Asset Analytics
Performance and Safety Management
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Transportation Systems

Managing Performance through Advanced Maintenance Engineering

Springer

Chapter 8
Smart Asset Management or Smart Operation Management? The Netherlands Railways Case

Leo A. M. van Dongen, Lex Frunt and Alberto Martinetti

Abstract Asset Management represents a key factor in the transportation sector, especially in the railway domain. The proper interaction between asset owner, user, asset manager and operator determines the success of the daily operations and of the long-term strategy as well. Through the years, this balance has been often neglected causing situations where the service was not reliable enough or not safe enough. In this context, maintenance operations play a significant role. The chapter introduces how smart asset management and smart operations management have been implemented in the last two decades within Netherlands Railways. First, an introduction on the company and on the methodology based on ISO 55000: 2014 Standard is offered. Second, an overview of the fleet management and development is discussed. Thirdly, a full reflection on the different levels of performance management is highlighted for underlining all the principles used for reaching short, medium and long-term strategy results. Lastly, the chapter will pinpoint the benefit of introducing dynamic maintenance planning and prognostics and health monitoring as future step to take in order to facilitate a continuous improvement.

Keywords Rolling stock · Smart asset management · Smart operations management · Netherlands Railways

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S. Singh et al. (eds.), *Transportation Systems*, Asset Analytics,
https://doi.org/10.1007/978-981-32-9323-6_8

8.1 Introduction

As is commonplace in various industrial sectors, a multitude of the investment costs or replacement cost is spent on cyclic maintenance, overhaul, modernisation and lifespan extension during the service life of rolling stock.

For the Netherlands Railways (NS) it is important to find the correct balance between the investment costs and other operating costs based on the required and agreed fleet performance as well as complying with legislation and regulations. The initial investment of a passenger rolling stock is roughly 2 million euros per coach. Having roughly 3000 coaches on the rails, NS has an overall replacement cost of the fleet of 6 billion euros (van Dongen 2015a). The total value chain of the domestic passenger transport amounts to 2.4 billion euros annually. Broadly speaking, 100 coaches per year (200 million euros) have been supplied over the past period. For the sake of simplicity, this recurring pattern of expenditure can also be classed as depreciation costs. In view of the large share in the total costs, keeping these investment costs low may initially seem attractive. However, the reality is more unruly: over the whole life cycle of the rolling stock fleet the maintenance costs rise to more than double the investment cost.

On an annual basis and on top of the initial purchase costs (van Dongen 2015a):

350 million euros for cyclic maintenance and parts overhaul;
100 million euros for overhauls and upgrades of the coaches.

As such, the share of the costs of rolling stock in the operating bill is roughly 30%.

The size of the fleet, the significance impact on various KPIs in the transport chain (punctuality, probability of finding a seat and cleanliness), as well as the effect on the reputation of the NS (brand image and incidents), such as indicated in Fig. 8.1, justify possession of the fleet and "in-house" asset management.

Asset management is not just aimed at technology, but also at flexibility in the fleet's deployment in the transport process across the entire life cycle.

The allocation of the fleet for the short cyclic maintenance across the available workshops is rearranged if required, along with new insights into the scale of future transportation and associated stock deployment. The workshops and maintenance equipment are adapted to the fleet's development where necessary.

This chapter outlines the broad approach to asset management, technical management and maintenance work on rolling stock at the cutting edge of product, process and technology, aligned with the transportation system.

8.2 Structure of Netherlands Railways

In response to the European legislation 91/440/EEC aimed at organisational separation of railway construction and maintenance from the transport operations, the public

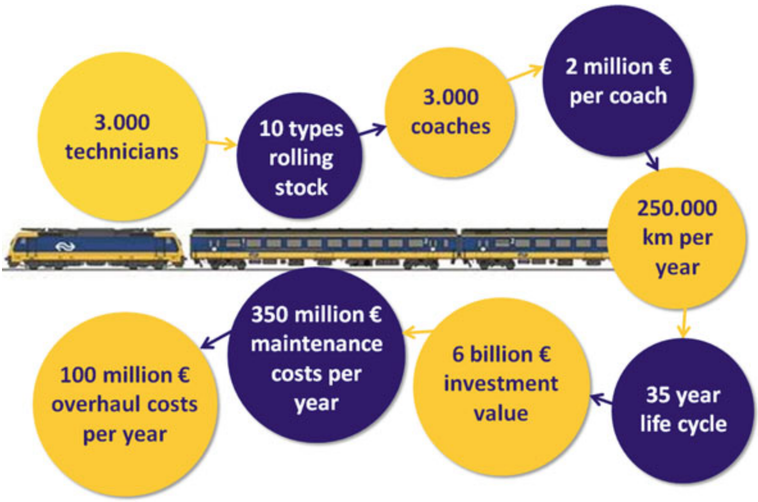

Fig. 8.1 NS rolling stock in actual numbers

limited company NS was divided in the 90s into a commercial NS Group and three implementing bodies: Railinfrabeheer, Railned and Verkeersleiding, later merged into ProRail. ProRail is responsible for construction, management and maintenance of the rail network, as a government-commissioned partner. Concession frameworks were stipulated by government, monitoring was organised in an independent governmental supervisory body: Human Environment and Transport Inspectorate.

NS Group was given the broad portfolio of commercial activities and divested itself of non-core business activities (rail construction, goods transport and telecom). The core tasks passenger transportation (including rolling stock maintenance), station operation, interchange and real estate development at railway junctions create mutual reinforcement. Through this reorganisation within the rail sector, driven by a strong focus on Return on Investment (ROI) and against the backdrop of the company's precarious future position, management did not have sufficient attention for the operational processes in their interdependence, which meant a reduction in service provision quality and a punctuality decrease to below the 80% standard.

