KTH Steel Scrap Model – Iron and Steel Flow in the Swedish Society 1889-2010

Alicia Gauffin, Sven Ekerot, Anders Tilliander, Pär Jönsson*
Dept. Applied Process Metallurgy, KTH Royal Institute of Technology, Stockholm, Sweden

Abstract: KTH Steel Scrap Model is a combined mass flow and mass balance model that calculates external scrap consumption, Swedish scrap, internal scrap and net flow of steel into the Swedish society. This paper presents the KTH steel scrap model, its input data and results. External scrap consumption is calculated based on mass balance analysis for different years and applied on production figures from 1889-2010 with additional estimations and assumptions. The external scrap usage ratio is defined as the external scrap compared to the crude steel production by the following scrap consuming processes; Martin converter, Electric arc furnace, oxygen blowing processes and foundries. Swedish collected steel scrap, internal scrap and net flow of steel into the Swedish society has also been calculated and compared to statistically obtained data.

Model output on external steel scrap consumption in Sweden was compared to an earlier analysis done by Jernkontoret for the timeline 1980-2003. The results show that mass balance calculations are volume wise corresponding to consumption figures based on trade statistics. In addition the difference in trend is assumed to be mainly due to stocking effect. Furthermore it is shown that mass balance and mass flow models could be used as a tool to calculate apparent scrap consumption based on crude steel production figures by process type.

Key words: steel scrap, mass balance, consumption, circulation, mfa

1. Introduction

Data for external scrap consumption in steel mills and foundries are not always readily available due to that single companies don’t want to reveal their consumption figures. Data for raw material usage in steel mills and foundries are therefore usually based on trade statistics for scrap obtained by custom reports and other official reports. However trade statistics are not wholly covering since it does not consider the indirect trade and are collected in different ways over the years. It is therefore interesting to find out other ways to estimate consumption figures in steel mills and foundries. Furthermore for countries where trade data is not readily available it is difficult to obtain an accurate picture of the iron and steel flow. In this paper we discuss the scrap consumption in Sweden since Sweden has rather good statistics compared to many other countries.

Although steel companies usually don’t report scrap consumption, they do most often report detailed figures of raw steel production. Based on raw steel production one could estimate the steel scrap consumption by using mass balance models. Mass flow and mass balance calculations of steel scrap consumption for certain countries and in time could be a more accurate source compared to registered trade data. Furthermore, these models could be used as a tool to offset trade statistics. This paper discusses these possibilities. In addition by obtaining a more accurate outlook on the steel scrap circulation; nations, governments and organizations would be able to enforce their efforts in securing raw material assets for a more environmentally sustainable industry.

A similar study as the present mass flow and mass balance calculations has been done by Järnbruksförnödenheter [1], Jernkontoret [2] and by Swedish steel industries. The models have not been published in the open literature. On global and regional level, a similar study has been done by P. Tardy from the association of the Hungarian steel industry [3]. Also an official study on steel scrap consumption on regional and global level is published by Bureau of international recycling (BIR) for the years 2005-2010 [4].

2. The model

2.1 Material flow analysis

This part of the paper defines the system of the iron and steel flow in the Swedish society. Figure 1 illustrates a material flow analysis (MFA) of the transformation stages of the iron and steel from liquid state to the scrap. Here, steel scrap is categorized depending on origin by the following categories:

- Internal scrap
- External scrap
    - Workshop scrap
    - Obsolete scrap

The scrap types are illustrated in the MFA in underlined italic style next to its production stage shown in Figure 1. Internal scrap is produced in the steel mills and foundries from the casting process to semi-finished and finished products. Internal scrap has known alloy content and is often consumed internally. Workshop scrap has a low content of contaminants and has a short recycling life since it is produced early in the manufacturing stage. Also in reality there are losses in all transformation stages in the MFA. In this case the system is simplified where the losses are summarized under the category next to the redundant.

