Risk Assessment of the Availability of Tantalum and Niobium

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Abstract

Tantalum and niobium are rare metals that have many important applications. The substitutability of the two metals is low. Therefore, the non-availability of these metals will prove expensive to firms. This leads to the need for the risk assessment of the availability of tantalum and niobium. In this paper, the risk factors that may affect the supply and the demand of tantalum and niobium in the future have been analysed. To prevent criticality of tantalum and niobium, the expected drastic changes in demand must be quickly met by the supply from mine production. The supply risk for tantalum and niobium due to political instability assessed using a variation of the Herfindahl-Hirschmann Index (HHI) and is found to be high. The need to address risks such as foreign exchange risk and safety risk has also been exemplified. The impact of existing and emerging technology on demand is also discussed.

Keywords: raw materials, risk factors, risk analysis, mining.

Introduction

Raw materials are essential to every economy. Applications of raw materials range widely, from household products to high-tech industries. The need to have a secure supply of the required raw materials that matches the speed of production and development of the products is therefore a subject of increasing importance. Securing the supply of raw materials is critical and a growing challenge. Procurement departments are burdened with the responsibility of ensuring reliable supplies of raw materials at competitive prices and at the required time. This leads to a need for risk analysis of the natural resources supply. The challenges to the availability of commodities must be recognised well in advance and counter-measures and steps to ameliorate impacts should be in place.

This thesis shall research some important aspects relating to the risk assessment of the availability of two important raw materials, tantalum and niobium. A number of possible risk factors and mitigation measures that may influence the supply and demand situation of the two commodities in the future are analyzed.
Chapter 2
Tantalum and Niobium
Application and Properties

Tantalum is a rare metal of high hardness. The most significant use of tantalum worldwide is in the production of electronic components; about 60% of tantalum is estimated to be used in the manufacture of capacitors (U.S. Geological Survey [USGS], 2009). Capacitor manufacturers use tantalum for its weight and electrical characteristics; even a very small volume of tantalum usage increases capacitance to a large extent. According to the USGS, substitute metals for tantalum, in most cases, reduce effectiveness of the capacitor, thus making tantalum a metal of high relevance (2009). Tantalum capacitors are used in automotive electronics, mobile phones, personal computers and wireless devices. Tantalum is also used to make super alloys for jet engines, turbines, nuclear reactors, power plants and cutting tools. The major applications of tantalum are shown in Figure 2.1.

Niobium, like tantalum, is a refractory material. Tantalum and niobium always occur together and are separated from fluoride-containing solutions of tantalum using solvent-based extraction methods. Niobium is used in the manufacture of special stainless steels. It is used for the production of super alloys which are used in the manufacture of jets, gas turbines, combustion equipment and reactors. Niobium and its alloys are used in medical devices and in surgical implants because they do not react with human tissue. The main end users for niobium are shown in Figure 2.2.

![Pie chart showing end users of tantalum](image1)

![Pie chart showing end users of niobium](image2)

Tantalum and niobium are similar to each other. They have high strength, high ductility, high reliability, high corrosion resistance and high thermal conductivity. A few other physical properties of tantalum and niobium have been listed in Table 2.1.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Density (g·cm⁻³)</th>
<th>Melting Point (K)</th>
<th>Boiling Point (K)</th>
<th>Heat of Fusion (kJ·mol⁻¹)</th>
<th>Heat of Vaporisation (kJ·mol⁻¹)</th>
<th>Specific Heat Capacity (J·mol⁻¹·K⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tantalum</td>
<td>16.69</td>
<td>3290</td>
<td>5731</td>
<td>36.57</td>
<td>732.8</td>
<td>25.36</td>
</tr>
<tr>
<td>Niobium</td>
<td>8.57</td>
<td>2750</td>
<td>5017</td>
<td>30</td>
<td>689.9</td>
<td>24.60</td>
</tr>
</tbody>
</table>

**Figure 2.1:** End Users of Tantalum. Source: European Commission, Enterprise and Industry, Critical Raw Materials for EU, p.190

**Figure 2.2:** End Users of Niobium. Source: European Commission, Enterprise and Industry, Critical Raw Materials for EU, Annex V of the Report to the Ad-hoc Working Group on defining critical raw materials, p. 142

**Table 2.1:** Properties of Tantalum and Niobium. Source: The Columbia Encyclopaedia, Sixth Edition, tantalum, 2008
As seen from Table 2.1, the two metals are similar to each other. However, there is a significant difference in the density of tantalum and niobium. The density of tantalum is almost twice that of niobium.

**Discovery**

For years, niobium was known as columbium. It was first discovered in 1801 by Charles Hatchett. The following year, Andres Gustaf Ekeberg made a discovery of another new element and called it tantalum. In 1809, William Hyde Wollaston analysed both columbite and tantalite mineral specimens and claimed that columbium and tantalum were the same element. This claim was disputed in 1844 when Heinrich Rose was able to differentiate between the two elements by their valence states. Tantalum has a valence state of +5 whereas columbium has a valence state of both +3 and +5. He then renamed columbium as niobium.

This issue was finally resolved in 1866, when Jean Charles Galissard de Marignac was able to prove that tantalum and niobium were in fact different from one another. Columbium and niobium were shown to be one and the same but the two names remained in use until 1949 when the International Union of Pure and Applied Chemistry (IUPAC) officially adopted niobium as the name for this element.