From 2013, a new NS management team uses five principle objectives to aim for improvement of the basic quality: timekeeping, providing service and information, working on social safety, providing sufficient transport capacity and ensuring clean trains and stations.

The government is making robust investments in maintenance, new construction and improvements to the rail network to an amount of 2 billion euros annually. The NS is awarded the concession on the main rail network and, as said, investments to the tune of 3 billion euros are made available for new rolling stock. Transportation on the regional networks is publicly tendered by the local authorities and is awarded to private parties such as Keolis, Qbuzz and Arriva.

Over the last few years, operational improvements have been such that train frequency along the large corridors has been doubled and punctuality has risen to 93%. Customer first, travelling from door to door and sustainability are important topics in the NS national scope.

The management of the compartmentalised transportation organisation and the maintenance organisation were "merged" with a view to the necessary enhancement of the train service quality as well as the train density on the rail network (an intercity train every 10 min): the transportation and maintenance logistics are interwoven so intensely that single operational planning and (re)scheduling is appropriate. The cooperation with the rail infrastructure manager (ProRail) was intensified for the same reason. The statutory board for NS's day-to-day management now consists of management teams for both Commerce and Development and Operations.

8.3 Asset Management Methodology According to ISO 55000

To refine its structure, NS opted for the Asset Management approach common in capital goods sectors such as aviation and the chemical industry: the globally accepted ISO 55000 standard (International Organization for Standardization 2014). This standard specifies which elements should be present in an asset management system and how these elements are connected to manage the assets in a purposeful, sustainable and cost-effective manner, aligned with the strategic objectives of the organisation and the needs of the stakeholders. Allocation of the division of responsibilities for the production resources (rolling stock series and maintenance equipment) is based on the above.

Each asset has an owner, user, manager and—in the operational domain—a service provider (maintainer) and operator (transporter). Separate from the hierarchical relationships, the pyramid in Fig. 8.2 shows these roles in the Asset Management approach.

The Chief Financial Officer (CFO), as *asset owner*, makes collegial decisions as part of the Executive Board on investments in fleet and maintenance operating assets. Taking into account the up-to-date investment amount (3.0 billion euros in rolling stock and 275 million euros in maintenance equipment), he is also the board representative in large investment projects.

The *asset user* in the Commerce and Development management team develops longer term plans based on passenger transport needs: network design, future timetables, and asset demands and deployment. This concerns the so-called "steering" of the business, where infrastructure, rolling stock and personnel are combined into a fitting and feasible plan. The Network Design department determines the longer-term demand for "resources": rail infrastructure including stabling capacity in line with ProRail, the personnel plan, the fleet plan, the stock deployment plan, and the strategic plan for maintenance locations and operating assets. All these proposals

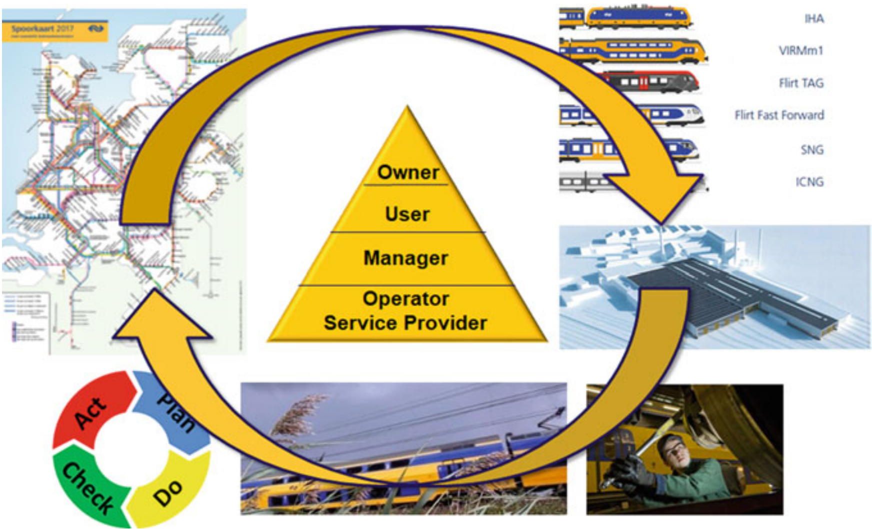

Fig. 8.2 NS asset manager structure based on ISO 55000: 2014

and decisions cannot be refined without input from the asset-responsible specialists, whereby input from the operational business is required for items such as the fleet plan and the stock deployment plan with life cycle plans, production plans and similar.

The *asset manager* (Chief Technology Officer, CTO) translates the asset user's requirements into appropriate actions that can be executed by the Service Provider and Operator to such an extent that the fleet and associated operating assets can (continue to) perform at the most optimised level. Correct specifications and support for new construction projects, development of maintenance concepts, transport preparation and continuation of new and adapted stock: all part of the activities within the scope of "structuring". The asset manager sets the standards for deployment, utilisation and maintenance of the company's capital goods within the framework of (inter)national legislation and regulations.

The *Operator* and the *Service Provider* are the daily user and maintainer of the operating assets: the so-called "performing". Together they ensure that the operating assets are deployed and maintained in accordance with the regulations, whereby the Traffic Control department—responsible for planning and (re)scheduling of the train service—plays a key role.

It is self-explanatory that these responsibilities cannot be borne in isolation. Good cooperation surpassing the boundaries of the domains described above is necessary to make a success of the organisation's development into the future. Contrary to the past, the effectiveness of the chain transport process is dominant and the departmental results are secondary. The feasibility of future plans must be tested in dialogue with experts from the operational domain and what's more, the organisation must also muster flexibility to realise future changes.

The asset management approach is recorded in the *Strategic Asset Management Plan for Rolling Stock*. This plan describes asset management policy, roles and responsibilities, context, Key Performance Indicators, stakeholders, current and future objectives and controls. Important in the SAMP are the four drivers established within the context of the business (social responsibility, the company's strategy and stakeholders' interests) and the related main objectives with which the fleet creates value for the company.