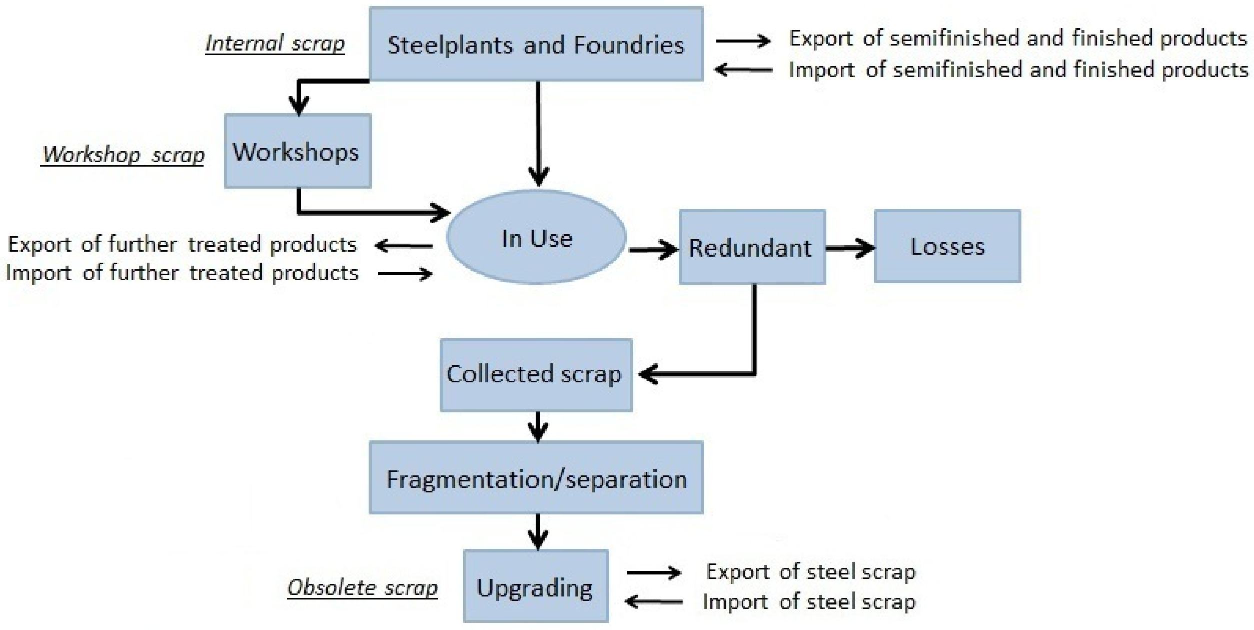

Fig. 1 Material flow analysis of iron and steel in the Swedish society

The timeline from the iron and steel enters the society until it is broken or thrown away is called the in-use phase. The product life lengths will depend on the weakest component in the product, whereby the life length of steel in the society is also dependent on life length of other materials. Steel that has been consumed in the society which potentially could be recycled is called the redundant, including what lies at scrap yards and worn out products. Obsolete scrap is steel scrap that has been collected out of the redundant and further treated into required size and alloy content. In this paper the workshop scrap and obsolete scrap added is called external scrap. The amount of steel scrap collected from the Swedish society is in this paper called Swedish scrap.

Steel can either be produced from iron ore or steel scrap depending on the process type. The iron ore based production of steel is represented by the Blast furnace process converting raw material into pig iron. The pig iron contains high amounts of carbon which makes the material brittle. The pig iron is therefore further treated into steel by a basic oxygen blowing (BOF) process consisting of Linz-Donawitz (LD), Kaldo or Oxygen Boden Maxhütte (OBM). The oxidation of the pig iron into steel alters high amounts of heat due to the exothermal reaction in the melt. To prevent high amounts of refractory wear, steel mills uses steel scrap to cool the melting process. The scrap based route steelmaking in Sweden is entirely represented by the Electric arc furnace (EAF) today.

2.2 External scrap calculation

The external scrap consumption in Sweden is in the model calculated based on raw material analysis for the following scrap consuming processes; Martin converter, EAF, EAF stainless, oxygen blowing processes and foundries. The external scrap usage ratios are calculated per reactor type and steel grade and are defined as external scrap divided by crude steel production.