**Mineralogy**

**Tantalum** - Tantalum can be most commonly found in hard rock deposits such as granites, carbonites and granite pegmatites. Pegmatites are the most common hosts of tantalum. Due to its high physical and chemical resistance, tantalum is also found during the separation of tin minerals from placer deposits. Placer deposits are “natural concentrations of heavy minerals caused by the effect of gravity on moving particles” (Encyclopaedia Britannica, “placer-deposit”, 2010).

**Niobium** - Pyrochlore deposits contain the largest amount of niobium. Most of the element that is produced today is mined from pyrochlore. These deposits occur in pegmatites. Niobium resources are also commonly found in columbite deposits.

**Secondary Sources**

An important source of tantalum and niobium reserves was The Defense National Stockpile Center (DNSC), which is part of The United States’ Defense Logistics Agency (USDLA). The stockpile, however, was depleted in Fiscal Year 2007 (USGS, 2009) and, in March 2008, the DNSC announced that these metals were no longer being offered for sale.

Tables 2.2 and 2.3 list the primary and secondary supply sources of tantalum and niobium respectively. It is clear from the data presented in the tables that both elements largely depend on production from primary concentrates for supply. About 40% of tantalum production is obtained from secondary sources, whereas in the case of niobium this figure is a mere 10-20% of the total amount produced.

**Sources**

**Primary sources**

**Tantalum** - Large scale producers of niobium produce significant quantities of tantalum. Tantalum is also produced as a by-product during tin production. It is present as a component of tin-slag. Recycling of tantalum is mostly done from new scrap produced during the manufacture of electronic components that contain tantalum, and from cemented carbide that contains tantalum and from super alloy scrap (USGS, 2009). Recycling of scrap is an important source for tantalum production. Recycling accounts for around 20% of the total input (TIC, 2010).

**Niobium** - Niobium can also be found in tantalum-containing minerals like columbite and columbite-tantalite, which occur in pegmatite and other alkaline intrusive rocks. Niobium is also found, albeit in extremely minimal quantities, in tin slag.
Table 2.2: Tantalum Sources. Source: Tantalum and Niobium International Study Centre, “Tantalum”, 2010.

Niobium scrap is recovered during recycling of niobium-containing steels and super alloys. However, scrap recovery of niobium is negligible. Figures on recycled niobium are not available to the USGS.

Table 2.3: Niobium Sources. Source: U.S. Geological Survey, 2009 & Tantalum and Niobium Study Centre, n.d. a Exact figures are unknown

Production

It is necessary, at this stage, to provide a distinction between the terms ‘resources’ and ‘reserves’, which are often used interchangeably leading to inaccuracy and ambiguity. Resources refer specifically to the estimated ore occurrence; reserves, on the other hand, refer to that portion of the resource that can be economically mined.

Tantalum - The largest producers of tantalum are Australia and Brazil. The largest operating mine is located in Nazareno, Brazil (TIC, 2010). The mine produces about 137 tonnes of Ta₂O₅ per year. This was about 5-10% of the total primary production in 2007-2008. Ethiopia, China, Russia and certain regions in Central Africa and Southeast Asia are other important producers of this mineral.

Additional quantities of tantalum are available from Brazil and Central Africa through the processing of small alluvial and eluvial deposits by prospectors. Tantalum is also produced from tin slag in South-Asian countries like Malaysia and Thailand (TIC, 2010).

In Australia, production in 2008 was about 680 tonnes of contained Ta₂O₅. However, Talison, which was one of the world’s largest producers of tantalum, suspended its activities at the Wodgina mine in Western Australia in December 2008. The USGS estimated that production from Australia decreased from 53% of total world production in 2008 to around 48% in 2009. In 2006, Brazil reported production of 215 tonnes of contained Ta₂O₅. In 2008, Canada reported production of 49 tonnes of contained Ta₂O₅ (USGS, Minerals Yearbook, 2008). In spite of the geological availability of huge resources of tantalum, exploration activities in central Africa remain largely restricted due to geopolitical factors. According to the USGS Minerals Yearbook 2006, “this region produced a little less than 1% of the world’s tantalum output for the past four years, peaking at 10% in 2000” (as cited in Global Capital Magazine, “Tantalum: Charged for Business”, 2008). World production of tantalum for 2008 and 2009 is listed in Table 2.4. The data for 2008 is diagrammatically presented in Figure 2.3.


<table>
<thead>
<tr>
<th>Source</th>
<th>Mine Production 2008</th>
<th>Mine Production 2009 b</th>
<th>Reserves c (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>557</td>
<td>560</td>
<td>40,000</td>
</tr>
<tr>
<td>Brazil</td>
<td>180</td>
<td>180</td>
<td>65,000</td>
</tr>
<tr>
<td>Canada</td>
<td>40</td>
<td>40</td>
<td>NA</td>
</tr>
<tr>
<td>Congo (Kinshasa)</td>
<td>100</td>
<td>100</td>
<td>NA</td>
</tr>
<tr>
<td>Rwanda</td>
<td>100</td>
<td>100</td>
<td>NA</td>
</tr>
<tr>
<td>Other d</td>
<td>188</td>
<td>180</td>
<td>NA</td>
</tr>
<tr>
<td>World Total</td>
<td>1,170</td>
<td>1,160</td>
<td>110,000</td>
</tr>
</tbody>
</table>

Figure 2.3: Producers of Tantalum. Source: U.S. Geological Survey, Mineral Commodity Summaries, 2010.
Niobium - The largest producer of niobium is Brazil, and the two largest known deposits of niobium are located here. The largest deposit is located in Araxa and it contains about 460,000,000 tonnes of Niobium Oxide (Nb₂O₅). This is roughly estimated to be sufficient to supply the world’s demand of niobium for the next 500 years (TIC, 2010). The second largest deposit, which has about 18,000,000 tonnes of Nb₂O₅, is found in Cataloa, Brazil. The third largest deposit, Niobec, is located in Canada, and makes Canada the second-largest producer of niobium. This deposit is located in Quebec and it has about 18,000 tonnes reserve. Approximately 85% of the world’s total production comes from these mines (TIC, 2010). The niobium found in these regions is mined from pyrochlore mineral deposits. Other mineral deposits of niobium also occur in Brazil, Nigeria and Australia, and in some central African countries.