- Safety and compliance: the asset "rolling stock" is deployable with guaranteed safety, meet the NS requirements related to safety and sustainability and exceeds compliance with legislation and regulations so that the "Licence to Operate" is safeguarded in both short and long terms.
- Fleet performance: the asset "rolling stock" performs in accordance with the requirements for reliability, availability and comfort to such an extent that the train service can be executed according to the plan, and that the fleet contributes to the NS objectives in accordance to agreements.
- Fleet costs: the asset "rolling stock" is maintained to such a level that all safety and performance requirements are met at minimal cost across the entire service life.
- Investments: Investments in the asset "rolling stock" lead to sufficient and good-quality trains that contribute to the probability of finding a seat, customer satisfaction and minimisation of service life costs. The introduction of new and adapted trains runs smoothly and has no negative effects on performance.

These main objectives together (Fig. 8.3) form a strong synergy in which improvement circles are continuously balanced towards an equilibrium through the NS strategy spearheads. It concerns a system of performance management within a frame-

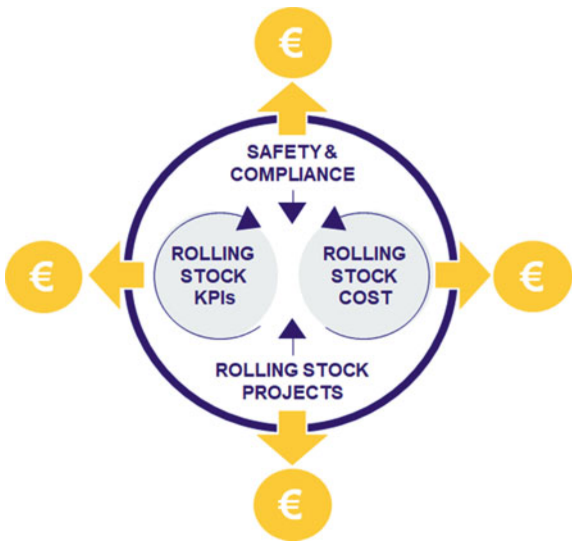

Fig. 8.3 NS rolling stock objectives

work used to determine sub-objectives and develop, control and improve processes to achieve these objectives. Flexibility and manoeuvrability of this performance management system are essential to respond to the fast-changing passenger and transportation needs.

8.4 Fleet Development

In the management of the fleet per rolling stock series, NS differentiates between the various life phases of the train series:

- **Investment** in new construction and modernisation projects: drafting functional/technical specifications, assessing offers, selecting, contract management and project management, participating in design reviews and freezes, quality control of supplies.
- **Phasing in** of new or modernised stock: training employees, ordering initial spare parts volumes, securing required maintenance documentation, testing, familiarising and introducing new stock and resolving teething problems.
- **Guarantee** for the fleet performance (with the fewest possible constructive changes): drawing up maintenance frameworks, monitoring costs (also: minimising costs while guaranteeing performance), monitoring and improving performance and incidents, drafting life cycle plans and determining annual plans for maintenance and overhaul volumes.
- **Enhance service life**: if desired via fleet development, specifying a package of maintenance and technical measures for longer operationally safe deployment of a rolling stock series.
- **Phasing out**: determining and managing the outflow schedule of specific units from the relevant rolling stock series with optimised throughput and utilisation of residual capacity in capital-intensive spare parts, controlled disposal within environmental requirement compliance and maximum reuse of materials.

In order to create maximum value across the various life phases of the stock series against controlled risks and costs, and to be able to make the right operational decisions, the NS creates an annually updated life cycle plan for each rolling stock series. This covers the entire service life, including the period after overhauls and planned phasing out. The plan features not only the most common technical and economical obsolescence but also focuses on compliance and commercial obsolescence. The latest specific performance, bottlenecks and needs of the stock series are charted every year and updated in these life cycle plans. Based on this, objectives and special actions are determined for the near future for each rolling stock series, which could include seasonal measures, interim system or component overhauls or even preparations for modernisation .

As discussed by van Dongen (2015a), the information from life cycle plans for the existing fleet also concerns relevant input for the long-term fleet development plan, in which the desired new construction projects and any modernisations are determined using the expected transport developments and the desired future functionality of the fleet.

8.5 Different Levels of Performance Management of the Fleet

During the rolling stock life, there is a clear distinction between three levels (Fig. 8.4) of performance management (van Dongen 2011):

- design for maintenance and operations (availability of the correct, safely deployable rolling stock, maintenance equipment and well-trained staff);
- first time right operations and maintenance execution and;
- final evaluation and permanent improvement of the rolling stock performance as part of the transport performance.

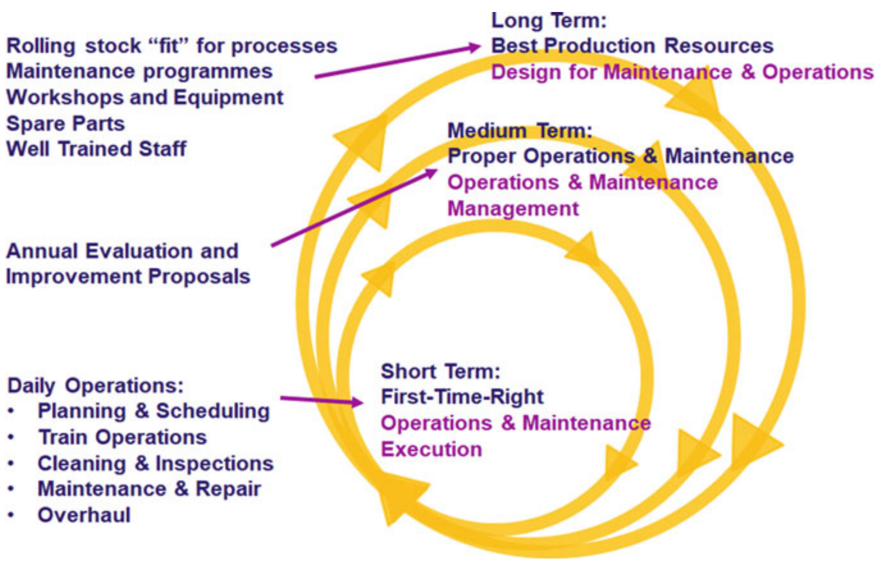

Fig. 8.4 Three levels of performance management in NS for rolling stock (modified from van Dongen 2011)

