Potential reliability improvements for SSAB railway transport

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Executive summary

This JVTC report identifies potential maintenance improvements and suggests maintenance actions which will support the reliability of the SSAB railway transport logistic system. Representatives from SSAB, Duroc Rail AB, EuroMaint, AAE, JVTC and SWECO have contributed to this report.

The SSAB railway transport system needs an extra 23.5% wheel-sets waiting to be used in the maintenance process. Failure mode 331 represents 73 % of all maintained wheel axles. SSAB cost of re-wheeling (IS3) is 12.8 times higher than re-profiling (IS1). LKAB/MTAB cost for IS3 is 4-5 times higher than IS1 cost per wheel-set. An increase in IS1 and a decrease in IS3 lower the total maintenance cost. This result is in line with the full scale test performed by SSAB in 2011.

More extensive studies on availability, reliability, maintainability, recoverability and maintenance supportability of the transport system should be carried out to find key performance indicators. The goal is to determine mean failure rate, decrease downtime and support maintenance.

SSAB should establish *holistic maintenance processes* jointly with the maintenance contractors to ensure consistent application of maintenance and enhanced maintenance support. The work can be organized and managed by a consultancy company with experience in railway operation and maintenance issues.

Contractors must agree on a *transparent maintenance information system* that includes the following information: wheel-set status descriptions and location data; preventive and corrective maintenance task descriptions; history of preventive and corrective maintenance actions; reports of failures and defects (failure catalogue), including the operating condition when the failure is discovered; condition monitoring data from detectors and manual inspections; economic and maintenance performance data.

A new work order system should be developed with maintenance tasks based on updated information from the contractors. The work order requests can be triggered automatically by the maintenance information in the system data on predetermined triggers such as wayside detector information, calendar time, elapsed time since last task, and travel distance; alternatively, they can be initiated manually during inspections.

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1 Introduction

The SSAB logistic system is subject to continuous improvements. This includes "pull flow" planning to make the best use of capacity and to minimize rolling stock cost and other cost driving components. This report identifies some improved methods of analysis and suggests maintenance actions that will support the reliability of the SSAB railway transport logistic system.

The reference group has contributed special knowledge, collected data and contributed data. The reference group consists of:
Dan Nordqvist, SSAB
Thomas Aro, Duroc Rail AB
Ulf L Eriksson, EuroMaint
Roland Rubischung, AAE
Björn Svanberg, Sweco

The steering group has contributed special knowledge and helped in brainstorming, sorting data, and managing the project. The steering group consists of:
Mikael Palo, JVTC
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1.1 Background

SSAB's railway transport system Norra Stålpendeln (NS) which runs between its Luleå plant and its Domnarvet plant in Borlänge has short cycle times. Therefore, its locomotives and wagons must be used efficiently. Any disturbances in the transport system rapidly disrupt the whole process, with losses in capacity and delays in the delivery of products to customers. It is essential that the maintenance of railway vehicles be planned correctly and performed at the right time. This calls for condition-based maintenance whereby the relationship between preventive maintenance (PM) and corrective maintenance (CM) is shifted in favour of planned preventive maintenance. The company must ensure that the maintenance actions (PM, CM) occur at the right time and in the right place and that they are cost effective.

Full scale tests on increasing the availability of wheels have recently been performed. Results show that the uneven yearly distribution needs for wheel maintenance, due to greater damage in winter, means that the wheel maintenance workshop is more heavily used at certain times of the year. Hence, SSAB operations at NS began to take steps towards more preventative maintenance for its wagon fleet in fall 2011, with an extra inspection of the wheels before the start of winter. This was done to decrease the sharp spike in maintenance that occurs with the first cold period of the winter season. A total of 680 wheel axles were given a maintenance overhaul. Those with wheel wear and wheel fatigue problems were sent to maintenance.

The sharp spike in maintenance need was reduced and maintenance was more spread out. The need increased the following month, compared to previous years, however, and the extra inspection is likely to have contributed. This reduced spike increased the availability of wagons – a good example of what preventive maintenance can provide.

According to Wireman [Ref. 1] the relationship between preventive maintenance and corrective maintenance should be 80/20: 80% preventive and 20% corrective maintenance. Less is assigned to the latter because it is more expensive. Today, most of the NS maintenance actions are corrective; however, implementing condition-based maintenance and preventative actions could reduce maintenance costs.

Unplanned failures, such as wheel failures, create disturbances in the system. Disturbances may mean that SSAB does not meet its planned logistic needs. This can lead to lost plant production and delays to customers. In the case of large disturbances, the total production may be reduced. In addition, the desired availability over time, 90-93%, may not be met.

At sharp maintenance peaks, often associated with severe cold and winter conditions, wheel axles become worn. Since the wheel failures that result from worn axles can have major negative effects, such failures should be prevented or at least reduced to increase the reliability of the whole transport system.

The wheel axles in SSAB's railway system, including at NS, are subjected to much wear and fatigue which impacts the wheel life. Replacement of the wheel axles is much more expensive than re-profiling the wheels, suggesting that if wheel axle life can be extended, the total costs will decrease.

It is essential to optimize the wheel axle maintenance; this must include an economic assessment of how much wheel degradation is acceptable.

Since the companies SSAB, Trafikverket, AAE, Duroc, EuroMaint and Green Cargo are interlinked, the derivation of the total transportation system costs and technical solutions requires corporation. This would give the transport system better overall economy and better maintenance than if each stakeholder considers individual needs.

An analysis of the technical-economic effects of wheel maintenance at SSAB's rail transport should be performed together a study of with how wheel failures impact wagon availability. It is also important to understand the cost that each maintenance action generates to create an overall picture of the maintenance.

1.2 Purpose

During summer 2012 the project will collect data and describe SSAB wheel maintenance activities to determine improved and cost effective maintenance.

1.3 Project goal

The goal during summer 2012 is to collect technical and economic maintenance information on wheel maintenance from the stakeholders, SSAB, Trafikverket, AAE, Duroc, EuroMaint and Green Cargo, and to identify areas for improvement. The collected data will form the basis for further work and research.

1.4 Effect goal/ potential savings

Identifying the major cost drivers and availability performance killers will achieve more cost effective maintenance for SSAB at NS.

2 Method

2.1 Research methodology

Quantitative methods of collection and analysis use numerical data while qualitative methods draw on non-numerical data, such as words or pictures. The methods can be combined [Ref. 2, pp.151].

