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MULTI SKILLED MAINTENANCE OF A HIGH SPEED RAILWAY

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KEYWORDS

Railway, maintenance, process-oriented simulation, multi-skill.

ABSTRACT

Periodic inspection and maintenance of railway lines is performed by maintenance teams. This paper concerns a preliminary investigation of the influence of using multi skilled teams on maintenance costs. A simulation model to determine the relationship between skill composition of teams and the maintenance costs has been prepared and applied on the case of a high speed railway line that is under construction. All maintenance tasks were given but preliminary periodic maintenance schedules had to be determined. The quality of the maintenance has been expressed as the percentage of maintenance tasks that are completed in time. It is concluded that a balanced composition of skills per team may reduce the cost of maintenance significantly.

INTRODUCTION

The high speed railway connection (HSL) from Amsterdam to the Dutch-Belgian border is currently under construction. It will connect the western part of the Netherlands, the 'Randstad', with the high speed European railway network. The HSL track is 125 kilometres long. 85 kilometres of the route consists of newly laid high-speed track. The maximum speed will be 300 km/h. The line will be completed in 2007. Figure 1 shows the HSL track with branches to the cities of The Hague and Breda

The consortium Infraspeed is responsible for the design, construction, financing and maintenance of the HSL rail systems. Infraspeed is building the superstructure (the railway system) of the HSL. For the 25-year period following completion of the superstructure a contract comprises the management and maintenance of the entire line under the authority of the rail manager ProRail. In the contract with the government, Infraspeed guarantees 99.46% availability of the line during 25 years. During this contract period, the Dutch government will pay Infraspeed an annual fee for making the HSL infrastructure available. The sum paid depends on the actual availability: if Infraspeed fails to realise the required availability, the fee is reduced (HSL Zuid web site 2006)

Figure 1 HSL track (HSL Zuid web site 2006)

In this paper the focus is on preventive inspection and maintenance. In particular the influence of the number of competences (skills) in maintenance teams on maintenance costs has been investigated. In the next section some maintenance aspects are discussed and the research question will be formulated. After that the simulation model of the preventive maintenance processes is explained and the results of the simulation experiments are presented. Finally conclusions are drawn.

MAINTENANCE

The purpose of maintenance of the HSL is to guarantee a predefined safety level and prescribed line-availability. The maintenance processes are currently under development. In this section the maintenance policy will be discussed and a way to evaluate the performance of the maintenance system is proposed.

Maintenance policy

Maintenance will include periodic inspection and preventive maintenance, corrective maintenance and reactive maintenance.

- Periodic inspections and preventive maintenance are defined as those activities required for determining and evaluating the actual condition of the asset and for maintaining the desired condition and operating standard.
- Corrective maintenance is defined as unplanned activities that can be carried out during a regular maintenance shift and/or possession.
- Reactive Maintenance is defined as unplanned activities that must be carried out to immediately restore track availability even if there is no possession planned. Reactive maintenance may lead to non-availability which will cause penalties.

In this paper periodic inspection and preventive maintenance are considered on the basis of pre-established intervals of time and employing pre-printed checklists, (TCRP 2003).
All preventive inspection and maintenance activities to be carried out have been specified and are available in maintenance manuals. The activities have been subdivided into tasks. Each task has its specific periodic maintenance interval, work to be done and skill needed for the operation. The preventive maintenance tasks will be automatically generated based on a 'preventive maintenance schedule'. The initial length of the maintenance interval depends on the assessment of the deterioration of the asset in the time interval and the increase of risk expected. The periodic maintenance intervals will be fine-tuned during the actual operation to obtain the economic optimum balance between system availability and maintenance costs. The preventive maintenance schedule is not yet available however. In this work maintenance schedules are required; consequently preliminary simplified maintenance schedules have to be generated.

The HSL

The HSL is being built out of a number of sub systems including the rails, the electric system (overhead wires and transformer stations), the system for communications, safety and signalling, the sound barriers, balustrades and fences, the facilities in the tunnel buildings, and emergency facilities and ventilation systems in tunnels. For safety reasons maintenance actions are not allowed near the track during train operation. To that end the area where the trains are running is defined by the so called 'train operating envelop' that is shown in Figure 2.