The world production of niobium for 2008 and 2009 are listed in Table 2.5. The data for 2008 is diagrammatically represented in Figure 2.4.

<table>
<thead>
<tr>
<th></th>
<th>Mine Production</th>
<th>Reserves (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2008</td>
<td>2009</td>
</tr>
<tr>
<td>Brazil</td>
<td>58,000</td>
<td>57,000</td>
</tr>
<tr>
<td>Canada</td>
<td>4,380</td>
<td>4,300</td>
</tr>
<tr>
<td>Other</td>
<td>483</td>
<td>400</td>
</tr>
<tr>
<td>World Total</td>
<td>62,900</td>
<td>62,000</td>
</tr>
</tbody>
</table>


Exploration

Tantalum - The existing producers of tantalum are listed in Table 2.6. The table also lists the exploration projects that are underway to increase supply.

Niobium – There is currently an oversupply of Niobium in the market. For this reason, very few new ventures are being initiated. The existing global producers of niobium are listed in Table 2.7.

From the study of some general aspects of tantalum and niobium, it can be inferred that the metals carry high significance with regard to applications in a variety of industries. It is also clear that the geological availability of tantalum and niobium is not a matter of major concern. Of greater relevance are the current market conditions of both tantalum and niobium and the factors which can have an impact on the supply and demand of the two metals.
### Table 2.6: Existing and Prospective Mines of Tantalum. Source: Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), 2010.

<table>
<thead>
<tr>
<th>Country</th>
<th>Site</th>
<th>Ta₂O₅ Content (ppm)</th>
<th>Ta₂O₅ Stock (t)</th>
<th>Status</th>
<th>Ta₂O₅ - Production (2007) (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Wodgina</td>
<td>270</td>
<td>23.300</td>
<td>Deferred</td>
<td>590</td>
</tr>
<tr>
<td></td>
<td>Bald Hill</td>
<td>435</td>
<td>90</td>
<td>Deferred</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Greenbushes</td>
<td>157</td>
<td>27.000</td>
<td>Deferred</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Mount Cattlin</td>
<td>200</td>
<td>6.800</td>
<td>in Production</td>
<td>0</td>
</tr>
<tr>
<td>Brazil</td>
<td>Pitinga</td>
<td>388</td>
<td>2.830</td>
<td>in Production</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Miabra</td>
<td>216</td>
<td>4.230</td>
<td>in Production</td>
<td>45</td>
</tr>
<tr>
<td>China</td>
<td>Yichun, Jiangxi</td>
<td>300</td>
<td>4.300</td>
<td>in Production</td>
<td>53</td>
</tr>
<tr>
<td>Canada</td>
<td>Nanping, Fujian</td>
<td>220</td>
<td>2.600</td>
<td>in Production</td>
<td>54</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Kenticha</td>
<td>143</td>
<td>14.000</td>
<td>Conceptional</td>
<td></td>
</tr>
<tr>
<td>Mozambique</td>
<td>Marropino</td>
<td>252</td>
<td>10.080</td>
<td>Feasibility</td>
<td>Plan: 300</td>
</tr>
<tr>
<td></td>
<td>Binneringie</td>
<td>230</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caitaqa</td>
<td>432</td>
<td>75</td>
<td>Prefeasibility</td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>Rosendal</td>
<td>255</td>
<td>270</td>
<td>Conceptional</td>
<td></td>
</tr>
<tr>
<td>Greenland</td>
<td>Motzfeldt</td>
<td>300-1.000</td>
<td>15.000-50.000</td>
<td>Conceptional</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>Upper Fir, Verity</td>
<td>217</td>
<td>2.900</td>
<td>Conceptional</td>
<td></td>
</tr>
<tr>
<td>Mozambique</td>
<td>Morua</td>
<td>196</td>
<td>680</td>
<td>Conceptional</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mutala</td>
<td>23.5</td>
<td>3.600</td>
<td>Feasibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Muiane</td>
<td>320</td>
<td>2.400</td>
<td>Feasibility</td>
<td></td>
</tr>
<tr>
<td>Saudi-Arabia</td>
<td>Ghurayyah</td>
<td>245</td>
<td>94.325</td>
<td>Prefeasibility</td>
<td>Plan: 270</td>
</tr>
<tr>
<td>USA</td>
<td>McAllister, Alabama</td>
<td>550</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2.7: Existing and Prospective Mines of Niobium. Source: Resource Capital Research, 2010.