2.1.1 Data collection and analysis

This project uses both qualitative and quantitative research methods. First, it preformed qualitative research in a series of interviews to get an overview of the work area and to determine potential areas of importance. Second, the project performed quantitative research by collecting and analysing maintenance action reports. The quantitative analysis can, under certain conditions, be extended to other cases.

2.1.2 Primary data

Primary data are defined here as data collected specifically for this research project. Some are primary data, collected in interviews. There are three types of interviews: [Ref. 2, pp. 320]

- Structured interviews use questionnaires with predetermined questions which usually have pre-coded answers. This interview constitutes quantitative research.
- Semi-structured interviews are not standardized. The interviewer usually has pre-determined topics and questions but these can vary between interviews. Additional questions can be added. This is qualitative research.
- Unstructured interviews have no predetermined questions and the interviewee is able to talk freely about the topic area. This type of interview is used when deeply exploring a topic. The unstructured interview is qualitative research.

The interviews for this project were semi-structured; either questions or a topic of conversation were given in advance. The interviews were characterized by additional questions since follow-up questions were given. This type of interview was chosen to identify potentially important work areas.

2.1.3 Secondary data

Secondary data are existing data collected for other purposes. The project has used secondary data because the raw data in the companies' reports were gathered for other projects.

3 Results and discussion

This chapter is divided into two parts; the first presents qualitative data and the second discusses quantitative data. Each provides a related discussion.

3.1 Qualitative data

Interviews were set up with SSAB, EuroMaint and Duroc.

3.1.1 SSAB

SSAB wants an availability of 93% over time on the wagons rented from AAE and 90% over time for those rented from GC. To facilitate availability a fast recovery after failures is important. This calls for more preventative maintenance; in addition, subcontractors should have spare parts available and the logistic capacity to change and maintain wheels.

In SS-EN 13306:2010, availability is defined as the ability for an item to be in a state to perform as and when required under given conditions, assuming that the necessary external resources are provided This ability depends on the item's reliability, maintainability and recoverability, and on maintenance supportability. Required external resources, other than maintenance resources, should not affect the availability of the item. Availability may be quantified using appropriate measures or indicators and is then referred to as availability performance.

The contractor should focus on mean failure rate, or the number of failures of an item in a given time interval divided by the time interval. Decreasing the downtime required for maintenance is important, as during this time the item is unavailable: in downtime, an item is characterized either by a fault or by the inability to perform a required function. Another key area is maintenance supportability (maintenance support performance), or the ability of a maintenance organization to have the correct maintenance support at the necessary place to perform the maintenance activity when required.

In-depth studies on availability, reliability, maintainability, recoverability and maintenance supportability of the transport system are necessary. Finding key performance indicators, for example, will lead to less downtime and better maintenance supportability.

3.1.2 Subcontractors

SSAB rents 316 wagons from AAE and 27 wagons from Green Cargo and uses them for the NS railway transport. AAE is responsible for wheel maintenance on its wagons, using subcontractors to perform the maintenance. The major subcontractors are Duroc and EuroMaint. EuroMaint changes the wheels of the wagons and usually sends the wheels to Duroc for maintenance; in turn, Duroc sends the maintained wheels to EuroMaint. MidWagon and SweMaint are also subcontractors with the same function as EuroMaint but handle a very small number of wheels.

Green Cargo wagons is a part of the Swedish wheel pool where SSAB sends its wheels for maintenance. AAE pays its subcontractors Duroc, EuroMaint, Green Cargo, MidWagon, and SweMaint. AAE openly reports its maintenance cost to SSAB. SSAB pays AAE and GC for the rental of the wagons and for all separate wheel maintenance costs. The maintenance wheel risk cost differs from year to year.

If AAE financed the risk cost of wheel maintenance on its own wagons, the company would have to add this to its overall maintenance costs. There is always some uncertainty in the amount of wheel maintenance needed because of the seasonal changes.

SSAB decided to control the risk cost and pay AAE and GC for the wheel maintenance risk cost as a separate maintenance activity. SSAB paid AAE around 50 million SEK for 2011, an unusually high cost. Assuming the same cost level for maintenance per wagon, regardless of the maintenance contractor, the GC total maintenance cost for 2011 was around 4 million SEK.

3.1.3 AAE framework

The Swiss company AAE does not use the Swedish standards but its own operation and maintenance standard, Technical Specification Operation (TSO).

AAE applies TSO on the 316 wagons rented by SSAB at its NS operation. The TSO maintenance management system differs from the Swedish system. The Swedish wheel safety system is supported by an individual wheel axle operation and maintenance *statistic database*; each axle is checked and controlled by the statistical system analysis. Because TSO does not collect enough individual axle safety statistics and usage history, it must rely on stricter condition based inspection rules, such as non destructive testing (NDT). Compared to the Swedish system, TSO system needs more condition maintenance inspections, causing the maintenance costs to increase.

For example, reprofiling wheels using TSO standards costs about twice as Swedish standards, and ultra-sound (NDT) after reprofiling appears in the TSO standards but not in Swedish standards. In addition, every wheel axle has a small ID tag with information about the wheel, such as type and diameter. TSO standards require a sticker on the inside of the wheel with the same information as the ID tag. This takes more maintenance time, contributing to higher maintenance costs. TSO standards do not allow the wheels to touch each other during transport or storage, but Swedish standards do; this means that more wheel axles can be stored or transported in the same space under Swedish standards.

3.1.4 Wheel axles, wagons and wear

AAE owns slightly over 1700 wheel axles, but the number is constantly being reduced as wheels become worn and must be disposed of or re-wheeled. Nearly 1300 of the wheel axles are used during operation; the rest serve as a backup to prevent stoppages in the system and create transport availability. Overall, the SSAB railway transport system needs an extra 23.5% axles waiting to be used.

The lifetime of a wheel is two to three years depending on operation conditions and maintenance cycle times in the maintenance plant. All wheels are re-profiled at least once a year.

Added together, the re-wheel cost, maintenance cost, purchase cost and revision cost are about ten times more expensive than re-profiling.

