PERSPECTIVES OF IMPLEMENTING AUTOMATED AND ROBOTICS-BASED TECHNIQUES IN ROAD INFRASTRUCTURE CONSTRUCTION AND MAINTENANCE OPERATIONS

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1. Introduction

In EU the road infrastructure services 90% of the movements of people and goods, whereas the transport services account for ca 5.6 million jobs and contribute to 7-8% of GNP. Huge investments are necessary every year in EU to cope with the three major problems marking the present road network in EU: aging; increased traffic demand; and increased truck traffic. For example in some European countries maintenance costs for motorways amount to about 30000 ECU/Km and for other major rural roads to about 10000 ECU/km each year.

To handle these aggravating the fiscal budgets roadway investments new innovative techniques are sought which will reduce the overall cost of Road Infrastructure Construction and Maintenance (RICM) operations without at the same time adversely affecting the quality and performance of the road network. In this context European Commission, Directorate General VII, Transport has initiated and financed a one year research project entitled **Automated and Robotics-based Techniques (ART)-New Solutions for Road Construction and Maintenance**, to address the issue. Ten partners from five EU countries have participated in the project and explored the potential of introducing ART for construction and maintenance purposes for rural and urban roads.

Based on the analysis carried out in this project the implementation features of ART in specific RICM operations selected for European conditions are presented in this chapter.

2. Selected Operations

Operations related to road construction and maintenance activities run into hundreds. Therefore starting initially from a long list of candidate operations for investigating their possibility for consideration in an ART implementation program a shorter list of operations came up finally. These operations include nine operations for urban, thirteen for rural roads and three operations for bridge rehabilitation (urban and rural), altogether 25 operations. The inspection aspect of maintenance operations was excluded from the assessment. Frequency of the operation and corresponding budget allocation have been the primer criteria for entering the list. Paving ranked at the top of the list.

For each operation of the short list a full description was given of the included tasks, their performance and qualitative requirements, needed operator's expertise, the necessary task-oriented machines and working conditions as well as the individual task evolvement within the operation. The description of the operations relied upon a variety of data delivered mainly by two road administrators and a contractor, participating as partners in the project, as well as by other organizations and contractors.

For each task of an operation then the suitability of adapting an automation or robotics technology was identified based on the following criteria:

- Task exhibiting a hazard or danger to working personnel;
- Task involving repetitive or tedious work;
- Task being costly;
- Expressed necessity for higher performance rate of task;
- Achievement of higher quality standards of task.

Table 1 comprises for example the suitability assessment data associated with each task involved in the paving operation.

Tasks for Paving Operation	**Task Characteristics**					
	Hazardous or Dangerous	Repetitive or Tedious	Difficult or High Expertise	Simultaneous Task	Coordina-ted Task	Suitable for ART
Sweeping	No	Yes	No	Yes	No	Yes (+)
Emulsion Spraying	Yes	Yes	No	Yes	No	Yes (+)
Material Mixing	No	Yes	No	No	No	Yes (0)
Material Loading and Transport	No	Yes	No	No	No	Yes (0)
Paver Feeding	No	Yes	No	Yes	Yes	Yes (+)
Truck Movement to Mixing Plant	No	Yes	No	No	No	Yes (0)
Placing Material	Yes	Yes	Yes	Yes	Yes	Yes (+)
Stopping the Paver	No	Yes	No	No	No	Yes (+)
Compac-tion	No	Yes	No	Yes	No	Yes (+)

Legend: (+) = high priority, (0)= low priority

Table 1: Suitability of Implementing ART for Tasks involved in the Paving Operation

3. Technological Assessment

Using ART in conventionally carried out RICM operations means either a conventional machine is technologically upgraded, for example by building in some sensor systems, or a totally new machine should be developed to cope with the new set ART requirements. To decide upon this a second more detailed assessment was carried out of the tasks included in the selected operations and identified as candidates for deploying ART by taking into consideration the resulting beneficial effects ART would impose to the operation, i.e. diminishing idle times, occupying less space, demanding less personnel etc. This second sorting of tasks pin-pointed the specific tasks or task activities, which should be technologically addressed in order to describe the automation or robotics related technological features needed for a corresponding preprototype development.