Maintenance in the train operating envelop is only allowed during a restricted (5 hours) time period during the night, when no trains are running. During the rest of the twenty-four hours period maintenance activities are only allowed on objects outside the operating envelop. During the day the work of the following night is prepared.

Research question

Traditionally, maintenance teams are single skilled. The main goal of this work is to verify the supposition that the use of multi skilled team compositions may lead to a reduction of maintenance teams needed and thus to reduction of costs. In order to compare different skill compositions it is necessary to have a measure for the quality of the maintenance.

A maintenance performance measure

In the public transport sector the term "quality of service" (qos) is used for the evaluation of a transport service, (Tervonen et al, 2000), (ERTMS/GSM-R, 2003). The qos is composed of a number of performance measures and even has qualitative components, (TCRP 2003). Both line availability and safety are related to the qos. In this work a performance measure for the quality of maintenance is defined using the following reasoning. Preventive maintenance task intervals are determined on the basis of the risk assessment in the case that the maintenance fails to occur. It can be argued that the risk of line unavailability increases if a preventive maintenance task is delayed. The main reason of delay will be the unavailability of maintenance teams. The more teams available the less delays will occur, but the higher the cost will be. Consequently there is a trade-off between the costs and the quality of the maintenance. In this work the percentage of preventive maintenance activities that are on time are defined as a simplified measure of the quality of maintenance, it will referred to as "maintenance performance". Because of this simplified definition of the maintenance performance, the values measured do not have an absolute meaning in terms of risk of failures. It will only be used to compare the quality of a number of maintenance team compositions.

MODELLING

In order to evaluate the research question, the maintenance system is simulated. Simulation has been chosen because it leaves the possibility to extend the model with corrective and reactive maintenance activities and all related stochastic aspects in a later stage. The "process interaction method" is used as a modelling method (Zeigler, 2000), (Fishman, 2001.). The method can be characterized by identifying the system element classes and describing the sequence of actions of each one. The sequence of actions of an element is called its process. In a process, so called "time consuming" commands appear. Examples are: *work, wait, drive suspend* and *standby*. A class is further characterized by its attributes. A special class is the "Set" class. A Set may contain system elements and is very useful to define data structures. In practice this method boiles down to the decomposition of the system into relevant classes of elements, preferably patterned on the real world elements of the system, the specification of the attributes and the description of the processes of the active classes. Process interaction modelling has a near resemblance to object oriented modelling. For process interaction simulation an appropriate simulation tool is needed. The first programming language applying process interaction is "Simula" (Birtwistle, 1973); two recent tools are Silk (Healy and Kilgore, 1997) and Tomas (Veeke and Ottjes, 2000 and 2002). Tomas, that is based on Delphi has been applied in this project. Next the main element classes are discussed.

Element classes and attributes

Class HSL

– WorkZoneSET *Set with all Work Zone's*

Class WorkZone

– TravelDist *Travel distance between WZ and Yard*
– Location
– NrofTeams *Number of Teams present in WZ*

Class Task

– name *name*
– StartTime *day from where the Preventive schedule will start*
– Interval *periodic interval*
– Required Shift *shift in which the Task can be performed*
– Required Skill *Skill required*
– Duration *time needed to execute the task*
– Amount of men *# of men required*
– WZ *work zone where the Task is done*
– Nr of Duplicates *number of same Tasks in the Work zone*
– PROCESS *Process of a Task*

Class Team

– Name *Team name*
– NrofMen *# of men in a Team*
– SkillSet *Skills available in the team*
– Hourrate *Cost per hour per Team member*
– Shift *Shift in which the Team has to work*
– Location *The location where the Team is stationed*
– PROCESS *Process of a Team*

The structure of the model is shown in Figure **3**.