The wagons used by SSAB at NS used to have STAX 22.5 tonnes/axle with a total weight of 90 metric tonnes per wagon and a maximum pay load of 69 tonnes. Since 2005, wagons have STAX 25 tonnes/axle with a total wagon weight of 100 tonnes per wagon and a maximum pay load of 79 tonnes. During operation of the earlier STAX 22.5 transport system, a wagon was loaded with about 65-66 tonnes in pay load; today, the average pay load is 71 tonnes. Assuming constant transport volume demand per annum, this implies that fewer wagons are in operation today. Increasing the axle load by 10% (22.5 to 25) would decrease the number of wagons in the system by about 7% compared to the number in 2005.

There are different ways to detect and monitor wheel wear and wheel fatigue. One is visual inspection of the wheels at the railway yard. Another is general wagon maintenance overhaul in the workshop. If a wagon with bad wheels is at the workshop, the wheels can be maintained before they have reached their maintenance limit (opportunity based maintenance actions). Wheel maintenance decision criteria are stricter and more rigid at the wagon workshop than at the railway yard.

Track wayside safety detectors, such as wheel-flat detectors, hot bearing detectors and hot/cold wheel temperature detectors, are managed by the infrastructure manager (IM) Trafikverket. The Swedish IM network of wheel impact detectors can detect damaged wheels and send an alarm to the operator. There is also a wheel revision once a year on the wheels used at NS; this is done according to workshop maintenance criteria.

3.2 Quantitative data

Information about the wagons at NS was gathered from the companies AAE and EuroMaint, The data collected are for the 316 wagons owned by AAE; the 27 wagons owned by Green Cargo are not considered in this report and data evaluation. The data are split into seasons.

3.2.1 Wheel maintenance data

Reported maintenance data from EuroMaint show the number of wheels maintained from August 2006 to August 2010; the data also show the failure mode for each wheel. This information comes from the FORD system. The maintenance contractor who performs the maintenance, EuroMaint, reports its actions to the FORD system;

since 2011 the FORD system has been managed by Interfleet. Relevant data are presented in Appendix 1.

3.2.2 Wheel maintenance cost data

The number of maintained wheel axles and their maintenance cost for 2011 is split by month and activity. The maintenance activities in the data are presented in Table 3.1

Table 3.1 The different maintenance activities and their explanations.

Maintenance activity	Explanation
IS1	Reprofiling
IS2	Reprofiling and bearing revision
IS3	Rewheeling

3.2.3 Failure Modes

There are 35 unique failure modes in the data, all with differing frequencies. The maintenance management system does not contain information on the maintenance activity performed and link this activity information to the failure modes. From the maintenance data on individual wheel sets, it is impossible to identify the root cause of maintenance or link that information to the effect of the performed maintenance actions.

For the sake of simplicity, we assume that the distribution for the performed maintenance activities is same for all failure modes. Given the existing data structure, it is the only available solution. The most frequent failure modes and the associated number of maintained wheel axles appear in Appendix 1; they are visualised in Figure 3.1.

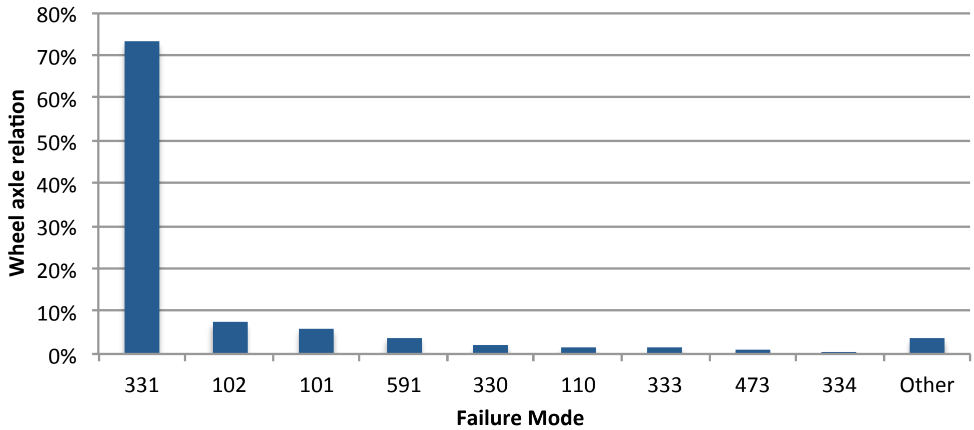

Figure 3.1: Wheel axles split into major failure modes with 26 less frequent failure modes as Other.

Figure 3.1 shows that failure mode 331 is significantly larger than the other modes. Mode 331 represents 73% of all maintained wheel axles.

3.2.4 Maintenance activities

The amount of each maintenance activity appears in Figure 3.2a. The relation between IS1, IS2 and IS3 is not constant; it varies by month and is presented in

Appendix 1. The number of maintained wheel axles also differs for each month; see Figure 3.2b.

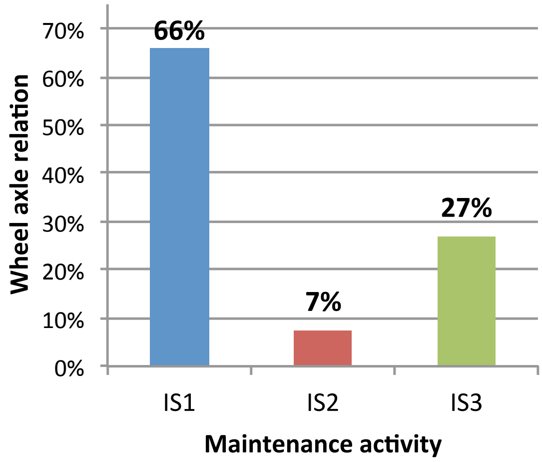

Figure 3.2a. The relationship between maintenance activities.

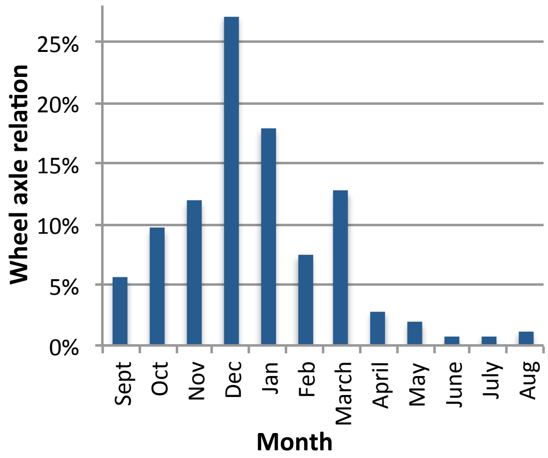

Figure 3.2b. The relationship between maintained wheel axles per month.