External scrap usage ratio (%) = external scrap / crude steel production

The ratios are calculated for different years and approximated between data points. The external scrap consumption in Sweden is calculated by applying external scrap usage ratios on crude steel production figures. The accuracy of the calculated values is dependent on production statistics and the amount of raw material data points. The external scrap usage ratio however does not consider a change in internal scrap amount due to process improvements.

Theoretically in an idealistic system without any losses, a decrease in raw material usage of internal scrap will increase the external scrap usage ratio per ton crude steel. Figure 2 shows an illustration of a decrease in the internal scrap amount from 30kt to 20kt. The external scrap usage ratio in case A is 70% while it has increased to 80% in case B. However external scrap can also be substituted with other Fe containing materials such as pig iron, sponge iron and Fe containing alloy additions depending on availability, price and requirement of composition. The influence on internal scrap on the external scrap usage ratio per process type has been considered in the model and is discussed further in the discussion part of this paper.

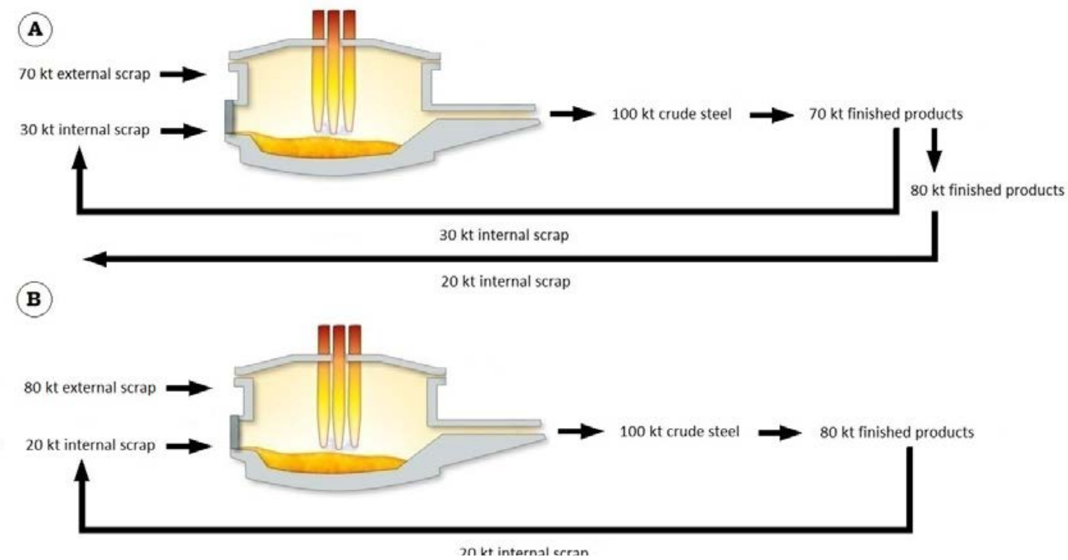

Fig. 2 Illustration of decrease in production of internal scrap results in increase of external scrap usage ratio

The two first external scrap consuming processes in Sweden were the Acid Martin process producing from 1869-1981 and the Basic Martin process producing from 1880-1981 [5]. The external scrap usage ratio for Acid and Basic Martin processes are taken from a raw material balance analysis done by Jernkontoret for the years 1962-1968 [2]. The average usage ratios from the study were applied on production figures for the whole timeline 1889-1961 and 1969-1981.

The external scrap usage ratio for the EAF process was also taken from the raw material balance analysis done by Jernkontoret for the years 1962-1968. The average usage ratio from the analysis was applied on production figures from 1913-1961. The external scrap usage ratio for the EAF process in 1983 was calculated based on raw material usage per steel mill and for 2010 taken from a mass balance calculation done by Järnbruksförnödenheter [1,6].

The first oxygen blowing process converting iron into steel in Sweden was the Kaldo process in 1956 [5]. The external scrap usage ratio for the oxygen blowing processes in 1983 was calculated based on raw material usage per steel mill [6]. At this time the only oxygen blowing process in practice in Sweden was the LD converter. All oxygen blowing processes are assumed to consume the same amounts of cooling scrap, whereby the external scrap usage ratio for the LD converter in 1983 is applied on total Blast furnace production figures from 1956-1973. From 1974 and forward the external scrap usage ratio are applied for each of the two remaining LD converter in Sweden. Steel scrap consumption per LD converter is taken from SSAB, which is the only remaining Blast Furnace producing company in Sweden today [7, 8].