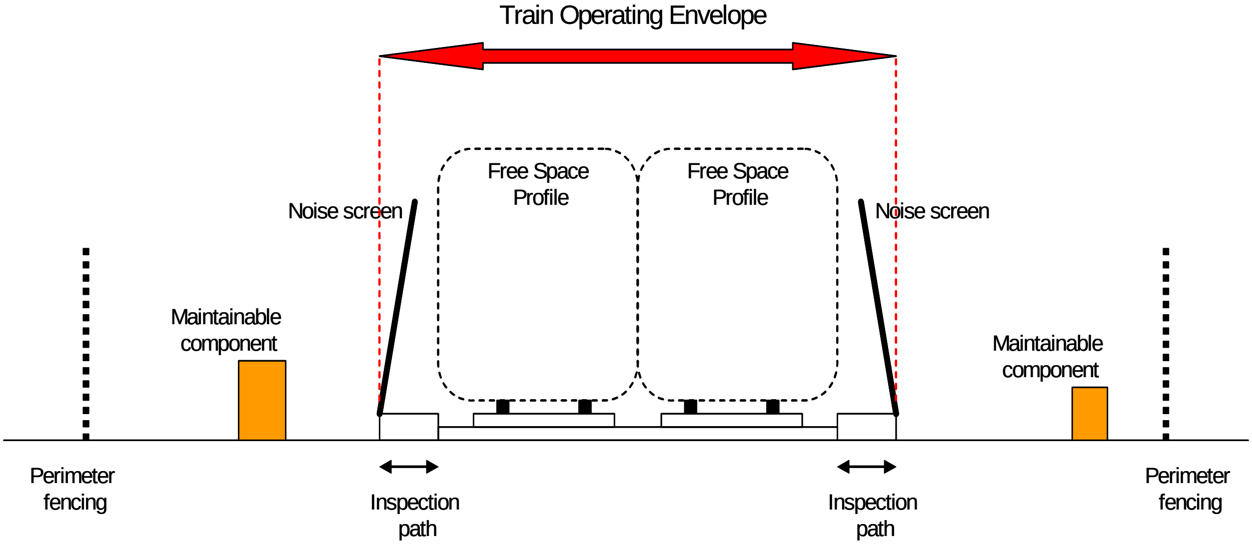

Figure 2 the train operating envelop

The operational working is determined by the processes of the elements. The processes of a maintenance team and a maintenance task will be shown in pseudo code.

Process of a Team

A team is only allowed to work in a regular shift. If the task to be done is within the train operating envelop only the night shift is appropriate. The selection of a task is rule based. Delayed tasks always have priority.

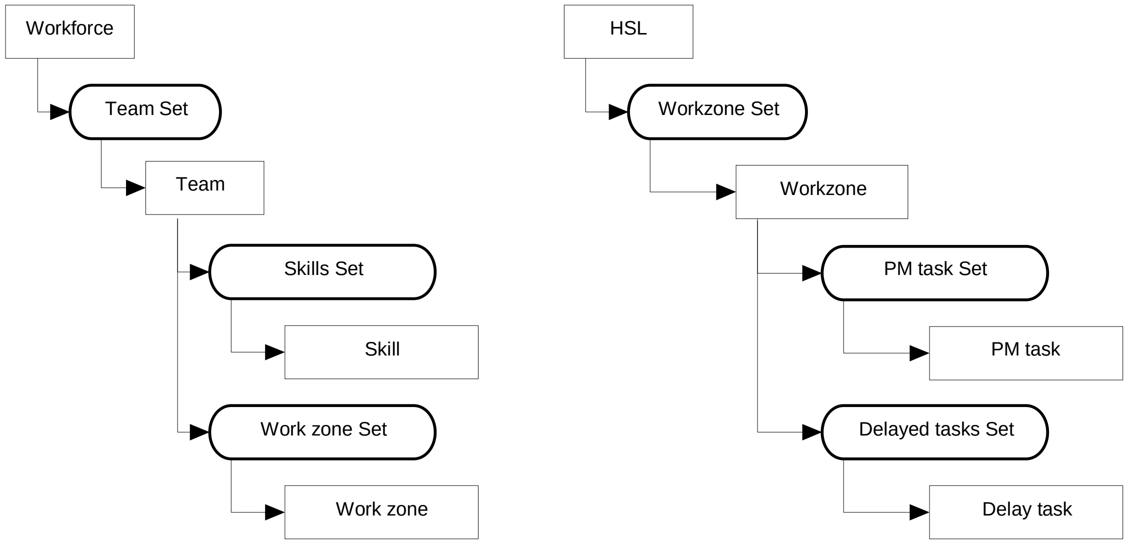

Figure 3. Structure of the model.