IS1 is the most significant maintenance activity, followed by IS3 and IS2; see Figure 3.2a. The amount of IS2 should be relatively constant over time because it is based on bearing revisions that are determined by travel distance for the wheel axle. Figure 3.2b shows that December has the most wheel-set failures. Less maintenance is required in the summer months.

3.2.5 Cost for maintenance activities

The maintenance activities IS1, IS2 and IS3 also differ in cost. The collected data allow us to determine the relative cost of the different maintenance activities, as shown in Figure 3.3. This data are from 2011 but we assume the same relation exists for all years.

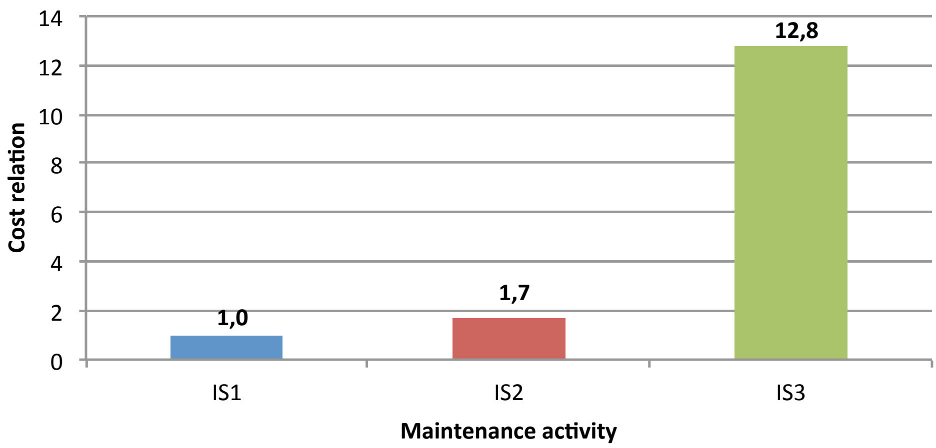

Figure 3.3: The relative cost of the different maintenance activities.

A similar investigation in 2001 by Åhren [Ref. 3], found that re-wheeling (IS3) was 4 times more expensive than re-profiling (IS1) per wheel-set for the LKAB railway wagon system. Figure 3.3 shows that the cost of IS3 is much greater than IS1 at NS. The IS3 cost is 12,8 times greater than IS1, more than what Åhren found for LKAB in 2001. It is important to decrease the IS3 cost as it is a cost-driver for the system. It is essential to balance IS1 with IS3 to lower to the total cost. A small increase in IS3 will generate a significantly greater cost increase than a similar increase in IS1.

Figure 3.4 shows a scatter plot of the data presented in Figure 3.3 with the addition of a trend line for the collected data. The data points present a cost for a specific number of maintained wheel axles. Along with the trend line is an equation for the cost of each maintenance activity.

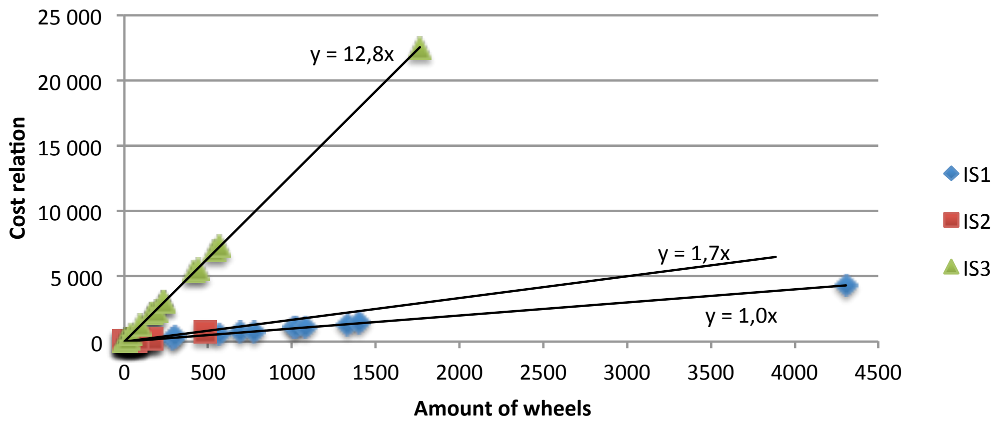

Figure 3.4: Scatter plot presenting the cost for a specific number of maintained wheel axles with the addition of a trend line.

The slopes (12.8; 1.7; 1.0) of the curves in Figure 3.4 indicate the cost sensitivity of each IS# and show that each maintenance activity cost can be used for a simple cost optimization for the wheel axle population.

The distribution of the wheel axles for each maintenance activity for 2011 can be seen in Table 3.2, in the first column labelled 0%. The column shows the current situation; other columns show a simulated change in the IS1 and IS3. For example, in column 5%, the IS1 is increased by 5% (5% more axles/annum of the total population is re-profiled) under the assumption of a reduction of 5% in the total wheel-set population/annum subjected to re-wheeling. The IS1 has been given an increase in the number of maintained wheels and the IS3 is decreased. The increase and decrease are in a linear "one-to-one" relation, giving the same percentage of increase (IS1) and decrease (IS3), to ensure that total number of wheel axles/annum remains constant.

Table 3.2: The distributions of the number of maintained wheel axles for each maintenance activity and the related cost.

Change	**0%**	**5%**	**10%**	**15%**	**20%**	**25%**
	Amount of wheels					
IS1	66%	71%	76%	81%	86%	91%
IS2	7%	7%	7%	7%	7%	7%
IS3	27%	22%	17%	12%	7%	2%
	Cost					
IS1	16%	17%	18%	19%	20%	21%
IS2	3%	3%	3%	3%	3%	3%
IS3	81%	66%	51%	36%	21%	6%
Total	100%	86%	72%	58%	44%	30%

Figure 3.4 shows the cost model results, while Table 3.2 shows the change in total wheel-set cost. In the table, the total cost is set to 100% at year 2011; the costs in the other columns are relative to this and show the proportion of these maintenance activities. IS2 is not changed in any way so that we can focus on the relationship between IS1 and IS3. In addition, the bearing maintenance is only reflected in the travel distance of the wheel axle.