8.5.1 Design and Introduction of New Trains (First Level of Performance Management)

In the past, the national railway companies laid down detailed technical specifications to stipulate the design of their rolling stock from a position of technical dominance. As the industry was fragmented at the time, the design and build were tendered to various (sub)suppliers: coach construction, traction installation, brake systems, door systems, wheelsets, bogies, gearbox units, signalling systems, etc. Attention for Reliability, Availability, Maintainability and Safety (RAMS) approach and Life Cycle Cost (LCC) approach were implicit yet significant in the specifications stipulated on the basis of experience. There was cooperation according to the Rhine Capitalism model (which means steering to stakeholder value instead of shareholder value) with strong dominance from technical aspects and sometimes even with technical innovation as the objective as such. Although the installation was elaborately specified beforehand, the client would often add his nationally stipulated user experiences from the transport and maintenance process when assessing the drawings during the design phase, and the construction was finally agreed using "design freezes". Substantive technical knowledge of the installation was transferred from sub-suppliers via main contractors to the owner/user. This meant the clients could avail themselves of extensive knowledge to create the operation and maintenance regulations from the documentation provided. Teething problems could be resolved together with the supplier during the initial commissioning. The other side of this coin was that the client was also expected to assume certain guarantee obligations from the aspect of substantive involvement and responsibility in the project.

Privatisation and increase of autonomy of public services meant that companies are increasingly focusing on their core activities. The customer is key and rightly so, and the attention is geared towards the development of the transportation product. Development and management of rolling stock are given a place in the chain. Train are designed, built and supplied by large companies and consortiums that develop and offer new systems and installations based on (in-house) market insights and technical experience. This offers perspectives related to standard platforms and technologies moving towards harmonisation on a European scale, although this remains a long-term objective.

In the event the order and construction of new trains are implemented, the final design could be ill-suited to the production organisation (transport and maintenance execution). The quality of the design and its continuation must be in balance. After all, cutbacks to the design quality cannot be compensated later through extra maintenance, or they might lead to complex, undesirable deployment limitations. It is important to underline how expensive design is still attractive due to less life-managing costs and less or no deployment limitations, which leads to optimised Life Cycle Costs (LCC).

When ordering a technically complex installation such as a train, it is impossible to specify everything in detail up front. This could lead to several interpretations and might be a source of misunderstandings. For this reason, the (future) users must participate in the various phases of the project (specification phase, assessment of the tenders, preliminary design, engineering, construction, build, testing and introduction). As discussed in Mulder et al. (2013), this could include joint design reviews and freezes, safeguarding of the production quality, training and introduction, familiarisation and resolution of teething problems. Sound and early cooperation with the supplier at the cutting edge of technology, maintenance and transportation processes are of importance: design for maintenance and operations (Fig. 8.5).

Various original equipment manufacturers of systems are suppliers of the integrators (rolling stock suppliers): this could include traction installations, brake systems, door systems, air conditioning, toilet systems and similar. In view of the long-term maintainability and service, it is also important to invest in a good relationship with them, starting from when the specifications and design of the train are initiated.

Parada Puig et al. (2013) clearly highlight how it is not only the quality of the design that is significant in the introduction of new trains; the impact on the transport and maintenance organisations should also be prepared properly. New developments and changes to the environment have a constant effect, with distinction between:

- Maintenance equipment. The new generation of NS trains has low floors for level boarding from the platform and therefore many installations are placed on the roof. This means that platforms have to be installed at height in the workshops so that fitters can work ergonomically and safely.
  Aerial work platforms will be required at service locations and washing equipment has to be adapted.
- Spare parts. To maintain trains, sufficient spare parts should be available from stock. This concerns large, replacement parts to be purchased as a one-off with the order, such as traction motors, bogies, wheelsets, HVAC units etc.