Figure 4 Screen shot of the simulation model

{Team Process}
Repeat:
Wait until shift and task available
Select Task
If Task is in WorkZone.PM TaskSet
Remove Task from WorkZone.PM TaskSet
Task.Ready = TRUE
If Task in WorkZone.DelayedTaskSet
Remove Task from WorkZone.DelayedTaskSet
Drive to Task.Location
Work Task.Duration
Task.Destroy

Process of a Task

A Task first creates a copy of itself and starts the process of that copy with a delay of "interval" time units. In this way the repetition of the Task is guarantied. Next the Task enters the proper PMTaskSet and waits to be executed by a team. In a steady state situation the executing will be finished before the repetition interval elapses. If the Task is not executed at the end of the interval, it leaves the PMTaskSet of its WorkZone and enters the DelayedTaskSet of its Workzone and continues waiting for execution. 'Now' is the current system time. The number of delayed tasks is used to calculate the performance quality.

{Task Process}
NewTask = copy of this Task
NewTask.StartProcess(Now + Interval)
Enter WorkZone.PM TaskSet
Wait Interval
If (not Ready)
Leave WorkZone.PM TaskSet
Enter WorkZone.DelayedTaskSet
Wait

Schedule generation

At the moment of this investigation no preventive maintenance schedule was available. Therefore the model is used in a slightly modified version to generate a preliminary schedule and to tune the work force. To do so all tasks are released at the start of the simulation run: Now = 0. The process of a Task however only starts at the very moment that it is executed for the first time. In this way the work load is leveled out. If there are not enough teams available the work in progress will increase continuously and if there is a surplus of teams there will be underutilization. These effects are used to tune the workforce needed. Figure 4 shows a screen shot of the simulation model with a plot of the numbers of tasks in the system and the under utilization of shifts.

EXPERIMENTS AND RESULTS

In this section the model is applied to the HSL case. Table 1 shows the subsystems of the HSL. Only the pre-defined maintenance tasks of the first five sub systems have been used. A number of basic scenarios have been tested, applying different skill compositions of teams. First preliminary preventive maintenance schedules have been derived for each scenario and after that the number of teams was fine-tuned to evaluate the benefits of teams with more than one skill. All runs cover a period of 10 years.

Table 1 sub systems of the HSL and skill required	
1.	civil structures, the substructure (CIV):
2.	noise and fencing (NFE):
3.	signalling (SIG):
4.	traction power distribution (TPD):
5.	track (TRA)
6.	ancillary electrical and mechanical equipment (AEM):
7.	buildings and miscellaneous (BMI):
8.	communications (COM):

Generating preliminary schedules

In order to generate a schedule, all maintenance tasks have been released at the start of the simulation run. The tasks are executed successively by the available teams. To get a stable situation, the number of teams is varied as well as the number of teams allowed in one work zone. Figure 5 shows a situation that does not stabilize. The number of issued tasks is growing steadily.

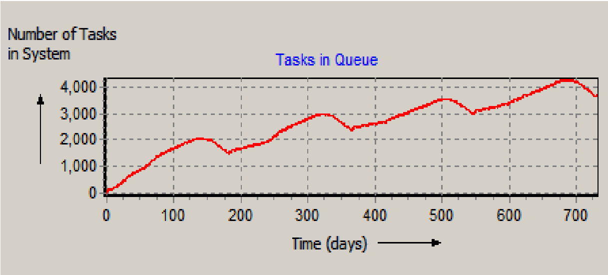

Figure 5 Tuning the workforce: growing number of Tasks waiting for execution.

In Figure 6 the result is shown of tuning both the number of teams available and the number of teams allowed in one work zone. The situation is in balance and the underutilization of the teams is minimal. The output of the run provides a preventive maintenance schedule consisting of a list of all preventive maintenance tasks and corresponding starting dates. Table 2 shows a part of a maintenance schedule, consisting of a sequence of pre-defined maintenance tasks.

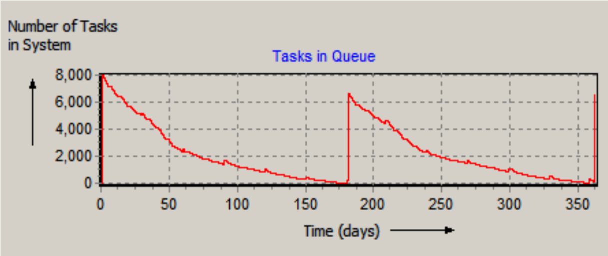

Figure 6 Tuning the workforce: Stable execution of the Tasks.