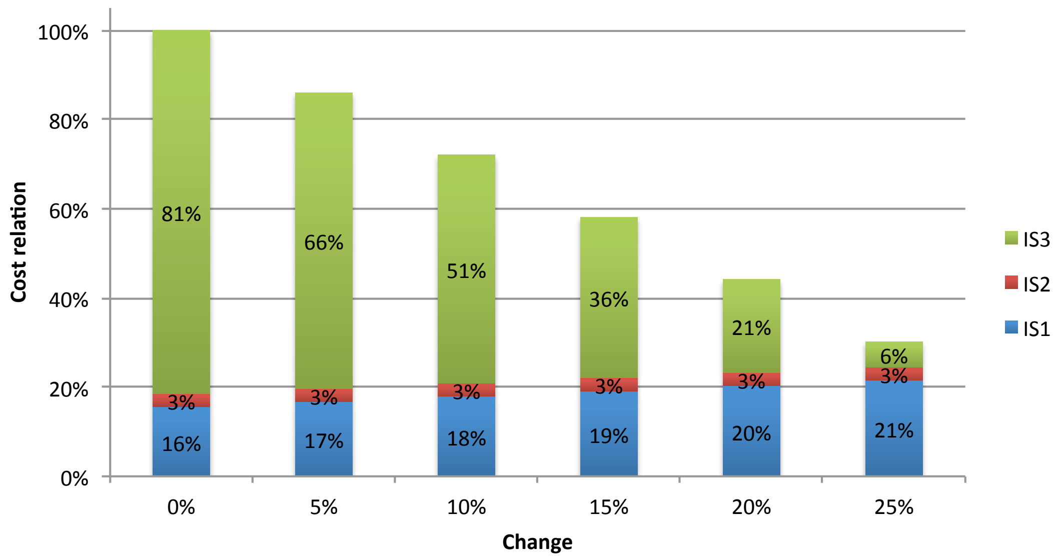

Figure 3.5: The distributions of the number of maintained wheel axles for each maintenance activity and the related cost.

Figure 3.5 illustrates the cost of each change in IS1 and IS3 from Table 3.2. An increase in IS1 and a decrease in IS3 lowers the total cost. Moreover, even a small change in IS3 can significantly affect the total cost. The figure shows that the cost is changing in the same direction as IS3; therefore, IS1 does not have a significant effect.

This result is in line with the full scale test performed by SSAB in 2011, described in chapter 1.2.

3.2.6 Wheel radius removal

Wheel life can be estimated be examining surface crack initiation and propagation. The propagation rates of surface cracks are non linear with usage and increase with the crack length. The depth at which surface cracks appear determines the amount of material that must be removed in workshop turning. When a crack reaches a critical size, from a technological, economic or safety perspective, it may be managed and controlled or removed using traditional wheel turning. If wear can be controlled, however, fatigue cracks do not develop and propagate. The philosophy of controlling rolling contact fatigue (RCF) is to manage and control material removal rate.

The difference between wheel profile wear and RCF is that profile wear is a non stochastic process; it is linear and RCF is non-linear with usage. This relation can be seen in Figure 3.6a [Ref. 4, pp.52]. It can also be described as in Figure 3.6b, where it is an intercept; from this point, it shows better wear rates than RCF. Interviews with technical field experts indicate that maintenance actions based on profile wear need to remove 5 mm of the wheel radius during each maintenance wheel turning, while with RCF, 15 mm or more must be removed.

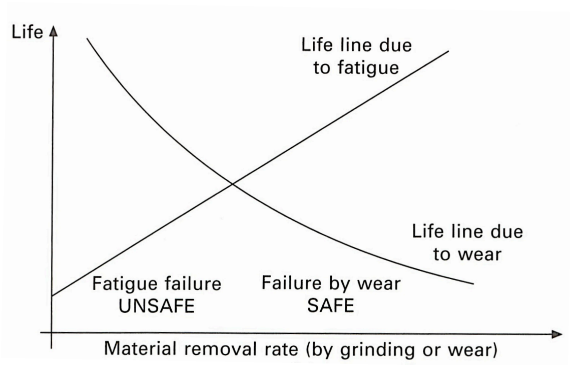

Figure 3.6a: Rail life vs material removal. [Ref. 4, pp.52]

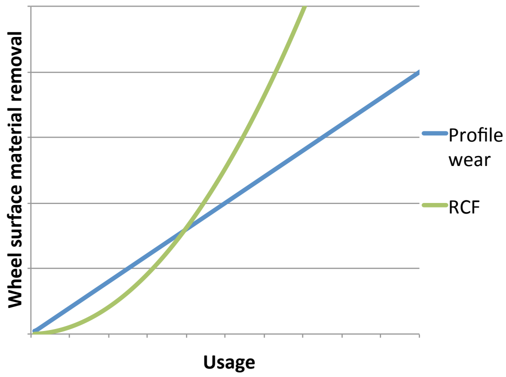

Figure 3.6b: The difference between profile wear and RCF.

We observe high numbers of IS3 actions and a high proportion of failure mode 331 (RCF related wheel surface failure), implying a short life of the wheel-sets compared to other freight operators such as MTAB [Ref. 3]. *However, maintenance data from the existing databases do not have enough information on usage, km travelled or tonnage-km usage in-between turning, to establish a good benchmark with other operators.*

Given the short life of wheel-sets, wheel turning likely does not occur at the optimal time in the existing strategy. Rather, it occurs after the interception on the non linear RCF curve (see Figure 3.6), resulting in increased wheel material removal at each maintenance cycle, compared with a more frequent turning cycle and less material removal as a controlled wear (turning) strategy.

When doing wheel turning at the intercept shown in Figure 3.6, less of the radius will be removed than if the interception occurs further along the exponential un-linear part (see Figure 3.6). This implies that wheel turning at the intercept creates more turning cycles before re-wheeling.

The location of the intercept for this wagon/wheel-set system is currently unknown, and requires investigation.

To do wheel turning closer to the intercept requires more frequent re-profiling, which means more IS1. Increasing the life of the wheels should be possible if IS1 is increased. If the life of the wheels is increased, the frequency of IS3 should decrease**.** As earlier discussed (see also Figure 3.5), *a small amount of change in IS3 would significantly change the total cost; thus, the total maintenance cost would be reduced if IS3 were reduced*.

3.2.7 Decision making process and evaluation

From the collected data we have identified a *decision making process and evaluation*. This process describes which data and the links between them are required for an in-depth analysis. This chapter contains explanations of which qualitative data have been gathered and which data are needed for analysis with the *decision making process and evaluation* as a basis; see Figure 3.7.