<table>
<thead>
<tr>
<th>Country</th>
<th>Site</th>
<th>Reserves/Resources (mt)</th>
<th>Mine Life (years)</th>
<th>Status</th>
<th>Production 2008 (mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>Araxa</td>
<td>500</td>
<td>400</td>
<td>Increased to 50ktpa by 2013</td>
<td>-</td>
</tr>
<tr>
<td>Canada</td>
<td>Cataloa</td>
<td>14.6</td>
<td>20</td>
<td>-</td>
<td>0.768</td>
</tr>
<tr>
<td></td>
<td>Niobec</td>
<td>23.5</td>
<td>18</td>
<td>Increased to 850ktpa by 2011</td>
<td>1.8</td>
</tr>
<tr>
<td>Egypt</td>
<td>Blue river (Upper Fir)</td>
<td>34.5</td>
<td>-</td>
<td>Exploration Stages</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Niocan</td>
<td>11</td>
<td>-</td>
<td>Awaiting</td>
<td>-</td>
</tr>
<tr>
<td>Gabon</td>
<td>Malboumie</td>
<td>360</td>
<td>-</td>
<td>Low recovery</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Leusche</td>
<td>30</td>
<td>-</td>
<td>Environmental Problems</td>
<td>-</td>
</tr>
<tr>
<td>Congo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.6: Existing and Prospective Mines of Tantalum. Source: Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), 2010.

1No Production 2009; 2Production for 2007; 3Production for 2008, reopening planned for April 2010; 4Reserve base January 2010; 5Total Inventories; 6Part of the Blue River Project; 7Opening November 2009

Table 2.7: Existing and Prospective Mines of Niobium. Source: Resource Capital Research, 2010.
From the study of some general aspects of tantalum and niobium, it can be inferred that the metals carry high significance with regard to applications in a variety of industries. It is also clear that the geological availability of tantalum and niobium is not a matter of major concern. Of greater relevance are the current market conditions of both tantalum and niobium and the factors which can have an impact on the supply and demand of the two metals.

Chapter 3
Tantalum and Niobium – Market

Demand

Tantalum - The growth in demand for tantalum over the past decade and a half has been slow compared to other metals in the electronics sector (Ruffini, 2008). Although it was estimated by both the USGC and TIC that, in the next 20 years, the global demand for tantalum would increase four-fold from 2007, December 2008 and 2009 saw global demand amount decline by about 40% (“Tantalum Ore: 2010 Shortfall Expected”, 2009). It was the sharpest decline in tantalum demand in the past twenty years. However, according to Roskill Information Services, demand would go up again by the end of 2010 (as cited in “Tantalum Supply Running on Empty”, 2010). This could place a tremendous strain on the supply chain to meet growing demand levels.

Figure 3.1: Demand Trend of Tantalum. Source: TIC as cited in Talison, “Challenges Facing the Tantalum Industry”, 2008.

Niobium - According to a press release by Tertiary Minerals plc in July 2005, the annual demand for niobium in 2005 was approximately 54,430 tonnes. TIC reported that in 2007, a total of about 58,000 tonnes of processors containing niobium have been produced. However, between 2008 and 2010, demand for niobium has not experienced any drastic changes. According to the Canada-based mining company Iamgold, the operator of the Niobec niobium mine, the effect of the 2008

Figure 3.2: Demand Forecast of Tantalum (in Mlbs). Source: TIC as cited in Talison, “Challenges Facing the Tantalum Industry”, 2008.

According to Clinton Wood, executive chairman of the tantalum mining group Noventa, the recent decrease in demand for the metal can be attributed to the fact that manufacturers of electronic devices using tantalum, now produce smaller products that require smaller amounts of the metal (as cited in Ruffini, 2008). Moreover, the 2008 recession caused a reduction in demand for electronics, which in turn resulted in declining demand for tantalum. However, a projected increase in demand for tantalum in the coming years, as seen in Figure 3.2, is expected. The demand for 2012, under the assumption of steady growth and a compound annual growth rate of 2%, is around 6,000,000 pounds, i.e. approximately 2,720 tonnes. It is, therefore, obvious that a supply shortage and inability to meet market needs will characterize the coming years.
global economic slowdown has been comparatively limited on the Niobium market (Iamgold Corporation, 2009). Experts expect demand to recover and continue to grow since niobium is widely used in the manufacture of special steel; demand for special steel, like high-strength low-alloy (HSLA) steel, is expected to experience long-term growth over the next few years. HSLA is a kind of alloy steel with elements such as manganese, nickel, chromium, etc. It has better mechanical properties than carbon steel. Special steel is used in construction and in the automobile industry. Therefore, with an increase in special steel demand, the demand for niobium is also expected to rise. The demand level in 2030 has been forecasted to be around 1,410 tonnes (BGR, 2010). Niobium is also used in stainless steel production. In 2008, about 10% of the steel produced globally contained niobium. This amount, according to a prediction by Roskill Information Services, is expected to rise to about 20% in the coming years (2009). Also, the demand for stainless steel is expected to recover from its declining trend over the last few years. Demand for niobium will increase correspondingly. The forecasted consumption of ferroniobium is shown in Figure 3.3. It is plotted versus crude steel consumption. It is seen from the graph that the trends correspond to each other.

Various factors have contributed to the shortage of tantalum. In the late 1990s, the technology sector grew at an extremely rapid rate. During these years, tantalum was stored up in inventories by companies based on the projection of demand for their products. These inventories are now near exhaustion and will no longer be able to significantly contribute to the supply chain of tantalum (Ruffini, 2008). As mentioned earlier, one of the main sources of supply was the DLA stockpiles. Since 2007, there has been no sale of tantalum by DLA. The surplus that resulted from the building-up of these inventories will therefore no longer prove beneficial to consumers (Burger, 2009).