For the specified task or tasks of each operation a *Technical Scenario* was established, showing the way the task or tasks would be carried out by using ART. Based on this scenario the necessary technological components for implementing ART could be identified and assessed as for their technological status. These components involve the following items:

- Kinematics;
- Gripper System Tools;
- Drive System;
- Undercarriage;
- Sensors;
- Control System;
- Man-Machine Interface;
- Information Flow.

A basic assumption in addressing these components was that for each machine at least **one human operator** would be involved irrespective of the automation level the investigated task or combined tasks or activities were conceived to achieve. Each of the above technological components could be assigned to one of the three classes "research", "development", and "product". "Product" refers to systems or system components which have attained a prototype status and are or can be readily available i.e. adapted, to the manufacturing industry for building the prototype.

Components were assigned the characterization "development" in case some further work is necessary to existing systems or system components to fulfil the set requirements for a RICM operation.

Finally under the term "research" were all systems or system components included, for which an intensive research work is further needed in order for the component to reach the "product" stage.

Assignment of the components needed to realize the technical scenario to one of the above three technological feasibility classes leads to the definition of the time perspective of deploying ART, i.e. short-, medium- and long-range, for each operation can be directly deducted.

Table 2 illustrates the technological assessment for the paving operation based on the corresponding technical scenario, focusing on the main tasks of laying the asphalt material by the paving machine (road paver).

Component	**Description**	**Research**	**Development**	**Product**
Kinematics	Kinematics of the conventional screed		●	
Gripper System Tools	None None			
Drive	Electrical drives Hydraulic drives			◈ ◈
Power Supply	Diesel-electric (low emission) Diesel-hydraulic (low emission)			● ●
Undercarriage	Standard			◈
Sensor Technology	Navigation System	●		
Control	Automatic motion: according to the navigation data Semi-automatic motion: kinematics, sensors, MMI Communication: wireless communication Quality Control of the process		● ●	 ◈ ●
Man-Machine Interface	Communication: display, control panel Interaction: steering wheel, joy-stick		●	 ◈
Information Flow	Wireless Communication Management System Simulation System Common Data Base	 ●	 ● ●	●

Legend: ◈ Component exists as product and can be directly used in the machine

MMI = Man-Machine Interface

Table 2: Technological Status of System Components needed for the Paving Operation (paver) according to the formulated Technical Scenario

4. ART Implementation Cost

Development cost of innovative ideas has always been a decisive factor. Therefore in the ART-Project the implementation average cost of the technical scenarios of the selected operations was estimated. This cost estimation reflects solely the man-power needed to apply a product, to develop a system or its components or to conduct the respective research and development summed up for all selected 25 RICM operations.

To estimate the ART implementation cost the following formulae were used

$$aver.(\cos t) = \cos t \bullet \frac{n}{N} \qquad (1)$$

where

aver. (cost)= average cost (weighted) for implementing component [kECU],
cost = actual development cost [kECU],
n = number of times component appears in the technical scenarios,
N= 25 (total number of operations considered),
and

$$total(\cos t) = \sum aver.(\cos t) \qquad (2)$$

Both formulae were applied for the extremes cost values, *minimum* and *maximum* estimated cost, and separately for the development classes "product", "development", and "research".

Table 3 shows the cost estimation procedure for the case of **kinematics**.

Having determined the development cost of every system component in order to implement the technical scenario an overall investment funds needed to implement ART in RICM operations in the short-, medium-, and long-range periods can be predicted. The results are shown in Table 4.