Failure mode ⟷ Maintenance activity ⟷ Cost ⟷ Travelled distance
- Wheel life length removed

Figure 3.7: A decision making process and evaluation that can be a basis for analyzes.

Data evaluation

The collected data show the failure modes of the wheel and their frequency. This project has identified 35 failure modes. The determination of the failure mode relies on operator-based inspection techniques which can be subjective with human factors involved in the decision making process. The use of standardized techniques by operators would achieve consistent quality; examples include wayside techniques such as automatic wheel profile measurements and wheel/rail force measurements.

Data on how much of the wheel radius has been removed during each maintenance activity are not available in existing databases and, hence, are not presented in this project. This information is desirable for further analysis. After each wheel measurement, information should be stored in an available system. Such information could be used to estimate the remaining useful life of the wheel axles, which could be helpful in planning activities such as purchasing or availability.

The travelled distance (usage) for a wheel axle between maintenance activities is a part of the process shown in Figure 3.7. This information is not currently available in the databases, but its availability would enhance further analyses. Such information would include the amount of transported tonnage to calculate the tonnage-km.

Missing links
The link between failure modes and maintenance actions shown in Figure 3.7 is not considered in this project because the link is hard to extract from the existing databases. Today's databases are separate and independent systems, and the interacting companies should cooperate to build a more comprehensive database. To find major cost drivers, it is essential to find the links between failure modes and maintenance actions, to link a particular maintenance action to a specific failure mode. For example, because IS3 is the most expensive maintenance activity, it is essential to link particular failure modes to this maintenance action.

It is not known how much each maintenance action affects the wheel-set life. It would be interesting, for example, to use what has been taken off the radius for each IS1 to estimate remaining useful life and to determine how much each failure mode affects the wheel radius.

We know how much each maintenance activity costs; this means that by linking a failure mode and maintenance activity, we can link cost and failure mode. This link will show which failure modes are the major cost drivers. Obviously, the major cost drivers should be the focus of attention. For example, if we can collect data on travelled distance together with total maintenance cost, we may be able to calculate the cost for each km, km/cost. The information could also be used to calculate tonnage-km/cost.

Link and effect decision model
Earlier we noted that an increase in IS1 would be beneficial, since the life length of the wheel would increase. Failure mode, maintenance activity, remaining useful life, life length removed by turning, travelled distance and cost must all be derived from the data. Figure 3.8 gives an example of a new strategy. The ΔR-axis shows the amount of the wheel radius that has been removed in turning; the upper horizontal safety limit line ($R_{minimum}$) represents the limit of the radius that can be removed, while the lower line (R_{start}) represents the relationship of the radius to the beginning of the wheel life. The x-axis represents usage, which can be in either km or tonnage-km. Figure 3.8 gives cases for different amounts of maintenance activities; the dots represent IS1 and the squares represent IS3.

Case 1: Two re-profiling cycles and then changing the wheel.
Case 2: Three re-profiling cycles and then changing the wheel.
Case 3: Four re-profiling cycles and then changing the wheel.

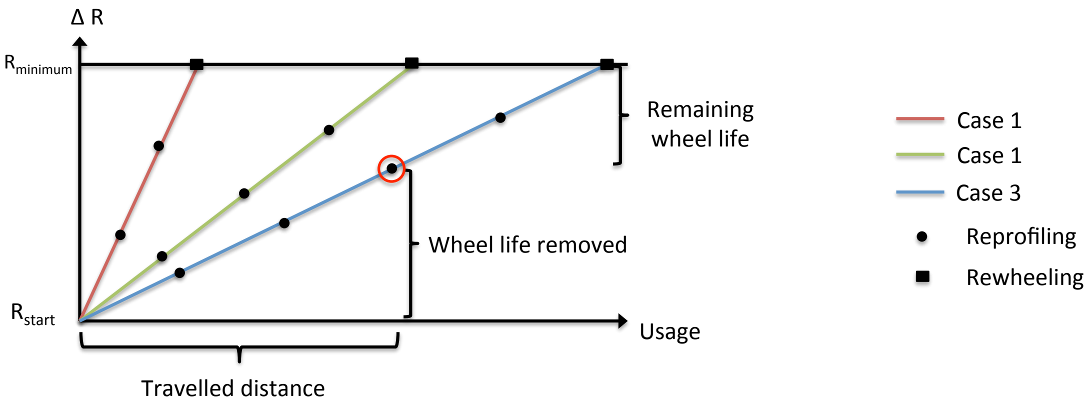

Figure 3.8: Three different life lengths of wheel axles with different amounts of IS1 and one re-profiling

Life cycle cost (LCC) can be used to calculate the different cases; this is a measurement for the economic consequences of a system during its whole lifetime [Ref. 5, pp.85]. Performing an LCC requires all the data mentioned in the *decision making process and evaluation*. The LCC can be calculated for the various cases/alternatives, and these can be compared. An in-depth analysis should include availability and the cost of removing a wheel for maintenance. LCC can create an overview of how the system works with all companies involved, including economic factors.

4 Conclusion

The available data and the known link-effects between data are inadequate to perform an in-depth analysis. The information used in this project comes from separate and independent databases, and some information is missing. Thus, system analysis requires extensive and time consuming efforts to combine and link data. The data necessary for in-depth analysis include the information mentioned in *decision making process and evaluation.*

The project concludes that with the current databases, we cannot provide an overview of SSAB's entire NS railway system, including economic and technological aspects and how the various companies are involved.

The project concludes that none of the subcontractors has requirements in terms of cost, such as "cost limits". This implies that there is no current control over the systems maintenance cost.

The quantitative data show that the IS3 cost is 12,8 times greater than IS1 and a small change in IS3 significantly changes the total maintenance cost. The qualitative data show that re-wheeling costs about ten times as much as re-profiling. Therefore, we cannot determine how much re-wheeling costs compared to re-profiling. However, the qualitative and quantitative data show that costs in 2011 were high compared to other years.

We have not found major cost drivers of the failure modes. We cannot make links between failure modes and maintenance costs with existing data and database links. Failure mode 331 is significantly more frequent than the other modes; however, given the lack of links to maintenance costs, this should be investigated in more detail.

Today's standards in selecting wheels for maintenance and the NS determination of the failure mode can be subjective, relying on human factors; this does not lead to consistency in procedures or quality.