Recycling is a source of tantalum, usually accounting for about 20% of the total tantalum produced (TIC, 2010). Recycling is now becoming more difficult due to the miniaturisation of electronic parts, which use lesser amounts of the metal, and to the higher recovery costs (Burger, 2009).
The retrieval of tantalum from tin slag, another source of tantalum, is also declining (“Tantalum: Charged for Business”, 2008).

In December 2008, one of the major producers of tantalum, Australia’s Talison Minerals, shut down operations at its Wodgina mine in Western Australia. The shutdown resulted after unsuccessful negotiations for price escalation to almost double the price compared to that of the previous year (Burger, 2009). According to a press release by Talison in November 2008, there were two external reasons for closing its Wodgina mine (Talison, 2008). One of the reasons was the 2008 economic slowdown and the ensuing reduction in demand for tantalum.

Table 3.1 shows a comparison of total tantalum supply in 2000 versus projected supply in 2010. The demand for 2010 is an estimated figure. In mid 2009, Talison quelled rumours about reopening the Wodgina mine and declared them to be incorrect. According to the statement, “Talison will only return to tantalum production as and when the market demand for its product dictates and that condition is yet to be met” (as cited in “Tantalum Ore: 2010 Shortfall Expected”, 2009). This means that there will continue to be a shortage of tantalum in the coming years. As seen from Table 3.1, a shortfall in supply is expected. However, the demand situation is expected to improve as the world economy picks up, and if varied applications of the metal (not limited to the electronics industry) are developed.

<table>
<thead>
<tr>
<th>Primary Supply</th>
<th>2000</th>
<th>2010F</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1.3</td>
<td>0</td>
<td>Assumes Talison Does Not re-Enter</td>
</tr>
<tr>
<td>Africa</td>
<td>0.79</td>
<td>1.025</td>
<td>Assumes DRC ore continues to flow</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.42</td>
<td>0.85</td>
<td>Paranapanema, AMG/CIF</td>
</tr>
<tr>
<td>Greater China</td>
<td>0.37</td>
<td>0.33</td>
<td>Nanping, Yichun, Others</td>
</tr>
<tr>
<td>SE Asia</td>
<td>0.25</td>
<td>0.27</td>
<td>Thailand, Vietnam, Other</td>
</tr>
<tr>
<td>Canada</td>
<td>0.17</td>
<td>0.15</td>
<td>Assumes Tanco Remains Open</td>
</tr>
<tr>
<td>Middle East</td>
<td>0</td>
<td>0.05</td>
<td>Assumes Beginning of Output</td>
</tr>
<tr>
<td>Russia/Kazakhstan/Other</td>
<td>0.05</td>
<td>0.14</td>
<td>Estimated</td>
</tr>
<tr>
<td>Total Primary Supply</td>
<td>3.35</td>
<td>2.815</td>
<td>Loss Of Talison Is Critical</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Secondary Supply</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrap and Recycling</td>
<td>0.75</td>
<td>0.5</td>
<td>True Variable</td>
</tr>
<tr>
<td>Stockpiled Inventories</td>
<td>0.65</td>
<td>0.42</td>
<td>Inventories Being Worked Down</td>
</tr>
<tr>
<td>US Defence Logistics</td>
<td>0.5</td>
<td>0</td>
<td>Exhausted</td>
</tr>
<tr>
<td>Agency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Secondary Supply</td>
<td>1.9</td>
<td>0.92</td>
<td>Loss of DLA is critical</td>
</tr>
<tr>
<td>TOTAL SUPPLY</td>
<td>5.25</td>
<td>3.735</td>
<td></td>
</tr>
<tr>
<td>DEMAND</td>
<td>5.2</td>
<td>4.2</td>
<td>Assumes 33% reduction from 2008</td>
</tr>
<tr>
<td>Shortfall</td>
<td>0.05</td>
<td>0.465</td>
<td>CONCLUSION: Shortfall</td>
</tr>
</tbody>
</table>

*Millions of Pounds

Table 3.1: Comparison between Tantalum Supply in 2000 and Estimated Tantalum Supply in 2010

The other reason was that there seemed to be a number of buyers in the electronics industry who purchased tantalum from Central Africa, particularly from the Democratic Republic of the Congo (DRC). Mining here is done under extremely poor and dangerous conditions, and often illegally. The price of tantalum from this region, however, is very low. With buyers turning to this region for supply of the metal, Talison incurred losses.

Increased demand might result in the reopening of the Wodgina and Greenbushes mines. On the other hand, if demand decreases (or remains at current levels) there will be a shortage in the supply of tantalum, resulting in an increase in its price.

Niobium - The supply market for Niobium is reasonably stable. According to the TIC, the largest reserve of Niobium, located in Brazil, is sufficient to supply world demand for the next 500 years (TIC, 2010).
As mentioned in section 2.6, CBMM, a Brazilian company and the world’s leading producer of Niobium, produced about 90,000 tonnes per annum of ferroniobium in 2008 (CBMM, 2010). However, in spite of a projected increase in future demand, it was forced to cut down its production to about 50,000 tonnes per annum in 2009 as a result of the decrease in demand for the metal during the global financial crisis. Experts believe the reduction in demand for niobium to be temporary. Therefore as demand of niobium increases, suspended production activities are expected to resume. CBMM is expected to resume production to about 60,000 tonnes per annum in 2010 (as cited in Resource Capital Research, 2010).