Figures 1, 2 and 3 illustrate the distribution cost of each technological component needed to be invested in order to implement ART in RICM operations in the EU on a short-, medium-, and long-range basis respectively

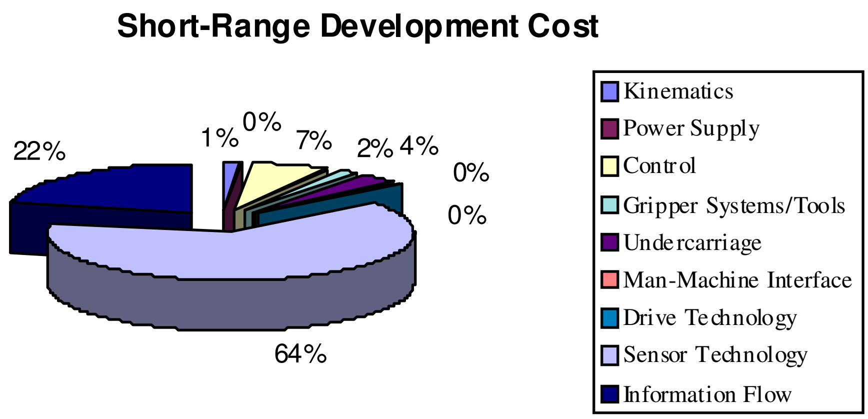

Figure 1: Distribution Cost of Short-Range Development Components of ART

Cost Estimation Steps		Product		Development		Research	
		Min	Max	Min	Max	Min	Max
Case 1: 6-axes Kinematics		4 x		2 x		0 x	
Case 2: Operation depending Kinematics		2 x		9 x		0 x	
No of Operations or Machines		6 x		11 x		0 x	
Single Cost	Case 1	0	50	0	200	0	0
Average Cost	Case 1	0	6.9	0	82.8	0	0
Single Cost	Case 2	0	100	50	300	0	0
Average cost	Case 2	0	6.9	15.5	113.8	0	0
Total Cost		0	13.8	15.5	196.6	0	0

Table 3: Cost Estimation of the Kinematics Component

5. The Paving Operation

As stressed above the paving operation ranked as the operation with the highest priority for adopting ART.

ART machines could contribute to alleviate the shortcomings that this operation suffers. First, the required high accuracy of height determination is satisfied by placing a stringline along the roadbed. This construction hinder the free movements of the machines in the work area, producing delays and difficulties in managing the vehicle movements and the material flow. Second, the structural characteristics of the