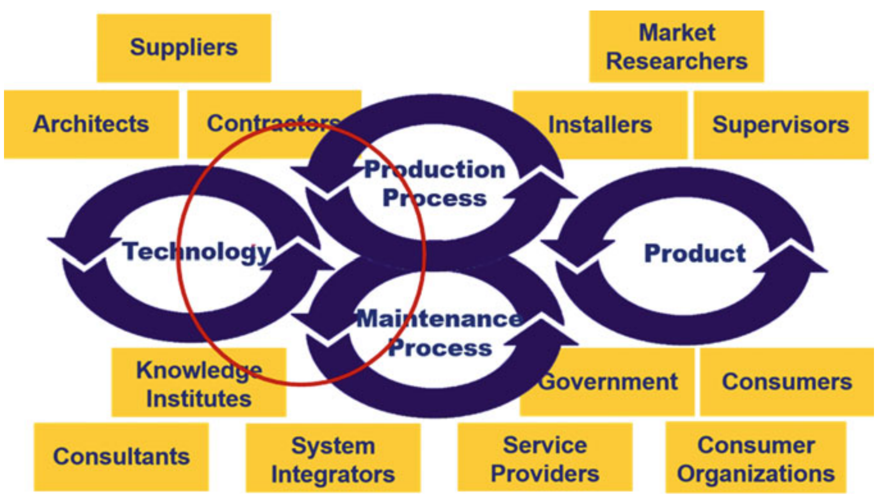

Fig. 8.5 Rolling stock "fit" for processes

- Maintenance programme. As discussed in van Dongen (2015a) for modern installations together with the technical design an initial maintenance concept is created, on the basis of Reliability Centred Maintenance (RCM) and Failure Mode Effect and Criticality Analysis (FMECA) including both daily and short-term maintenance and long-cycle maintenance schedules listing light and heavy overhaul services.
- Working methods. In order to structure the processes in a predictable manner, working methods must be described in procedures and documents. This concerns, among other things, deployment conditions limited or not limited by certification, configuration documentation, maintenance intervals, service descriptions, work instructions, fault diagrams, response plans, seasonal measures, processing scenarios and similar.
- Training employees. Train drivers, conductors, technicians, work planners and planners must be trained in a timely manner in order to be able to work with the trains adequately. Training involves training documentation, simulators and instruction aboard the train. Training should take place in alignment with the gradual inflow of the new rolling stock series. In view of proper "familiarisation", it is important to gain steady and intensive initial experience with the train. If training is offered too early and only a few hours of experience are gained, there is an increased chance of operating errors and faults.

Gradual introduction and handover from the industry to the NS take place using joint cooperation in successively: system testing, type testing for homologation, obtaining the Commissioning License, technical pilot operation and commercial pilot operation with the first trains towards phased inflow and deployment of the entire series of trains. This is the last step in the long-term introduction of the new generation of trains.

8.5.2 First-Time-Right Operations and Maintenance Execution (Second Level of Performance Management)

Safety, availability and reliability of the trains in daily use are not only guaranteed through technically perfect designs and maintenance concepts. The attitudes of the managers, operators and technicians in the use phase determine the results to a large extent as well. This involves alertness in procedures, work instructions, working conditions, good housekeeping, job descriptions, tasks and responsibilities. Open communication encourages great strides forwards: work only takes place if the conditions are clear and safe. In a nutshell, this approach is based on the Kaizen, Lean Working and First Time Right principles (Berger 1997; Hasle et al. 2012; Russo and Schoemaker 2002).

The poor operational performance at the start of this century has prompted the NS to initiate a programme of improvements comprising several spearheads in the primary maintenance processes:

- Delivery quality after maintenance is key and a report on the associated Product Quality Index is created daily for each workshop.
- Safety is a precondition. NS has invested much in the objective: "every employee goes home healthy, every day." This programme involved risk identification and assessment, safety training and regular safety walks conducted by members of the board. A process has been implemented for identification and follow-up of stock-related safety faults directly managed by the CTO.
- Training backlog was eliminated so that employees are actually able to carry out their work adequately. This also includes the development of training documentation, error diagrams and processing strategies for faults. Also encouraged is social innovation (ideas from the work floor) by having employees present their improvement plans that are directly assessed by managers from the company and, if applicable, to award an implementation budget for these plans.
- The "pit-stop programme" (carefully described in Chap. 12) has honed the prioritisation of planned and unplanned maintenance during the repair of defects. By structuring pit-stop tracks for fast, unplanned repairs, important contributions to the availability of the fleet were achieved.

These efforts have brought about important improvements to results. Withdrawal for short cyclic maintenance decreased from 400 to 200 coaches. The share in the delay of the train service as a result of non-functioning stock and the number of safety faults per million km have decreased. The budget for cyclic maintenance costs over the last decade stands at roughly € 325 million while the fleet performance rose from 625 to 675 million coach kilometres per year. The number of Lost Time Incidents (LTI) decreased from 15 to 0.5 lost time incidents per million working hours, specifically from 60 to 2 lost time incidents per year. These achievements, the attention for the employees and also their input in process improvements saw the employee satisfaction rise from 6.3 to 7.4 out of 10.

8.5.3 Permanent Improvement of Stock Performance (Third Level of Performance Management)

Once decisions on investments have been made and a train has been designed, the intrinsic quality of the design is determined on the basis of FMECA. This "new-build quality" can be retained within acceptable margins. For continuation, the behaviour is measured, registered and analysed to guarantee the RAMS with "customised operations and maintenance". Methods such as RCM and Risk-Based Inspection are applied here.

In the case of management of an installation according to short-term and medium-term approach, it is important that transport operations, maintenance execution and the asset manager work together closely.

The NS has created rolling stock teams in the workshops for each rolling stock series: as the "owner", a rolling stock manager is responsible for the safe deployability of the rolling stock, together with the production manager of the workshop and is supported by a reliability engineer, a configuration engineer, a business analyst and a maintenance engineer from the desired objectivity (standard setter) as a permanent guest at the table (van Dongen 2015a).

The installation's behaviour is measured: performance, usage data, fault behaviour and similar are registered in digital information systems. Figure 8.6 provides an insight into the fault behaviour of the NS fleet divided into various primary causes. Similarly, cross sections can be created to various systems on the trains. Analysis of the data can determine the links between maintenance work and use of the installation. The maintenance plan can be continuously optimised on the basis of these progressive insights.

A maintenance concept may seem static; however, it can be adapted according to experience gained.

The feedback received from engineers and technicians involved can be used to propose design adaptations. These experiences are also included in the improvement of specifications for new trains. This involvement can lead to new maintenance concepts and improvement of quality, rising the attention of the manager responsible, of the maintenance engineer and the production manager of the maintenance company.