**Price**

**Tantalum** – Tantalum is not traded in the commodities market - the price of the metal is established confidentially through negotiations between the producer and the buyer. The price varies depending on contract size and material content. The price of any metal is usually volatile, depending on supply and demand conditions. An increase in price is usually the result of an inability of the supply side to meet increased demand. A decrease in price results due to an oversupply of metal. In the case of tantalum, prices show a relatively long-term upward trend, with drastic increases in price during periods of high demand. Table 3.2 shows the historical prices of tantalum.

<table>
<thead>
<tr>
<th>Year</th>
<th>Tantalum Price</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>$3.40/lb ($7,505/tonne)</td>
<td>NA</td>
</tr>
<tr>
<td>1965</td>
<td>$7.75/lb ($17,108/tonne)</td>
<td>up 128%</td>
</tr>
<tr>
<td>1975</td>
<td>$16.00/lb ($35,320/tonne)</td>
<td>up 106%</td>
</tr>
<tr>
<td>1985</td>
<td>$22.75/lb ($50,110/tonne)</td>
<td>up 42%</td>
</tr>
<tr>
<td>1995</td>
<td>$27.75/lb ($50,110/tonne)</td>
<td>up 22%</td>
</tr>
<tr>
<td>2001</td>
<td>$39.00/lb ($86,092/tonne)</td>
<td>up 41%</td>
</tr>
</tbody>
</table>


The increase in price in 2001 was due to a feared supply shortage. Companies stocked up their inventories with tantalum, leading to high demand and, therefore, to extremely high prices. However, towards the end of the dot-com bubble, the demand decreased and this led to the prices plummeting down. With prices being so low, it became uneconomical to develop new mines for the supply of tantalum and, in some instances, as in the case of the Wodgina mine in Western Australia, to even discontinue operations.

As demand for tantalum is predicted to increase over the coming years, there will remain a shortage in supply. For this reason, it is certain that the price of tantalum will increase in the future.

**Niobium** – Niobium, like tantalum, is also not traded in the commodities market. The price is negotiated between suppliers and buyers and depends on factors of supply and demand. When the demand is high, prices soar.

Such was the case in 2000 (Cunningham, 2003). Demand was high during the dot-com speculation, and therefore the price of niobium increased.

The price of niobium has decreased from the second half of 2007, owing to low demand levels. In the future, however, the price is expected to rise. According to interim CEO of IamGold Corporation, Peter C Jones, as the steel market stabilises and demand for steel increases, the price of niobium will also increase (as cited in Mining Weekly, 2010).

Changes in the price level of tantalum and niobium between 2006 and 2008 have been graphically represented in Figure 3.4. While tantalum has had drastic increases and smaller decreases in price, the niobium metal price over the years has remained relatively stable.

![Figure 3.4 Tantalum and Niobium Prices. Source: Talison, "Challenges Facing the Tantalum Industry", 2008.](image-url)

From market analysis of the supply and demand situations of tantalum and niobium, the underlying causes that affect availability of the metal can be...
better understood. The demand for tantalum is expected to increase in the future due to its indispensable use in the electronics industry (BGR, 2010). Demand levels of niobium are also expected to rise due to an expected increase in the use of niobium in the manufacture of steel, and also due to an expected increase in demand for special steel.

On the one hand, the supply of niobium is sufficient to meet projected increases in its demand, and its price is therefore expected to increase at a steady pace. The supply of tantalum, on the other hand, is under stress, and therefore will affect availability of tantalum in the market. This in turn will lead to increased prices in the future. To keep prices down, the supply situation must improve. Availability will therefore depend on new projects and their timely realisation. For instance, if the situation in Central Africa improves, with better political stability and sustainable mining practices, the stress on supply would be relieved to a large extent. The supply risk could thereby be greatly reduced. The prospects of major changes occurring in the near future, however, seem bleak.

The importance of a secure supply of raw materials to meet world demand is clear. This leads to a need for a risk analysis of the availability of natural resources. The tools of risk analysis, therefore, are of prime importance, and may be used to ensure a reliable supply of raw materials at competitive prices, and at the required time.

**Chapter 4**

**Risk Assessment**

**Why Risk Assessment?**

An undistorted and reliable supply of raw materials is critical. There are many challenges which pose a threat to the availability of raw materials. Risk analysis, comprising the identification, assessment and management of risk factors is, therefore, essential to ensure a reliable supply of natural resources, especially when one takes into account that the timely availability of the required material is not assured. The terms ‘risk analysis’ and ‘risk assessment’ are used interchangeably by various organisations and countries (Beer & Ziolkowski, 1995). However, they do not have the same meaning. In this paper, the term risk analysis will refer to the complete process involving identification of risk, assessment of risk, and its management, whereas risk assessment will refer to the actual calculation and measurement of risk value.

**Risk analysis methodology**

“Risk is the product of the probability of occurrence and the consequence of the identified hazard” (Beer & Ziolkowski, 1995). The methodology is basic and applicable to any risk analysis project. The probability that a hazard will occur is estimated by the risk analysis team and the consequence directly measured or retrieved from literature. Risk values are finally arrived at, by using one or many of the existing risk assessment methods and tools.

The estimations of probabilities and the underlying assumptions of the assessment tools should be chosen carefully, in order to avoid overestimating or underestimating the risk value. After a thorough risk assessment, risks need to be prioritised, characterised and correctly interpreted. Measures to mitigate and reduce risk are then implemented.

