume **Concerns the full sale of all built vehicles**	Euro/year	2 400 577 920

3.5 ENKI

KPIs	Unit	2019 production
Annual production	Items/year	700000
Mean cost per unit	Euro/item	0.70 €
Mean production time	Person hours	2 People; 8 hours
Overall production time for all products	Person hours	11.200.000
Mean time for the activity the REMODEL robot will carry out (X4)	Person hours	8h per day
X4 over total production time	%	50
Mean salary of operators	Euro/hour	3000 €/months
Mean cost of X4	Euro/item	24000
Mean X4 cost per unit	%	34300

Mean time to market	Days	3 weeks
Index of delivery delay / non-compliance at the final test	% Estimated time /Actual time	0
Traceability of wiring and tests	--	Total
Sales volume	Euro/year	750000 €/year (of extruded tubes)

4 The Strain Index Method

The strain index method, proposed by J. S. Moore and A. Garg in 1995, allows a semi-quantitative assessment of the risk of biomechanical overload in the performance of work activities involving repeated movements of the upper limbs. It is illustrated in the UNI ISO 11228-3 standard and it is one fo the methods actually adopted in the risk assessment phase.
The method is applied in the case of work activities consisting of a single repetitive task and allows the planning of appropriate preventive measures. However, it allows the assessment of the risk borne only by the distal part of the upper limbs (forearm and hand), while it does not take into account the other joint districts (shoulder and elbow); it also does not consider the influence of the so-called "complementary factors", which often contribute to a considerable extent to determine risk conditions. The evaluation of the risk index is very simple and requires the use of questionaries or video footages. The calculation of the Strain index consists of product of six values, each of which is a function of a specific risk factor characteristic of work activity: intensity of effort; duration of effort in the cycle; frequency of actions; posture of the hand and wrist; performance of the activity; duration of the task in the shift. Depending on the extent of the aforementioned risk factors, the method provides for the assignment of a numerical value for each of them. The index is then calculated as illustrated in the UNI ISO 11228-3 standard. The studies conducted indicate, for this method, a good discriminating ability between non-risky activities and work associated with the onset of musculoskeletal disorders.

The following are the six factors that contribute to the determination of the Strain index.

4.1 Intensity of effort

The value to be attributed to this parameter is obtained by means of a qualitative scale. In practice, in the study of the repetitive task one of the following judgments is attributed to the required effort:

1) slight;
2) medium;
3) high;
4) very high;
5) maximum.

The evaluation must be carried out for each limb. The opinion expressed corresponds to a value that will enter into the calculation of the risk index.

4.2 Duration of effort in the cycle

In carrying out a given action, the duration of the application of force contributes to determining risk conditions from biomechanical overload. The calculation of the Strain index provides for the quantification, for each limb and in percentage terms, of the application of force within a cycle.

Five duration classes are considered:

1) <10% of the cycle;
2) 10% - 29% of the cycle;
3) 30% - 49% of the cycle;
4) 50% - 79% of the cycle;
5) ≥80% of the cycle.

Classes correspond to a value that will enter into the calculation of the risk index.

4.3 Frequency of actions

It is one of the most important biomechanical overload risk factors. Also in this case we proceed with the analysis of the activity to attribute to the repetitive task a value proportional to the number of actions performed in a minute. Assessment is done for each limb.

There are five categories of frequency:

1) < 4 actions / minute;
2) 4 - 8 actions / minute;
3) 9 - 14 actions / minute;
4) 15 - 19 actions / minute;
5) ≥ 20 actions / minute

Each class corresponds to a score that contributes to the calculation of the Strain index.

4.4 Hand and wrist posture

In carrying out repetitive activities, the importance of posture, especially in conditions requiring high frequency and intense effort, is remarkable. This protocol provides for the assessment of the posture assumed by the hand and wrist of each limb but does not allow the quantification of the risk to the shoulder and elbow. The posture assumed by each upper limb will therefore be attributed one of the following qualitative judgments, which corresponds to a value that enters the calculation of the Strain index:

1) very good;
2) good;
3) discreet;

4) poor;
5) very poor.

4.5 Speed of carrying out the activity

The production or organizational needs often impose a high speed of carrying out tasks, but the latter can also be attributable to a non-ergonomic design of the activity. When the actions are carried out suddenly, the involved joint districts cannot correctly predispose themselves to movement and are then subject to fatigue and, in some cases, to muscle-tendon injuries. In the calculation of the Strain index, the speed of carrying out the task is assessed qualitatively for each limb, attributing to it one of the following five judgments:

1) very low;
2) low;
3) average;
4) high;
5) very high.

The expressed value contributes to the calculation of the risk index.

4.6 Duration of the repetitive task within the shift

This factor can also influence the extent of the risk. In addition, a long-lasting task involves fatigue, to which the body can respond with the assumption of incongruous postures, thus determining additional risks of the repetitive task, according to the following five categories:

1) ≤ 1 hour;
2) 1-2 hours;
3) 2-4 hours;
4) 4-8 hours;
5) 8 hours.

Each of the listed classes corresponds to a score that must be considered in the calculation of the risk index.

4.7 Risk ranges

The product of the six values, identified as illustrated in the UNI ISO standard 11228-3, provides the Strain index. Depending on the size of the risk index it is possible classify the task into three groups, see Table 1.

Table 1: Risk entity.

Strain Index	Risk Entity	Corrective Actions
< 3	**Negligible risk** The risk of onset of pathologies on the distal part of the upper limb does not exceed the one the population is exposed.	None. Risk assessment should however be repeated periodically.
3 - 7	**Low risk**	Redesign the layout of the task by

	The risk of onset of pathologies on the distal part of the upper limb significantly exceeds the one the population is exposed.	acting on several factors or take other measures organizational.
> 7	**High risk** There are conditions of risk from biomechanical overload. Concrete possibility of onset of pathologies of the part distal part of the upper limb.	Need to urgently redesign the repetitive task according to ergonomic criteria. The priority of interventions can be determined by analyzing the different factors of risk.