Table 2 Part of the preventive maintenance schedule with Task definitions	
DCIVPla142	{PMName}
5	{Duration}
182	{Interval}
CIV	{Required Skill}
Night	{Required Shift}
2	{# of Men}
1	
WZ3	{Work Zone Name}
NW	{Location}
1	
7	{StartTime}
8	
DTRATRAVIS15	{PMName}
5	{Duration}
30	{Interval}
TRA	{Required Skill}
Night	{Required Shift}
2	{# of Men}
1	
WZ4	{Work Zone Name}
NE	{Location}
1	
8	{StartTime}
DSIGBALVIS303	{PMName}
5	{Duration}
365	{Interval}
SIG	{Required Skill}
Night	{Required Shift}
2	{# of Men}
1	
WZ9	{Work Zone Name}
SW	{Location}
1	
8	{StartTime}

The preventive maintenance schedules have been used for the further simulation experiments to establish the maintenance performance. In stead of releasing all tasks at a time, they are released on their planned starting times. Figure 7 shows the results for single skilled teams with a maximum of 2 teams per work zone. The workload has levelled out. The peaks in the numbers of released tasks can be explained by the fact that a large number of short tasks have been clustered.

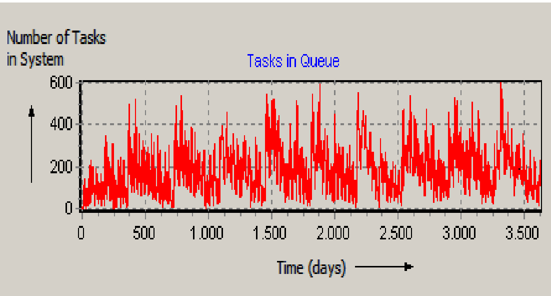

Figure 7 Released tasks as a result of preventive maintenance planned according a preventive maintenance schedule over a period of 10 years.

The hypothesis in this work is that using multi skilled teams will reduce labour costs while keeping the maintenance performance at a desired level. The next step is simulating all skill compositions and, in case of underutilization, decreasing the number of teams. Table 3 shows a part of an input file with team definitions. The skill name refers to the sub system of Table 1.

Table 3 Part of team definition input	
{ HSL Team input }	
13	{Number of Teams}
TeamTRAS1	{TName} {6}
3	{NrofMen}
1	{Efficiency}
90	{Hourrate}
Night	{Shift}
South	{Location}
2	{NrofSkill}
TRA	{Skill 1}
SIG	{Skill 4}
TeamNFES	{TName} {9}
3	{NrofMen}
1	{Efficiency}
90	{Hourrate}
Night	{Shift}
South	{Location}
1	{NrofSkill}
CIV	{Skill 2}

The final results of the experiments are shown in Figure 8, in which the maintenance performance and the maintenance costs have been plotted as a function of the team compositions. Scenario 1 (Sc1) shows the initial result with single skilled teams. Scenario 2 (Sc2) has been obtained by combining at most two skills per team. The logical combinations of skill couples have been prepared by Infraspeed as a part of an earlier test, concerning only two skills per team. The results of the scenarios Sc3 -Sc8 are obtained by further varying skill composition starting from scenario 2 and tuning the number of teams. For each scenario the maintenance performance has been determined and compared with the single skill case. Only results with a maintenance performance at least as high as measured for the single skilled case, are accepted. In Figure 8 for each scenario the maintenance performance and the matching costs are shown. It is concluded that several multi skill compositions perform at lower costs at least as good as the single skill case. It was decided to proceed with the further development of scenario 8 (Sc8) in which at most 3 shifts are combined.