**Which type of risk?**

There are many different types of risk. More than just one type of risk can impact the supply of a material. Therefore in every project, different kinds of possible risk factors need to be analysed. Five major types of risks are listed in Table 4.1.
Risk Assessment of the Availability of Tantalum and Niobium
Anitha Sivaramakrishnan

Table 4.1: Types of risk. Source: Author based on World Economic Forum, “Global Risk Report 2010.”

The listed risks are the most prominent ones in the global landscape and also include the risks featured in the Global Risks 2010 report published by the World Economic Forum.

As seen in Table 4.1, one broad risk type can have many different sub-categories of related risks. Risks affecting the availability of raw materials could vary according to the specifications of each project.

**Risk pathways**

It is necessary to define the terms risk trigger or risk factor, and risk pathway. A risk trigger or a risk factor refers to the issues that trigger and increase the chances of the occurrence of an undesirable event. A risk pathway traces the flow of risk starting from the risk trigger or risk factor to the final undesirable event.

The risks that have an impact on an organisation can be traced back to internal and external risk factors. Risk factors such as changes in government regulations, earthquakes, inflation, technology etc. have either a direct or an indirect influence on the different components of a business, including the sensibilities of its customers, its competitive position, its ability to deliver products, and its supply chain. Due to the impact of triggers on these business components, the cost structure or productivity of the firm receives a significant negative impact. The risk pathway, starting from the different risk factors and ending with an impact on the core business, is illustrated in Figure 4.1.
Risk Triggers for the Assessment of Tantalum and Niobium

A few risk triggers that could have an impact on the availability of the tantalum and niobium have been identified and elaborated, and the supply risks of the two metals have been assessed.

I. Commodity supply risk - of metals can be affected by any change in the political and economic situation of the producing countries. In the case of niobium, production is largely concentrated in two countries. In the case of tantalum, production is concentrated in about five countries; two of which belong to areas of the African sub-continent where the political situation is highly volatile. Changes in the political stability of the major producing countries could, therefore, result in an immediate supply deficit. Hence, the assessment of the commodity supply risk due to the political instability of the producing countries is particularly applicable to both these metals. The methodology used to assess the commodity supply risk is described in section 4.2.1. The Herfindahl-Hirschmann Index (HHI) is used in the assessment of the commodity supply risk. The HHI is typically used to determine competition and anti-trust dealings between enterprises. However, in the case of the assessment of the supply risk of a commodity, a modified form of the HHI is used. Production concentration and point estimates of the ‘political stability and absence of violence’ component of the World Bank governance index are incorporated into the HHI to arrive at a supply risk value. Also discussed are the existence and availability of substitute metals for tantalum and niobium and their rates of recycling. These are two important factors that have a direct influence on the availability of tantalum and niobium (European Commission, 2010).

II. Foreign Exchange Risk - The foreign exchange risk is an external trigger, and it is beyond the control of the parties involved. When conducting business across borders, buyers and sellers of raw materials, such as tantalum and niobium, are forced to face fluctuations in the foreign exchange rates since the demand for the metals is not restricted to the producing countries. Foreign exchange risks can influence the supply of raw materials indirectly by making a project uneconomical. Therefore, the analysis of market risks resulting from foreign exchange rate fluctuations is both important and necessary. Hedging tools such as options and forward contracts are usually employed by firms to protect the business against interest rate and exchange rate volatility. The risk that these instruments are exposed to due to changes in interest rates and exchange rates need to be measured. The ‘Value at Risk’ (VaR) is a popular risk measurement method used by financial and non-financial institutions for the analysis of market risks. It is a measure of the possible losses that a single investment or portfolio, which is a mix of investments, can suffer. The VaR is an important tool used by firms to make trading and hedging decisions. Three different approaches can be adopted for the calculation of the VaR. In section 4.2.2, the ‘Historical Simulation’ approach for the calculation of the VaR is described using an example. The mathematical calculations involved in the Variance-covariance approach and the Monte Carlo Simulation approach for calculation of the VaR are beyond the scope of this thesis, and therefore will not be discussed.

III. Safety Risks - The availability of raw materials can also be influenced by internal triggers such as improper operation and maintenance of machinery, improper control of pollution, poor safeguarding of workers against workplace accidents and many other such operational hazards. These hazards may result in the shutting down of production for days, weeks or months at a time. If such a scenario occurs at a mine or at any other middle level member of the supply chain, it could lead to a restriction in the supply of materials to the end users. The assessment of these hazards is therefore essential for the operation of any project. The risk assessment techniques for the assessment of safety and health hazards in a tantalum and/or niobium mine are described in section 4.2.3. Safety hazards, the probabilities of their occurrence and the consequences identified and used in the examples are general assumptions. In reality, estimates are usually made by teams comprising experts, specialists and a cross-section of personnel. The methods described can be applied to the mining of any material and are based on the recommendations.

Supply Risk

The risk factors that affect the supply or availability of tantalum and niobium are discussed in detail in this section. Political stability of producing countries is a major influencing factor in the supply risk of a commodity. Recycling as a source of material and the availability of substitute metals are two other factors whose influence on supply risk must also be taken into consideration to understand the complete supply risk scenario of any commodity (European Commission, 2010).

A. Commodity supply risk

To carry out the commodity supply risk assessments of tantalum and niobium, modified forms of the Herfindahl-Hirschmann Index (HHI) are applied.