Digitisation means that designing, testing and controlled implementing of software changes is becoming increasingly important. The asset manager and maintenance organisation adapt their organisation to this. In order to achieve a fine-tuned contribution of the rolling stock teams to the reliability of the ultimate train product, a key performance indicator for reliability was sought that would closely align with direct customer inconvenience, cancelled trains due to technical issues: a train that

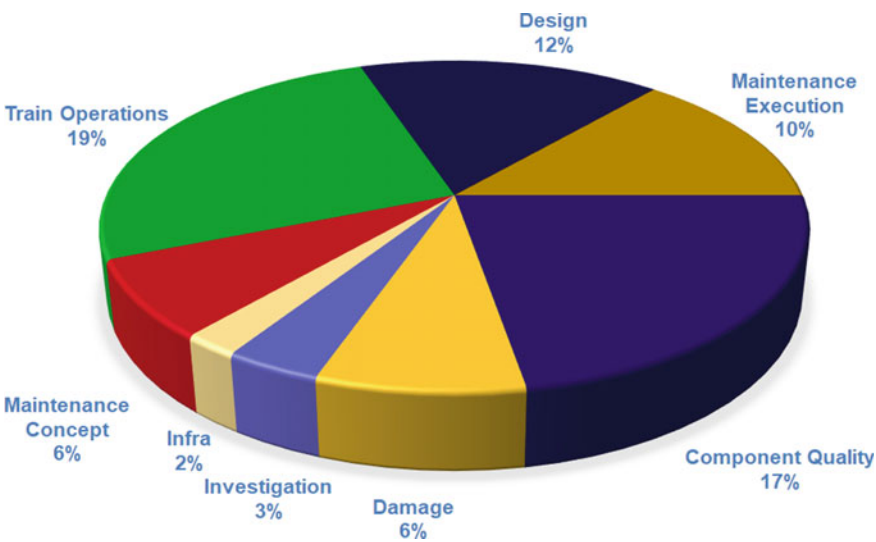

Fig. 8.6 Root causes of cancelled trains

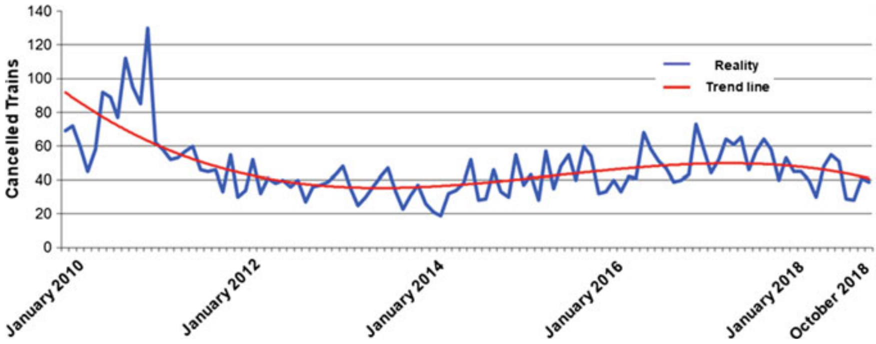

Fig. 8.7 Cancelled trains up to December 2018

cannot leave within 10 min after the failure notification. Attention for the prevention of recurring events and First Time Right repairs on the basis of proper fault diagram analyses has allowed the NS to reduce the number of stranded trains from 80 to 40 per month (Fig. 8.7).

Contrary to this positive development on the conventional network, there is a relative increase caused by trains recently introduced on the High-Speed Line (current level 3%). There is a mix of underlying causes. The rolling stock used on the HSL line has not been specifically designed for use on the HSL. This leads to deviating loads on the material (including running gear and pantograph) and strongly deviating instructions for operation and usage. The HSL infrastructure is characterised by complex safety systems and procedures and is a combination of regular and HSL tracks with various complex switchovers in voltage systems and security systems. The necessary constant optimisation of the infra-stock system leads to frequent changes to the control software. An increase in transport also plays a role. In order to continuously guarantee rolling stock performance, adaptations to the actual high-speed fleet are required in advance of the inflow the InterCity New Generation anticipated in 2020–2021. Furthermore, the network designer (asset user) as well as the asset manager are not only calling for adaptations to the stock but also the infrastructure, whereby (improvement to the) cohesion of the system is crucial.

The life cycle plan for each rolling stock series is updated every year, in a performance report. The long-term maintenance requirements of the various installations are determined. There is consolidation of this maintenance requirement across the entire fleet, "balanced" along with viable withdrawal, capacity inventory and budgeting through rearranging maintenance intervals and turnaround times where possible. The life cycle plan also indicates the residual service life of a stock series and whether service life prolongation is possible. As such, this serves as input for the previously described fleet planning.

8.6 The Way to Dynamic Maintenance Planning with Real-Time Monitoring

Modern trains with ever increasing mechatronics and digital control systems have so much "internal" data that it allows for extraction of information on the technical status of the installation. In addition, sensors can also be used if required for targeted monitoring: think of vibration recorders on critical bearings. Monitoring is more than determining or diagnosing faults. With registration and analysis of the progress of relevant parameters, monitoring can also provide an insight into the degradation behaviour before an actual fault occurs. This can be done through "on the spot" monitoring, but also via wireless data communication, remotely. These techniques can establish up-to-date maintenance requirements and plan the work: for the short-term targeted service work and for the long-term, clustered services at a moment suitable for maintenance execution. Reliability engineers (responsible for the reliability of installation) can provide advice on repairs or maintenance from the control room before a fault occurs.

As discussed by Mooren Ceng and van Dongen (2013), using monitoring and automated data processing allows for more accurate information to be obtained than in the past and clearer steering along with the value drivers "rolling stock performance" and "maintenance costs".

New trains are manufactured in order to provide data and information through thousands of sensors controlled by a Train Management System (TMS) (van Dongen 2015b).

In the pilot project presented by Mooren Ceng and van Dongen (2013), 54 double deck trains have been equipped with a special system for downloading on-board failure reports, operational events (doors opening/closing, coupling), and counters (compressor operating hours etc.) connected to an operational dashboard for the NS control room.