Re-profiling at the intercept of normal wear and RCF removes less of the wheel radius. Re-profile closer to the intercept increases the amount of IS1. However, the location of the intercept is unknown.

5 Recommendations and future research

Data about NS should be gathered and made available in a system database. Data should include information mentioned in the *decision making process and evaluation* and it should cover a long period.

The maintenance system should be reviewed, including the relationship between the contractors and various economic and technological aspects.

Since re-wheeling is significantly more expensive than re-profiling, efforts should be made to decrease the amount of re-wheeling.

Failure mode 331 is significantly more frequent than all the other failure modes. Therefore, relationship of the failure modes to various economic and technological aspects should be studied. To find the major cost drivers of the failure modes, we must find the links between failure mode and maintenance activity. Maintenance costs, together with travelled distance for a wheel axle and transported tonnage, can be used to calculate cost/km, something useful for further analyses.

The intercept between normal wear and RCF should be investigated. The company must decide if the intercept should take a safety, economic or a technological perspective.

Benchmarking should be applied to other similar railway systems to gain knowledge and find ways to improve.

The selection of wheels for maintenance and the determination of the failure mode should be standardised for consistency and quality.

5.1 Example of improvements

SSAB should establish a holistic maintenance process jointly with the maintenance contractors to ensure consistent application of maintenance and maintenance support for planning and execution. Such work can be organized and managed by a consultancy company with experience in railway operation and maintenance issues.

For this purpose, a general description of the essential processes is given in Figure 5.1. Each organization should tailor its processes according to SSAB needs and the context in which maintenance and maintenance support is being applied.

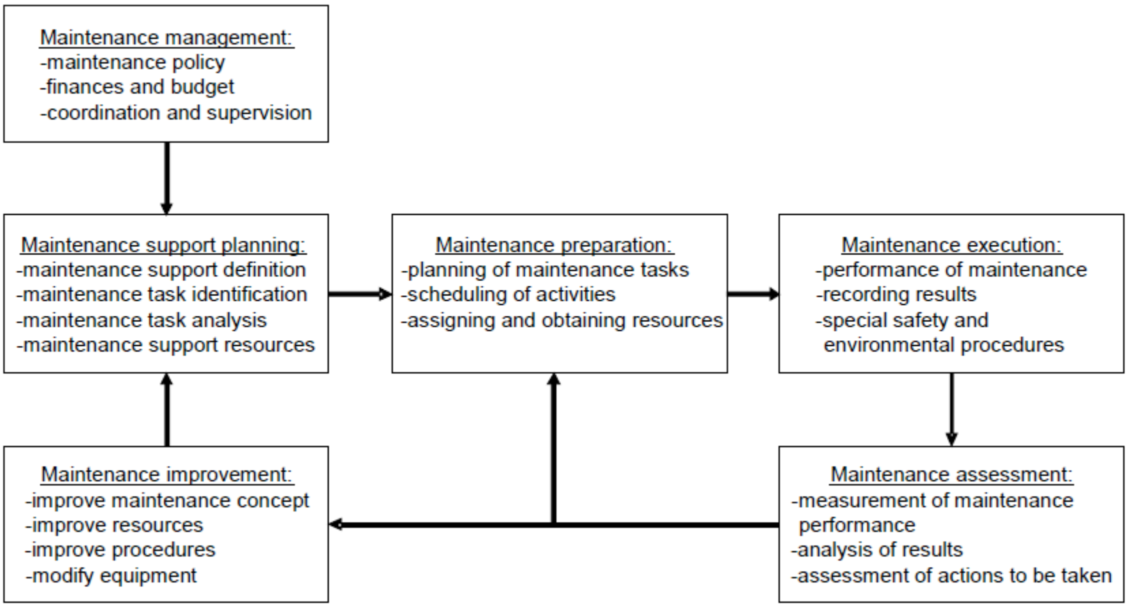

Figure 5.1: General maintenance processes [Ref. EN 60300-3-14].

SSAB has contracts with second and third parties whereby long-term service agreements provide maintenance and maintenance support. SSAB must ensure, via the maintenance contract, that the operators GC and AAE are responsible for planning and developing maintenance and maintenance support for the system. This occurs during the initial stages of the operation and maintenance phase.

The contractors have complete responsibility for all aspects of maintenance and maintenance support with the guarantee of performance and availability. A clear definition of maintenance and maintenance support objectives and responsibilities is very important for cost effective maintenance and problem free operation.

The elements of maintenance and maintenance support planning are illustrated in Figure 5.2.

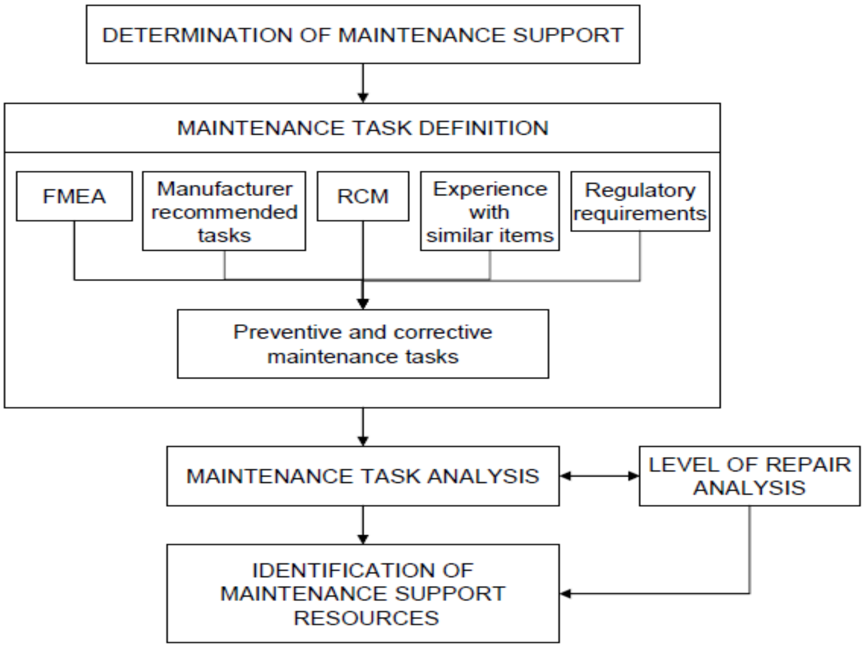

Figure 5.2: Maintenance and maintenance support planning process [Ref. EN 60300-3-14].