Between the years 1954-1983 the continuous casting technique was introduced in Sweden [5]. The casting production figures are taken from the Census of World Casting production from 1982-2010 [9]. The external scrap consumption ratio for all iron, steel and malleable casters are taken from Bureau of International Recycling BIR [4]. Average external scrap usage ratio for the period 2006-2009 were applied on production figures for the whole timeline 1982-2010.

2.3 Swedish scrap

The Swedish scrap is calculated by taking external steel scrap consumption in steel mills and foundries, reducing import and add export of steel scrap. The amount of exported and imported steel scrap is taken from trade statistics [1-2]. To secure the interest of the Swedish steel industry there was an export regulation of steel scrap from Second World War and forward [2]. However, the export regulation had to be heaved when Sweden joined EU in 1994. Export statistics on steel scrap is only available from 1970-2010 and are taken from Jernkontoret [2]. The export of steel scrap is assumed to be minimal before 1970 and is neglected in the model for the timeline 1889-1970. Import statistics on steel scrap are taken from Järnbruksförnödenheter from 1930-1969 and from Jernkontoret from 1970-2010[1-2].

2.4 Internal scrap

The statistics on internal scrap can be obtained by either production or consumption figures. Statistics on internal scrap based on consumption figures does not consider the storage time of the internal scrap either the exported amount of internal scrap. Production statistics on internal scrap are therefore better if one wants to look at evolvement in process efficiency from year to year. However neither production nor consumption figures on internal scrap considers the amount of legowork from imported and exported iron and steel goods.

From 1919-1956 statistics on internal scrap are obtained on consumption figures, from 1962-1967 on production figures taken from Jernkontoret [2]. For the years 1968-2007 the internal scrap is obtained by statistics on production taken from SCB [10-11]. The SCB statistics is none continuous for some scrap categories over time. This could be due to that internal scrap is hard to keep track on since it doesn’t have any market value when it is consumed internally. Jernkontoret therefore offsets the SCB data based on industry information.

One can also calculate the internal scrap by reducing the semi-finished and finished product deliveries from the crude steel production. The calculated amount of internal scrap does not consider the stocking time of steel products before delivery. Thus when using the calculated amount of internal scrap one has to assume that all internal scrap stays within the country and no legowork is performed on exported or imported iron and steel goods.

2.5 Net flow of steel into the Swedish society

Net flow of steel is defined as total steel consumed and used in applications and products in the Swedish society. Net flow of steel is calculated by steel deliveries from steel mills and foundries minus export plus import of semi-finished and finished steel products. Net flow of steel into the Swedish society is taken from Jernkontoret for the period 1900-2010 [2].

For the period 1988-2010 net trade of further treated products were also taken into account. Further treated products are defined as a complexity of materials consisting of different parts. The largest net exported and net imported product groups in 3-digit level at SCB´s homepage were evaluated for the timeline 1988-2010 [12]. Out of the major net traded product groups the ones assumed to contain the largest amounts of iron and steel was elected. The five largest net exported product groups containing iron and steel were chosen to the following product groups;

- trucks and special vehicles

- machinery for mechanical management of materials
- machinery for construction work
- other motor vehicles
- combustion engine pistons

The five largest net imported product groups containing iron and steel were chosen to the following product groups;

- tractors
- air pumps and compressors and centrifuges
- transmission shafts and warehouse parts
- trailers and containers for transportation
- electrical machinery and apparatuses

The metal content for each product group was roughly estimated based on interviews with Saab, Atlas Copco and from articles [13-15]. The study was performed to see if export and import of further treated products should be considered in the net flow of steel into the Swedish society.

3. Results

The result shows the external scrap, Swedish scrap arising, internal scrap and net flow of steel into the Swedish society from 1889-2010. The model output with the iron and steel flow is shown in Figure 3. The internal scrap is only obtained for steel mills from 1919-2010 due to lack of earlier data. The net flow of steel, external scrap and Swedish scrap is obtained for the whole time line 1889-2010 and includes foundries.