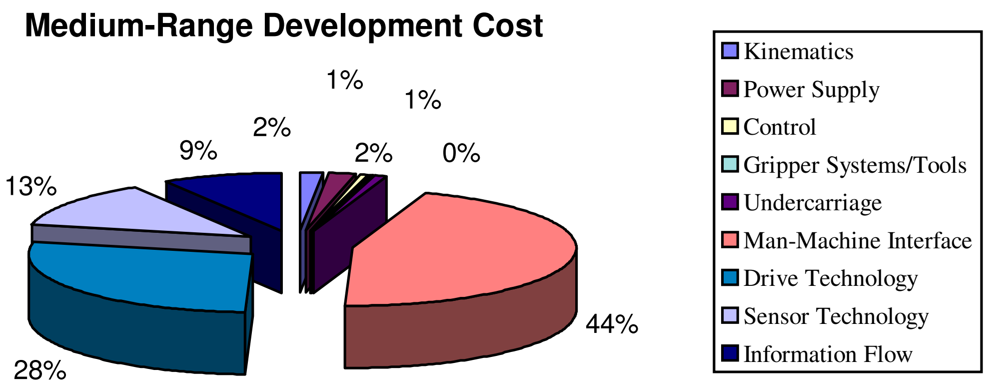

Figure 2: Distribution Cost of Medium-Range Development Components of ART

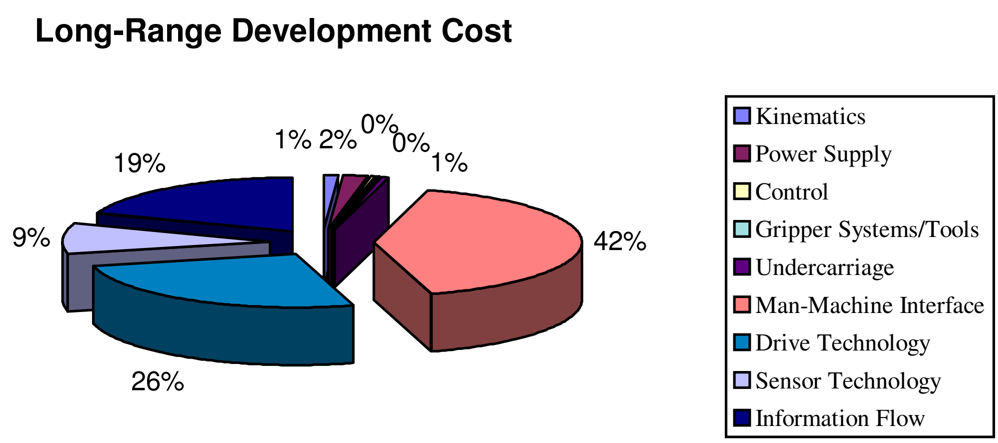

Figure 3: Distribution Cost of Long-Range Development Components of ART

As it can be deducted from Figures 1 to 3 the development cost for the short-range period will concentrate in applying sensor technology while the medium- and long-range development cost will be expended to the man-machine interface systems .

Implementation Period	Implementation Cost [kECU]
Short-range	279.0 .. 680.0
Medium-range	1584.1 .. 9095.6
Long-range	2290.9 .. 12699.0

Table 4: Investment Funds needed to Implement ART in high ranked RICM operation in the EU

pavement are deteriorated from stops of feeding the paver with material, as well as by insufficient compacting due to poor control of the compaction levels. Finally, the operation is slow due to idle times, to extensive surveying work, and to performance controlling work.

Thus, the main objectives of introducing ART techniques in alsphalt paving operation aim at:

- Releasing the operation for surveying infrastructure that blockade the vehicles movements.
- Improving the performance quality.
- Reducing the operation time.

For this specific operation a design scheme was developed, for which a description of the various technological aspects is given, as determined in the technical scenario for the automated paver.

The functional modules needed for an automated the paver sum up to twelve and are illustrated in Figure 4. These twelve modules operate in an autonomous mode. Initial values are fed to the planner, which is controlling the paving individual tasks by linking the input information to the correct module. The positioning and navigation of the paver is performed in the *rural area* through a GPS (Global Positioning System) and especially a technique called Real Time Kinematics (RTK) with On the Fly (OTF) capabilities, a system that utilizes the position of satellites to calculate the position in space of an antenna receiving signals from a constellation of satellites. Since the road pavement surface is a three-dimensional one, known in differential geometry as *ruled surface*, a three-GPS-antenna concept is proposed to be built on the paver, which will determine not only the position in space of the paver, and especially its screed, but also the rotating angles of the machine in reference to its longitudinal, radial and vertical (normal) axes (roll, pitch and lead angles).

Expected construction accuracy of the pavement surface is better than **0.5 cm horizontally** and **1 cm vertically**, which fully comply with required construction standards of the road pavement surface.