Initial results showed that withdrawal in case of extra arrivals can be reduced by an average of 12% as a result of the fact that the repair can be planned in advance. For example, the turnaround times of repairs to door systems and air conditioning can be reduced by 35%.

On the basis of this pilot, it has been decided that all 415 intercity trains and commuter trains introduced after 1990 will be fitted with real-time monitoring. Of course, 285 new trains due for delivery will be added. The status of the main systems is measured: high voltage, low voltage, traction installation, brake system, doors, safety systems, air conditioning, lighting, sanitary facilities and air supply. The helpdesk employees can see at a glance which installations are faulty or failing, can zoom in on the cause of the fault and can then choose a number of default processing scenarios. Furthermore, the employees in the control room can see the same screens as the driver on the train, enabling effective communication and action in case of telephone contact.

There is intensive cooperation with ProRail for measuring the train's status on the track, with a view to system integration. The Gotcha system, originally built to measure the axle loads of freight trains, also measures the wheel quality of NS trains. Flat spots on the wheels as a result of slip or blocking can be detected by this system and, depending on the severity of the damage, the defective wheels can be directed to the underfloor wheel lathe within 5000 or 20,000 km. This way, real-time monitoring facilitates planning of the maintenance activities. NS and ProRail continue this development further into a Camino Rail Field Lab with the aim to roll out more extensive monitoring within the integrated rail transport system. The reverse principle of utilising monitoring of the infrastructure from rolling stock certainly deserves closer consideration (think of track alignment, quality of the overhead lines and EMC).

It remarks how the times are a-changing, shifting from an old-fashion and "greasy hands" maintenance to a flexible, digital and proactive approach. Whether an organisation is ready for a dynamically flexible maintenance programme, or whether it just benefits from a rigid schedule for the entire installation, or a mix of both with fixed schedules for large components in combination with status-dependent maintenance, depends on what an organisation wants and is capable of.

8.7 Prognostics and Health Monitoring: Next Step!

In the past, the operational organisation for fault registration was dependent on reports from travelling personnel or service engineers. This meant in effect that the disruption of a fault was already causing an inconvenience. The introduction of Real-Time Monitoring and other Industry 4.0 solutions (Reyes Garcia et al. 2019) means the trains automatically report the faults and the helpdesk receives the notification. This way, faults can be resolved before any inconvenience is experienced in operational processes. It goes without saying that this requires astute maintenance execution to be able to respond quickly and adequately.

Based on the permanently available status information for the various stock systems, contextual anomaly detection methods can be developed that allow imminent faults to be detected and resolved before actually occurring. Possible deviations are detected in the early stage of degradation and its severity can be identified using decision diagrams. One bottleneck in the methodology is preventing "false alarms": the detection methodology should feature the correct analysis and evaluation algorithms in combination with different classifications for alarm levels.

In this respect, the NS has conducted initial feasibility studies from the rail track infrastructure on air leakage in brake systems and axle bearing temperature with "hotbox detection" and is preparing for introduction after the rollout of real-time monitoring (Peters 2017; Lee 2017).

8.8 Smart Asset Management and Smart Operations Management

Good business management and information system are vital for efficient, effective and predictable business operations. Moreover, it is the prerequisite for good management of capital goods performance.

In addition, stricter legislation demands greater demonstrability and predictability of the operational transportation and maintenance processes. In order to achieve this, it is not just the basic processes that should be in order but certain administrative matters should also be well-structured, this could include: certified products (stock and parts), certified maintenance concept, standardisation of maintenance processes, planning and work planning, training and certification of employees, quality checks on maintenance execution, controlled release of rolling stock marked as complete, development of processing strategies for stock fault notifications and registration of the activities carried out.

Figure 8.8 shows how asset management and operations management overlap.

The vertical axis shows the life cycle of the operating assets required for passenger transportation: from concept and business case, via acquisition, design, construction and delivery to actual operational management (driving and maintaining) and subsequently decommissioning. The horizontal axis represents the "Customer Journey": departure from location, transport to station, traffic management, driving and stopping the train and subsequent transport to destination. The customer experience mostly concerns information, travel and visiting.

On the intersection between Asset Management and Operation Management, the available digital information facilitates the operational management at strategic, tac-

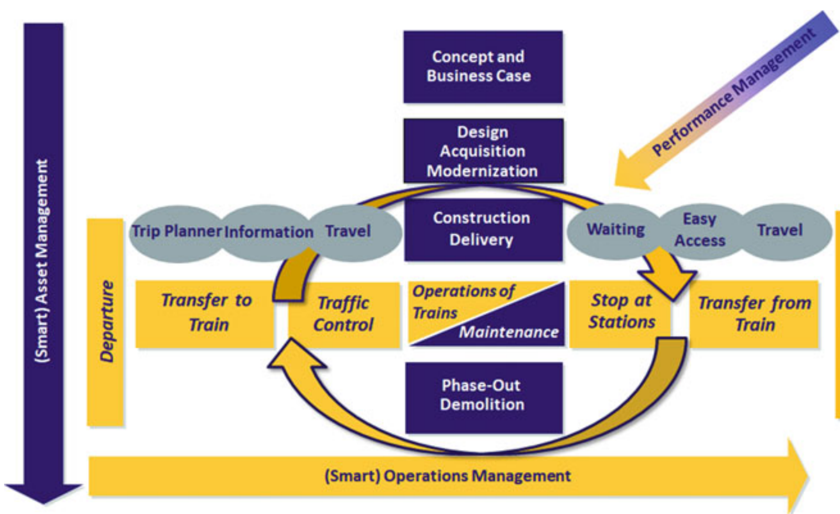

Fig. 8.8 Smart operations and smart asset management

tical and operational levels. Data on the product, the operational production processes and the condition of the assets are the main drivers. Efficiency and effectiveness can be enhanced by also linking smart asset management and smart operations management properly from a digital point of view. Performance management takes place at this intersection. What's more, this structure brings the longer-term strategy and the short cyclical operational processes closer together. Examples are energy saving in stabling of the trains overnight and drivers advices for improved punctuality and coasting saving traction energy.