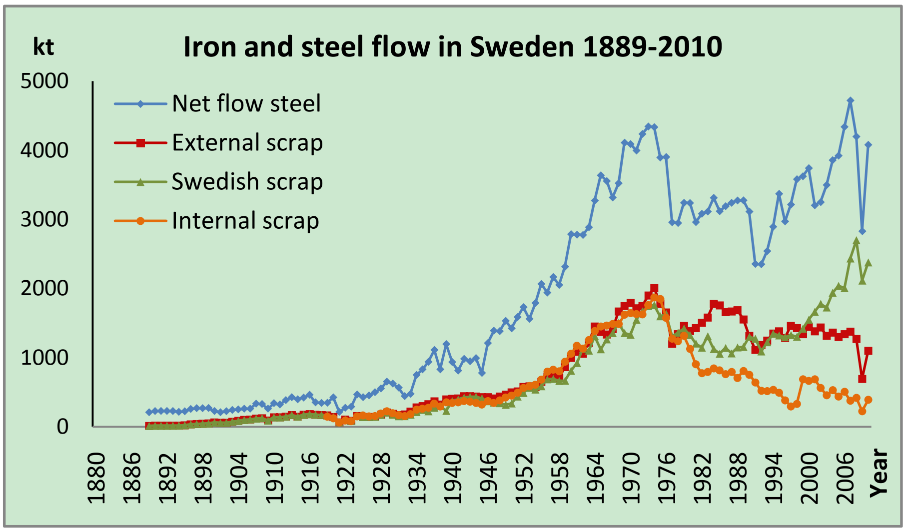

Fig. 3 Model output illustrating iron and steel flow in the Swedish society 1989-2010

The external scrap and Swedish scrap was compared to an analysis done by Jernkontoret [2]. The Jernkontoret analysis is based on industry knowledge, crude steel production and Järnbruksförnödenheter's domestic and import statistics [1-2]. The analysis done by Jernkontoret is thereby trend-wise following the stocking effect or the price effect of scrap. The external scrap and Swedish scrap was volume wise and trend wise compared for the timeline 1980-2003. Volume wise correlation refers to the area correlation beneath two graphs x and y, according to equation 1.

$$Correl(Volume) = \frac{\int_{t1}^{t2} x}{\int_{t1}^{t2} y} \qquad \text{Equation 1}$$

The trend wise correlation is calculated by the degree of similarity between two data sets x and y according to equation 2.

$$Correl(Trend) = \frac{\sum_{i=1}^{n}(Xi-\bar{X})(yi-\bar{y})}{\sqrt{\sum_{i=1}^{n}(Xi-\bar{X})^2 \sum_{i=1}^{n}(yi-\bar{y})^2}} \qquad \text{Equation 2}$$

Correlation coefficient close to 1 indicates a good relationship while a correlation coefficient 0 indicates no relation between the data sets. The comparison between the KTH steel scrap model and Jernkontoret´s analysis for external scrap is shown in Fig. 4 and for Swedish scrap in Fig. 5.