Identified areas for improvement include the formulation of general guidelines on goals, objectives and policies. In addition, wheel-set availability and reliability should be improved.

A holistic contractor organizational structure, including maintenance data support for decision making and analysis process, is called for. SSAB, with its contractors, should investigate the use of condition monitoring techniques and tools and evaluate cost and other maintenance limits and optimization constraints. These developments could be initiated and driven by setting a joint (SSAB and contractors) goal for expected service life and availability for wheel-sets and wagons.

There is a need for better maintenance task identification so that maintenance tasks are identified by analysing wheel-set failures using a structured approach such as reliability centred maintenance (RCM) based on an failure mode, effects and criticality analysis **(**FMECA) and data from real-life experience. FMECA data identify preventive maintenance tasks in order to do the following: detect and correct wheel-set failures either before they occur or before they develop into major defects; reduce the probability of future failures; detect hidden failures that have occurred; increase the cost-effectiveness of the contracted maintenance; support the shift from IS3 to IS1.

Due to the number of contractors and stakeholders, transparent information systems are critical. High quality maintenance information is necessary for the wheel-sets, to measure and analyse maintenance performance and to support the regulatory requirements of the contractors.

For example, an updated technical maintenance manual for the wheel-set containing descriptions and procedures that cover improved fault diagnosis (i.e., failure catalogue, list with illustrations) at the workshop turning machine is recommended. Improved recording of the wheel diameter before and after the turning of the wheels and recording the service time (ton-km, distance in km, etc.) between repairs are also recommended. This should be discussed by and introduced at Euromaint and DUROC.

It is necessary to establish contractor training based on existing skills and job requirements as per the updated technical manuals. This will lead to cost-effectiveness.

Contractors must agree on a transparent maintenance information system that contains information including the following: wheel-set status descriptions and location data; preventive and corrective maintenance task descriptions; history of preventive and corrective maintenance actions; failures and defects (failure catalogue), including the operating condition when the failure is discovered; condition monitoring data from detectors and manual inspections; economic and maintenance performance data.

An updated work order system can be used at DUROC, AAE and Euromaint to initiate, control and document specific maintenance tasks according to the updated information from the contractors. An updated work request could be triggered automatically by the maintenance information in the system data on predetermined triggers, such as wayside detector information, calendar time, elapsed time since last task, distance in km, or it could be initiated manually at inspections. Finally, reported data can include results, observations and resources actually used, thus providing the basis for assessment and improvement.

The purpose of introducing a holistic computerized information system is to facilitate the assessment of maintenance effectiveness, such as availability, reliability and maintainability. SSAB related performance factors can be expressed in terms of the following: the availability of wagons for transportation; the downtime of wagons; safety performance; operating costs; maintenance costs; transport quality. Measurements to be reported on the wagon and wagon equipment (wheel-set) or on groups of equipment (bogie) include: availability, reliability, maintainability, down-time, mean time between failure, mean repair time, time-to-failure using a statistical representation, planned and unplanned maintenance cost.

Assessment of updated preventive and corrective maintenance tasks on wheel-sets can be performed either each time maintenance is performed or on a periodic basis. SSAB and its contractual partners should establish and use a standardised method of collecting and analysing data and interpreting results. The results should be used to support and justify improvements. A holistic and transparent computerized maintenance information system should enable this process, managing data and analysing results from the different contractors.

Reviews of preventive maintenance should cover the effectiveness of maintenance, technical aspects of the maintenance tasks and safety.

For corrective maintenance, major failures should be investigated to identify preventive and corrective actions; for major or costly failures, this should include root cause failure analysis with a team of experts, gathering evidence, analysing the results, performing fault tree analysis to determine the root cause of failure, and recommending preventive actions.

Such reviews of corrective maintenance will reveal repetitive failures and trends related to operating conditions, vendor problems and quality issues.

6 References

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Appendix 1

Table 1 presents some of the data from EuroMaint. The data were represented in an excel document.

Orsak	Beskrivning	Vagnen anmäld skadad
331	RUNTOMGÅENDE KROSSÅR/SPRICKOR	2010-03-04
102	PLATTA. BRUS UA. NEDISAD	2008-02-06
331	RUNTOMGÅENDE KROSSÅR/SPRICKOR	2007-01-24
331	RUNTOMGÅENDE KROSSÅR/SPRICKOR	2007-01-24
101	PLATTA. BRUS UA. EJ NEDISAD	2010-01-12
331	RUNTOMGÅENDE KROSSÅR/SPRICKOR	2008-02-08
331	RUNTOMGÅENDE KROSSÅR/SPRICKOR	2007-12-03
331	RUNTOMGÅENDE KROSSÅR/SPRICKOR	2010-04-03
332	TUNNT HJUL/LITEN DIAM. SVARVRA	2010-06-11
331	RUNTOMGÅENDE KROSSÅR/SPRICKOR	2007-02-08
575	HJUL VARIT UR SPÅR	2008-06-28

The failure modes and associated number of maintained wheel axles are shown in Table 2. The table includes explanations of the failure modes in Swedish.

Orsak/Failure mode	Beskrivning / Explanation in Swedish	Amount of wheels
331	RUNTOMGÅENDE KROSSÅR/SPRICKOR	4,788
102	PLATTA. BRUS UA. NEDISAD	479
101	PLATTA. BRUS UA. EJ NEDISAD	385
591	NEDTAGNING PGA BROMSBLOCKPROV	252
330	LOKALA KROSSÅR.	141
110	PLATTA. LÄCKAGE I LEDN./SLANG	99
333	SKARP FLÄNS	98
573	DIAMETERDIFF I BOGGIE	54
334	ANNAT PROFILFEL	33

This Table 3 shows the relation between IS1, IS2 and IS3 year 2011, both for the year and the relation each month.

	Amount of wheelset		
Maintenance action	**IS1**	**IS2**	**IS3**
All years	66%	7%	27%
Per month			
January	76%	6%	18%
February	91%	5%	4%
March	73%	9%	18%
April	82%	11%	6%
May	74%	19%	7%
June	67%	33%	0%
July	89%	3%	8%
August	39%	4%	57%
September	21%	11%	68%
October	32%	5%	64%
November	54%	11%	35%
December	63%	2%	35%