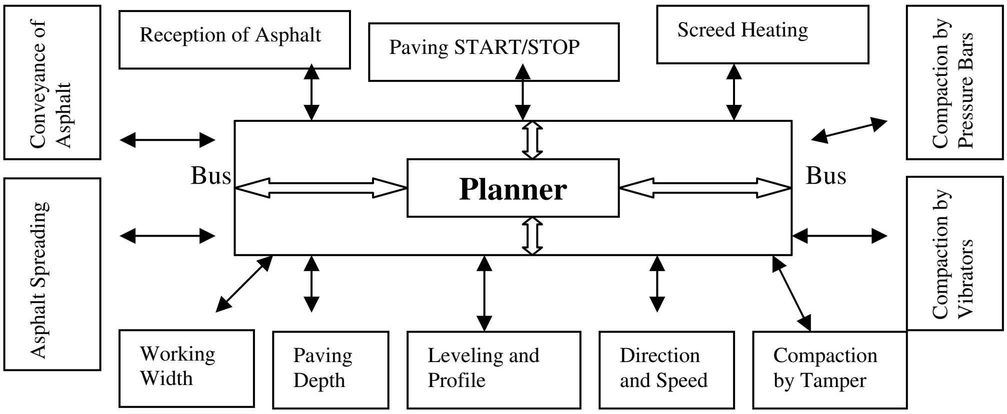

Figure 4: Block Diagram of Functional Modules for the Automated Road Paver

Figure 5 shows for example the concept of the first functional module, the reception of asphalt. According to this concept two sensors S1 and S2 are provided at the front of the paver, which aim at sweeping the rear of the feeding truck and at detecting the position of the truck in relation to the paver. A force sensor S3 is further provided on the push roller to determine the force required for pushing the truck and its position in relation to the road paver. The sonic sensor S4 serves to pick up the asphalt level in the material hopper. Two further sensors S5 and S6 are provided on the hopper sides to pick up the positions of the hopper sides when folded out. Two actuators A1 and A2 for the electrohydraulic adjustment serve to fold the hopper sides in and out. Two displays D1 and D2 on the left and right side of the road paver inform the operator of the machine on:

(1) forwards motion,
(2) reverse motion,
(3) stop,
(4) releasing brake,
(5) dumping,
(6) dumping stop.

A computer module controls the reception of the asphalt, whereas the planner regulates the asphalt reception at a high level according to a block diagram of sensors, actuators, displays and a selector switch corresponding to the above given task description of Figure 5.

Similar concept descriptions are existing for the remaining eleven functional modules.

Criteria	Description	Benefit
Working time duration	Time operation is expected to fall down by 20%. The simultaneous construction of two layers contributes considerably to this outcome.	++
Idle time	Idle time is reduced, since the use of feeder ensures continuous material flow. No “stop & go” process takes place anymore.	+
Quality	The elimination of “stops’ during the material placing improves the quality in terms of structural characteristics. They also are affected positively by controlling in place the compaction levels, which optimizes the rolling task. The automatic navigation enhances the result in terms of final geometric shaping.	+
Total operation cost	Total cost is expected to decrease due to time and labor reductions.	+
Machines	(Due to better performance more trucks are in the worksite simultaneously).	(-)/=
Workers	Aiding personnel on the paver and on the roadway for machine guiding are not needed anymore.	++
Space	The occupied roadway space is reduced, since no stringline is required for height determination. Also, there are no working personnel moving on the roadway, so the relevant safety buffer space is not occupied.	+
Safety	Safety is significantly improved, since no workers are moving on the roadway.	++

Legend: + : lightly beneficial, ++ : enough beneficial, (-)/= : same as before

Table 5: Expected Beneficial Features of the Automated Road Paver Prototype

Figure 5: Paving Task “Reception of Asphalt” Implementing ART

In Table 5 the beneficial features of the new automated road paver are illustrated, which are expected to result when prototypes will be built and introduced in road construction and maintenance.

6. Conclusion

The European Project ART – Automated and Robotics-based Techniques investigated the feasibility of implementing automation and robotics technology for 25 selected Road Infrastructure Construction and Maintenance operations. There are two main recipients of this information. The first one is the manufacturing industry, which can directly assess the results of the ART project and take the appropriate decisions on its future development plans. The second recipient is the transport policy makers in Europe, which can identify the benefits of implementing Automation and Robotics Technology for Road Construction and Maintenance activities in the European Continent and make the necessary investments to get the best of the technology on the road the as far as possible.

Acknowledgement

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