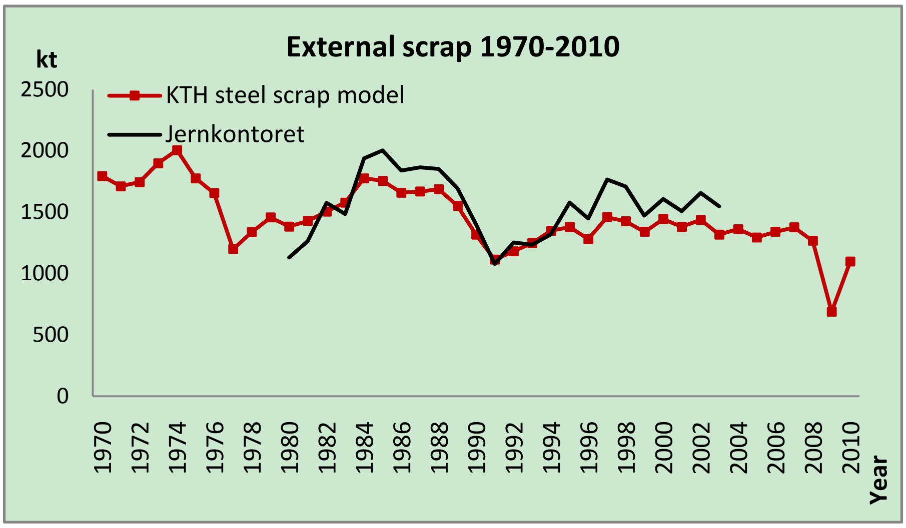

Fig. 4 External scrap from KTH steel scrap model (1970-2010) and Jernkontoret analysis (1980-2003)

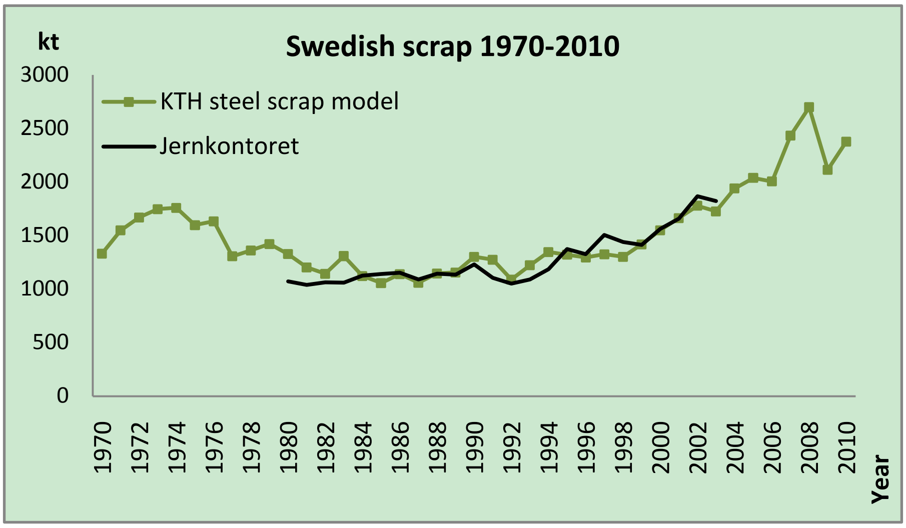

Fig. 5 Swedish scrap from KTH steel scrap model (1970-2010) and Jernkontoret analysis (1980-2003)

For the total external scrap consumption, the trend correlation coefficient between the KTH steel scrap model and

Jernkontoret´s analysis was 0,85 while the volume correlation was 0,93. For Swedish scrap arising the trend correlation coefficient was 0,89 and the volume correlation was 0,98. The result shows that mass balance calculations are volume wise corresponding to consumption figures based on trade statistics. The difference in trend is assumed to mainly be due to stocking effect. Furthermore, the results show that mass balance calculations could be used as a tool to calculate scrap consumption.

The statistically obtained data for internal scrap and calculated values of internal scrap were compared for the timeline 1919-2010, shown in Fig. 6.

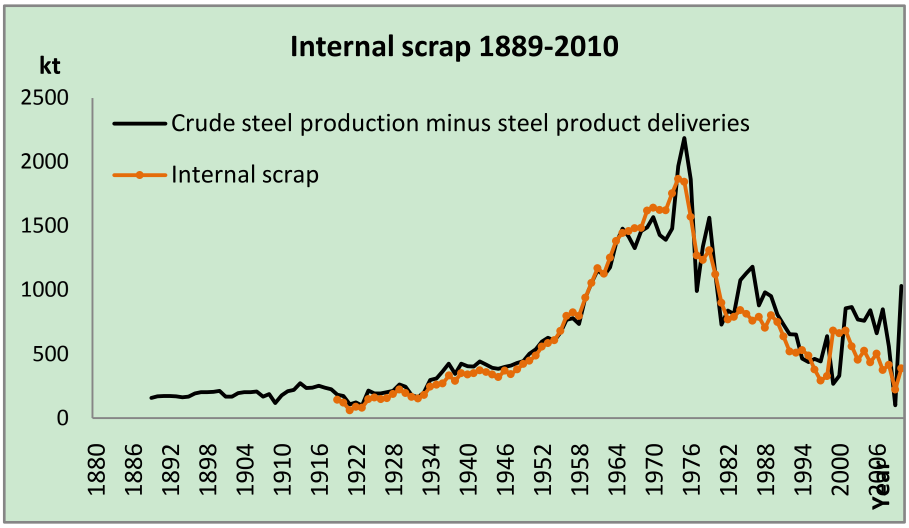

Fig. 6 Internal scrap from statistics (1919-2010) and calculations (1989-2010)