The strain index calculation is not only aimed at discriminating risky tasks from others who are not; analyzing the value assumed by each factor, it is possible determine which of them are responsible for high risk conditions and plan any preventive measures, calibrating them on them. This analysis also has the function of allowing the determination of intervention priorities. Once the critical aspects of a repetitive task are identified and the priority of intervention are determined, it is possible to proceed with the redesign of the task or workstation work according to ergonomic criteria. An ergonomic design of the task must take account of the characteristics and possibilities of the worker, who should be put in a position to modulate the pace of work.

4.8 Bibliography

1. UNI ISO 11228-3:2009: „Ergonomics - Manual handling - Part 3: Handling of low loads at high frequency“
2. ISO/TR 12295: 2014 “Ergonomics – Application document for international standards on manual handling (ISO 11228-1, ISO 11228-2 and ISO 11228-3) and evaluation of static working postures (ISO 11226)”.
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4. MOORE J. S., RUCKER N. P., KNOX K., 2001. Validity of generic risk factors and the Strain index for predicting nontraumatic distal upper extremity morbidity. American industrial hygiene association journal, 62, pp. 229-235.

5 Risk Analysis

5.1 UC1 Risk Analysis

The risk analysis of this use case takes into account the most critical activity during the cabling task, that is the usage of the screwdriver.

Intensity of effort : 1
Duration of effort in the cycle: 1
Frequency of actions: 1
Hand and wrist posture: 3

Speed of carrying out the activity: 2
Duration of the repetitive task within the shift: 4

Strain Index: 24

From the analysis of the common cabling task accomplished during the execution of UC1, a very high value of the Strain Index is recognized. It follows that there is a high potential for the REMODEL robotic technologies to significantly impact into the quality of the working environment for this use case. The focus will be posed in reducing the number of cabling tasks the human operator must accomplich to complete the production, in order to reduce in particular the duration of the repetitive task within the shift and the duration and speed required to complete the tasks due to their reduced number.

5.2 UC2.1 Risk Analysis

In the risk analysis of this use case, the task of placing cables of the pin table is considered as the most risky activity.

Intensity of effort : 1
Duration of effort in the cycle: 2
Frequency of actions: 1
Hand and wrist posture: 1
Speed of carrying out the activity: 2
Duration of the repetitive task within the shift: 4

Strain Index: 16

From the analysis of the common task accomplished during the execution of UC2.1, a very high value of the Strain Index is recognized. It follows that there is a high potential for the REMODEL robotic technologies to significantly impact into the quality of the working environment for this use case. The focus will be posed in reducing the number of tasks carried out by the human operator, in order to reduce in particular the duration of the repetitive task within the shift and the duration and speed required to complete the tasks due to their reduced number.

5.3 UC2.2 Risk Analysis

In the evaluation of the strain index connected to this use case, the act of cable placement on the jig and the use of the tape pistol is taken into account.

Intensity of effort : 1
Duration of effort in the cycle: 2

Frequency of actions: 2
Hand and wrist posture: 1
Speed of carrying out the activity: 3
Duration of the repetitive task within the shift: 4

Strain Index: 48

From the analysis of the wiring harness assembly task accomplished during the execution of UC2.2, a very high value of the Strain Index is recognized. This task is very repetitive and executed at relatively intense speed. It follows that there is a high potential for the REMODEL robotic technologies to significantly impact into the quality of the working environment for this use case. The focus will be posed in moving the tasks from the human operator to the robot.

5.4 UC3 Risk Analysis

In the evaluation of the strain index for this use case, the manouvers executed by the human operators to allocate the branches of the wiring harness in the proper place are taken into account.

Intensity of effort : 1
Duration of effort in the cycle: 2
Frequency of actions: 2
Hand and wrist posture: 1
Speed of carrying out the activity: 2
Duration of the repetitive task within the shift: 4

Strain Index: 32

From the analysis of the wiring harness allocation task accomplished during the execution of UC3, a very high value of the Strain Index is recognized. It follows that there is a high potential for the REMODEL robotic technologies to significantly impact into the quality of the working environment for this use case. The focus will be posed in reducing the number of handling tasks the human operator must accomplich to complete the wiring harness allocation, in order to reduce in particular the frequency of the repetitive task within the shift and the duration and speed required to complete the tasks due to their reduced number.

5.5 UC4 Risk Analysis

In the evaluation of the strain index for this use case, the curring of the tube for the preparation of the tube surface for the visual inspection is taken into account as the more risky and difficult for the human operator.

Intensity of effort : 1
Duration of effort in the cycle: 1
Frequency of actions: 1
Hand and wrist posture: 3
Speed of carrying out the activity: 1
Duration of the repetitive task within the shift: 3

Strain Index: 9

From the analysis of the tube cutting task accomplished during the execution of UC1, a very high value of the Strain Index is recognized. It follows that there is a high potential for the REMODEL robotic technologies to significantly impact into the quality of the working environment for this use case. The focus will be posed in moving the cutting task and the related handling activities from the human operator to the robot, in order to improve the ergonomics of the task.

6 Conclusions

The data reported in this deliverable establish the comparison basis to evaluate the REMODEL impact according to the call specifications. The 2019 production data are reported to evaluate increase in the production as well as improvements in the time to market and customization capabilities thanks to the REMODEL robotic technology. The analysis of the strain index for all the use cases is carried out to evaluate the actual state of the production process from that point of view, and evaluate which improvements the REMODEL technologies will bring to the quality of the working environment along the development of the project.