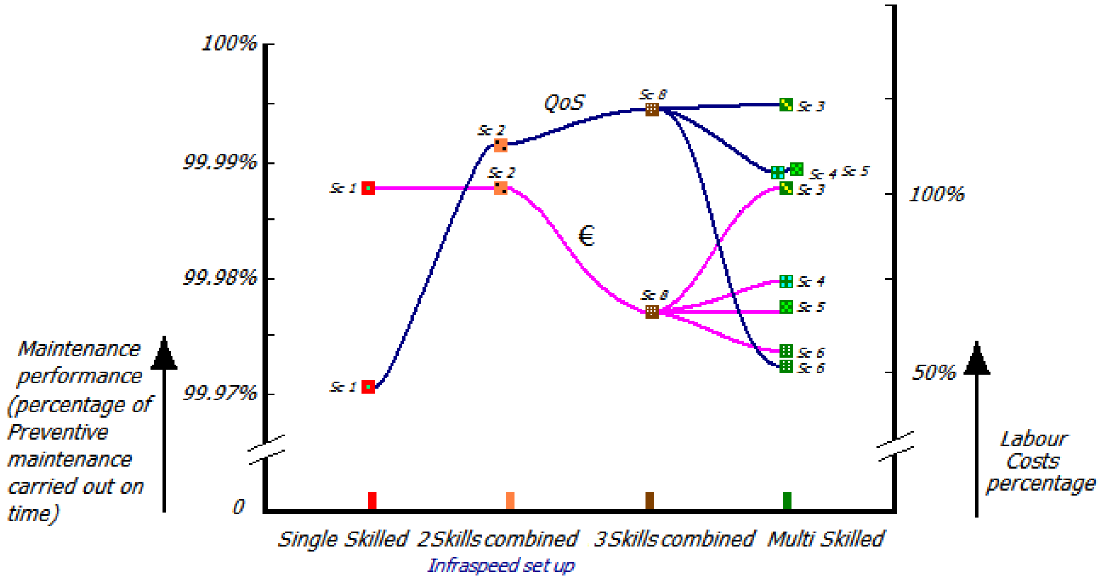

Figure 8 Labour cost and maintenance performance versus maintenance team skill composition

CONCLUSIONS AND FURTHER RESEARCH

A simulation model has been developed and implemented to determine both the maintenance costs and maintenance performance as a function of the skill composition of the maintenance teams. All required preventive task definitions were available at the start of the simulation project. All preliminary maintenance schedules however had to be generated. A modified version of the model was used for that purpose.

It is concluded that using multi skilled maintenance teams and tuning the composition of skills in the teams reduces the number of teams required. The maintenance costs can be reduced significantly compared with only single skilled operation. Aspects that not have been taking into consideration are the extra costs of training personal to obtain multiple skills and to employ them.

Further research is necessary to incorporate stochastic aspects and corrective and reactive maintenance and to optimize the tuning of skills and scheduling the teams.

REFERENCES

Birtwistle, G. M., O. J. Dahl, B. Myhrhang, K. Mygrard (1973), Simula Begin, Van Nostrand Reinhold, New York.

ERTMS/GSM-R, 2003. *Quality of Service Test Specification*, QoS Working Group of UIC, V1.0, 2003, www.aeif.org

Fishman, G.S. 2001. *Discrete Event Simulation. Modelling, Programming, and Analysis.* @001 Springer-Verlag New York, Inc. ISBN: 0-387-95160-1, 52-59

Healy, J. R.A. Kilgore, 1997. "Silk,: A Java-Based Process Simulation Language". *Proceedings of the 1997 Winter Simulation Conference, IEEE,*

HSL zuid web site 2006 :
http://www.hslzuid.nl/hsl/uk/Organization/index.jsp

TCRP report 100, 2003, "*Transit capacity and Quality of Service*", Transportation Research Board, 2nd edition, http://trb.org

Tervonen, Juha, Prianka N.Seneviratne and Heli Kilpala , 2000. "Performance *improvement strategies for railway enterprises*", Technical research centre of Finland, research notes 2018, 2000, www.inf.vtt.fi
Veeke, Hans P.M., Jaap A. Ottjes, 2002. TomasWeb: web site: www.tomasweb.com

Veeke, Hans P.M., Jaap A. Ottjes, 2000. Tomas: Tool for Object-oriented Modelling And Simulation. *In proceedings of Advanced Simulation Technology Conference (ASTC2000).* April 16-20, 2000, Washington, D.C. pp. 76-81. The Society for Computer Simulation International (SCS), ISBN: 1-56555-199-0

Zeigler B.P., Praehofer H and Kim T.G., 2000. "*Theory of Modelling and Simulation* 2nd Ed. Academic Press, San Diego.