Since the calculated value of internal scarp doesn’t consider the stocking effect of semi-finished and finished products neither the legowork performed on imported and exported goods or the amount of internal scrap exported, the difference in data is assumed mainly to be due to these reasons. Also the fault that statistics are collected in different ways over time effects the correlation of the graphs.

The net flow of further treated product groups for the period 1988-2010 was also evaluated. The five largest net imported and exported product groups containing iron and steel was chosen based on SCB statistics [12]. The total net trade of iron and steel content in further treated products for the timeline 1988-2010 was calculated to -5189 kt, whilst the total net flow of semi-finished and finished steel products into the Swedish society were calculated to 79366 kt for the same timeline. The net export of iron and steel content in further treated products corresponds to average -6,5% of total net flow of semi-finished and finished steel products into the Swedish society. This indicates that further treated products should if possible be accounted for in calculating the net flow of iron and steel into the society for major net exporting or importing countries.

The KTH steel scrap model was applied on World production figures taken from World Steel association for the years 2005-2010 and compared to the BIR analysis [4,16]. The external and workshop scrap for the KTH steel scrap model was calculated by applying usage ratios on crude steel production data. The external and workshop scrap was compared volume wise shown in Table 1.

Table 1 Comparison of BIR analysis and KTH steel scrap model on Global scrap consumption and arising 2005-2010.

Source:	KTH steel scrap model (Mt)		BIR (Mt)	
Scrap type:	Internal	External	Internal	External
2005	168	263	169	293
2006	151	283	185	315
2007	202	298	197	343
2008	143	294	195	335
2009	44	249	170	290
2010	300	290	190	340

The results shows that external steel scrap for 2005-2010 is volume wise correlating to the BIR analysis with 87% whiles the internal scrap correlates 91%. Overall, the scrap usage and arising based on the KTH steel scrap model seems to underestimate the scrap amounts for both scrap types compared to BIR analysis.

4. Discussion of effect of internal scrap

The external scrap usage ratio for the oxygen blowing processes from 1955-1973 are extrapolated values from 1983. The statistical data for internal scrap for the timeline was an average value of 31% whilst the internal scrap was 19% in 1983. The external scrap usage ratio in the oxygen blowing process is therefore probably overestimated for the period 1955-1973.

The external scrap usage ratio for Acid Martin and Basic Martin from 1889-1982 are an average value extrapolated from 1962-1968 [2]. The average external scrap usage ratio was compared to external scrap consumption in 1913 obtained by trade statistics [17]. The both consumption figures were found to be similar. This indicates that no major change in process efficiency occurred while the Martin processes were producing. The average external scrap usage ratio for 1962-1968 was therefore applied on crude steel production figures for the whole timeline 1889-1982.

The external scrap usage ratios for EAF from 1889-1961 are an average value extrapolated from 1962-1968 [2]. The figures were thereafter extrapolated towards 1983 data. The statistical data for internal scrap for the timeline 1962-1968 was average 31% while it had decreased to 19% in 1983 due to the continuous casting technique [2]. The internal scrap further decreases to an average value of 9% in the 2000th. The external scrap usage ratio for 2010 has however not changed much since 1983 which indicates that the external scrap usage ratio probably is underestimated for the EAF process from 1983-2010. However it is important to notice that external scrap has also been substituted by other raw materials such as pig iron, sponge iron and Fe containing alloy additions over time.

It is however important to note that the internal scrap figures are obtained from all steel making processes including non-external scrap using processes such as the Thomas and Bessemer processes producing until 1972. To be able to evaluate the effect of internal scrap amount on external scrap usage ratios one has to assume that all steel making processes produce the same amounts of internal scrap.