8.9 Life-Cycle Logistics R&D-Programme

Progress goes beyond the incremental and obvious process improvements.

The NS wants to keep improving the product in the longer term and has therefore been involved for some time in carrying out a research programme together with the three Dutch technical universities (TU/Delft, TU/Eindhoven, and UTwente). An interdisciplinary team of doctoral candidates, students and employees are working in the following fields:

- Strategic decisions: rolling stock selection and design choices related to maintainability, think of accessibility of technical systems, diagnostic systems, repair strategy, etc.
- Tactical organisation of the maintenance execution: structure of the maintenance concept, dimensioning of production capacity and stocks, allocation of work packages to locations, cooperation with suppliers.
- Operations research: dynamic allocation of task plans using up-to-date stock maintenance requirements on one hand and operational feasibility on the other.

8.10 Conclusions

Passengers want to be able to move effortlessly through the public transport system: fast, safe, with ease and at any desired moment. To achieve this, the NS has a sizeable fleet. These operating assets have a significant impact on the objectives set by the NS: customer satisfaction, punctuality and passenger convenience. So, professional asset management is important: sufficient, safe and comfortable rolling stock at an acceptable cost level, now and in future.

The NS has an asset management system for managing safety and compliance, stock performance, stock costs and investments: at strategic level in view of the long-term availability of the correct operating assets, at tactical level by way of correct analysis and management of performance, and at operational level via first-time-right execution in the primary processes.

The availability and interconnectivity of modern digital technologies and control systems, both in the fleet and the operational management, allows business performance to be steered more efficiently and effectively in both long and short terms. This firmly connects Asset Management and Operations Management more significantly than in the past. Assets and operations are increasingly managed in cohesion. Improvements to the connection and cohesion with the asset management of the infrastructure manager with the same resources are the next step here in transport process optimisation.

Asset Management and Technology facilitate the long-term strategy of the company, support the day-to-day operational management and should matter-of-factly keep an eye on customer value and costs.

References

Berger, A. (1997). Continuous improvement and Kaizen: Standardization and organizational designs. *Integrated Manufacturing Systems, 8*(2), 110–117. https://doi.org/10.1108/09576069710165792.

Hasle, P., Bojesen, A., Langaa Jensen, P., & Bramming, P. (2012). Lean and the working environment: A review of the literature. *International Journal of Operations & Production Management, 32*(7), 829–849. https://doi.org/10.1108/01443571211250103.

International Standard Organization. (2014). *ISO 55000:2014—Asset management—Overview, principles and terminology*.

Lee, W. J. (2017). Anomaly detection and severity prediction of air leakage in train braking pipes. *International Journal of Prognostics and Health Management, 21*. ISSN 2153-2648.

Mooren Ceng, F. P. J. H, & van Dongen, L. A. M. (2013). Application of remote condition monitoring in different rolling stock life cycle phases. In R. Roy, A. Tiwari, A. Shaw, C. Bell, & P. Phillips (Eds.), *Proceedings of the 2nd International Through-Life Engineering Services Conference* (pp. 135–138) (Procedia CIRP, Vol. 11). Cranfield: Elsevier Ltd. https://doi.org/10.1016/j.procir.2013.07.050.

Mulder, W., Basten, R. J. I., Jauregui Becker, J. M., & van Dongen, L. A. M. (2013). Work in progress: Developing tools that support the design of easily maintainable rolling stock. In R. Roy, A. Tiwari, A. Shaw, C. Bell, & P. Phillips (Eds.), *Proceedings of the 2nd International Through-Life Engineering Services Conference* (pp. 204–206) (Procedia CIRP, Vol. 11). Cranfield: Elsevier Ltd. https://doi.org/10.1016/j.procir.2013.07.034.

Parada Puig, J. E., Basten, R. J. I., & van Dongen, L. A. M. (2013). Investigating maintenance decisions during initial fielding of rolling stock. In R. Roy, A. Tiwari, A. Shaw, C. Bell, & P. Phillips (Eds.), *Proceedings of the 2nd International Through-Life Engineering Services Conference* (pp. 199–203) (Procedia CIRP, Vol. 11). Cranfield: Elsevier Ltd. https://doi.org/10.1016/j.procir.2013.07.033.

Peters, M. F. E. (2017). Early warnings for failing train axle bearings based on temperature. *International Journal of Prognostics and Health Management, 21*. ISSN 2153-2648.

Reyes Garcia, J. R., Martinetti, A., Jauregui Becker, J. M., Singh, S., & van Dongen, L. A. M. (2019). Towards an industry 4.0-based maintenance approach in the manufacturing processes. In V. González-Prida Diaz & J. P. Zamora Bonilla (Eds.), *Handbook of research on industrial advancement in scientific knowledge* (pp. 135–159). IGI Global. https://doi.org/10.4018/978-1-5225-7152-0.ch008.

Russo, J. E., & Schoemaker, O. J. H. (2002). *Winning decisions: Getting it right the first time*. New York, US: Currency Doubleday.

van Dongen, L. A. M. (2011). *Maintenance engineering: Maintaining links*. University of Twente, Inaugural lecture 9th June 2011.

van Dongen, L. A. M. (2015a). Asset management: A maintenance engineer's view. *International Journal of Performability Engineering, 11*(2), 181–197.

van Dongen, L. A. M. (2015b). Through-life engineering services: The Ned-Train case. In L. Redding & R. Roy (Eds.), *Through-life engineering services: Motivation, theory, and practice*. Decision engineering (pp. 29–51). Springer. https://doi.org/10.1007/978-3-319-12111-6_3.