5. Conclusions

Results were compared to earlier analysis done by Jernkontoret, the Swedish steel branch organization, for the timeline 1980-2003. For total external scrap consumption the trend correlation coefficient between KTH steel scrap model and Jernkontoret´s analysis was 0,85 while the volume correlation was 0,93. For Swedish scrap arising the trend correlation coefficient was 0,89 and the volume correlation was 0,98. The result shows that mass balance and mass flow calculations is volume wise well correlating to consumption figures based on trade statistics. The difference in trend is assumed to be mainly due to stocking effect. Deviations are also assumed to be due to uncertainties in estimating internal scrap arising and Fe bearing substitutes over time. Overall conclusion is therefore that mass balance and mass flow models could be used as a tool to calculate apparent scrap consumption based on crude steel production figures by process type.

Acknowledgement

The authors would like to thank MISTRA, the foundation for strategic environmental research for the financial support.

The authors would also like to thank the following persons for the valuable inputs to this study.

Göran Andersson, Yngve Axelsson, Alf Abrahamsson from Jernkontoret

Göran Mathisson and Stefan Rova from Järnbruksförnödenheter

Dirk Durinck from McKinsey

References

[1] Statistical data and analysis of steel scrap consumption. Aktiebolaget Järnbruksförnödenheter, Nybodagatan 1, 17142 Solna, Sweden, internal report

[2] Statistical data and analysis on steel flow during 1889-2010. Jernkontoret, Box 1721, Stockholm, Sweden, internal report

[3] P. Tardy. Demand and arising of ferrous scrap: Strains and consequencec. Archives of metallurgy and materials, Volume 53, Issue 2, 2008, p 337-343

[4] World steel recycling in figures 2006-2010. Bureau of International recycling ferrous division, Brussels, Belgium, p 9 & p 14

[5] J.O. Edström, K.G. Bergh, P.O. Boman, Iron- and steel- production development in Sweden 1850-2000 part II. 1st ed., Jernkontoret, Stockholm, Sweden, 2004, p297-330, p88, p490, in Swedish

[6] Statistics Sweden, Industry and rock work statistics special tasks, Form 4 Iron- and steelwork etc., Örebro, Sweden, 1983, in Swedish

[7] Private communication, Roger Säterkvist, SSAB Merox AB, Järnverket, Oxelösund, Sweden

[8] Private communication, Håkan Kieri, SSAB EMEA, Svartöns industriområde, Luleå, Sweden

[9] Census of Global Casting production, American Foundry Society in conjunction with Modern Castings Magazine, 1982-2010, Hanna, Zappa & Polz, Inc.

[10] Statistics Sweden, Industry and rock work statistics, Industry part 1 and part 2, Production distributet by tariff,

waste and steel scrap (282.0), product group 73.03, 1968-1995, in Swedish
[11] Statistics Sweden, Business activities, Industrial production, 8 and 9 digit level, 1996-2010, product groups 7204100-7204500, in Swedish.
[12] Statistics Sweden, Trade in goods and services, Imports and exports of goods by commodity groups according to SITC rev3/rev4, 3-digit level, not adjusted for non response, 1988-1994 & 1995-2010, product groups 711-971.
[13] Private communication, Eva Johansson, Saab Automobile AB, Trollhättan, Sweden
[14] Private communication, Anders Hedqvist, Atlas Copco Rock Drills AB, Örebro, Sweden
[15] J. Davis, R. Geyer, J. Ley, J. He, R. Clift, A. Kwan, M. Sansom, T. Jackson. Time-dependent material flow analysis of iron and steel in the UK Part 2. Scrap generation and recycling. Resources, Conservation and recycling, Volume 1, Issue 1, 2007, p 118-140, Table 2.
[16] Steel statistical yearbook 2011 Edition. Internaltional Iron and Steel institute, Brussels, Belgium, p 27 & p 31
[17] J. Af Geijerstam, M. Nisser. Mining – mines and metalproduction. 1st ed., Sveriges Nationalatlas, Stockholm, Sweden, 2011, p 138. in Swedish