Data

In order to assess supply risk, production concentrations of countries producing tantalum and niobium, retrieved from the World Mining Data, 2009 and the World Bank ‘Worldwide Governance Indicator’ are incorporated into the HHI. Although the indicator recognises six major components of governance (political stability and absence of violence, regulatory quality, control of corruption, absence of violence/terrorism, government effectiveness, rule of law, and voice and accountability), point estimates of only the ‘political stability and absence of violence’ indicator are considered here.

The World Bank defines the political stability and absence of violence estimates to be ‘a measure of the perception of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including political violence and terrorism.’

Methodology

HHI is a measure of concentration of firms or enterprises in the market and is used to determine competition and anti-trust dealings. One modified form of the HHI is the HHI©, which instead of measuring enterprise concentration is a measure of the country concentration. Basically, the HHI is the sum of the squares of enterprise concentrations of the commodity, whereas HHI© is the sum of the squares of country concentrations of the commodity. The range of this index varies from 0 to 10,000 and the calibration is as follows:

| HHI = Sum [(enterprise concentration)²] |
| HHI© = Sum [(country concentration)²] |

Range - 0 -1,000 - Low Risk
1,000-2,000 – Moderate Risk
2,000-10,000 – High Risk

As the first step to assess the commodity supply risk, the ‘Political Stability and Absence of Violence Index’ (ps) from the World Bank is incorporated into the HHI© to arrive at the HHI(C, ps). HHI(C, ps) is the sum of the political stability times the squares of country concentration. The range varies from -25,000 to +25,000.

I.e. HHI(C, ps) = Sum [political stability * (country concentration)²]

Range - -25,000 to +25,000

From the HHI(C, ps), the Commodity Supply Risk Index (CSRI) can be arrived at. CSRI is the HHI© less the HHI(C, ps), i.e. CSRI is the sum of the squares of country concentration less the sum of political stability times the squares of country concentration.

I.e. CSRI = HHI© - HHI(C, ps)

Since the scale of CSRI is yet to be properly calibrated, in this example the risk calibration used for HHI© is also used as CSRI calibration in order to determine risk level as low, medium and high risk. Table 4.2 lists the production share percentage of tantalum and niobium producing countries. This data is used to calculate HHI©.

Using the country-wise production share data from Table 11, HHI© is calculated. For example, HHI© for 2007 is calculated as follows.

HHI© 2007 = Sum [(country concentration)²] = Sum [(Brazil)² + (Canada)² + (Australia)² + (Rwanda)² + (Congo, D.R)² + (Mozambique)² + (Ethiopia)² + (Nigeria)² + (Burundi)² + (Bolivia)²] = Sum [(94.13)² + (5.02)² + (0.50)² + (0.15)² + (0.00)² + (0.08)² + (0.10)² + (0.08)² + (0.02)² + (0.00)²] = 8885.0649
The HHI© 2007 is equal to 8885.0649. This figure is very high and can be attributed to the significant increase in the concentration of production in Brazil as seen in Table 4.2 (World Mining Data, 2009). Table 4.3 contains the political stability index as listed by the World Bank. The values range from -2.5 to 2.5. Countries with higher values have higher political stability. Data in Table 11 and Table 12 are then used in the calculation of HHI(C, ps) and CSRI.

<table>
<thead>
<tr>
<th>Country</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>90.69</td>
<td>92.88</td>
<td>93.59</td>
<td>94.13</td>
<td>93.26</td>
</tr>
<tr>
<td>Canada</td>
<td>7.96</td>
<td>6.11</td>
<td>5.65</td>
<td>5.02</td>
<td>5.04</td>
</tr>
<tr>
<td>Australia</td>
<td>0.81</td>
<td>0.56</td>
<td>0.45</td>
<td>0.50</td>
<td>0.77</td>
</tr>
<tr>
<td>Rwanda</td>
<td>0.27</td>
<td>0.24</td>
<td>0.14</td>
<td>0.15</td>
<td>0.34</td>
</tr>
<tr>
<td>Congo, D.R</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.21</td>
</tr>
<tr>
<td>Mozambique</td>
<td>0.01</td>
<td>0.00</td>
<td>0.11</td>
<td>0.08</td>
<td>0.16</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>0.12</td>
<td>0.11</td>
<td>0.11</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>Nigeria</td>
<td>0.09</td>
<td>0.06</td>
<td>0.05</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>Burundi</td>
<td>0.02</td>
<td>0.03</td>
<td>0.01</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Bolivia</td>
<td>0.03</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4.2: Country share in production (In percentage).

As seen from Table 4.3, countries in the African continent have a negative index. Political instability remains one of the major sources of threat in these countries. This region has large resources of tantalum, and therefore calculation of supply risk due to political instability becomes extremely important. The incorporation of these values in the calculation of the HHI(C, ps) and CSRI for 2007 is shown.

<table>
<thead>
<tr>
<th>Country</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>-0.08173</td>
<td>-0.08235</td>
<td>-0.12746</td>
<td>-0.17138</td>
<td>-0.1194</td>
</tr>
<tr>
<td>Canada</td>
<td>1.012935</td>
<td>0.964726</td>
<td>1.034623</td>
<td>1.021873</td>
<td>1.033814</td>
</tr>
<tr>
<td>Australia</td>
<td>0.932351</td>
<td>0.900177</td>
<td>0.904679</td>
<td>0.897181</td>
<td>1.077206</td>
</tr>
<tr>
<td>Rwanda</td>
<td>-0.82098</td>
<td>-0.54558</td>
<td>-0.61848</td>
<td>-0.1061</td>
<td>-0.1353</td>
</tr>
<tr>
<td>Congo, D.R</td>
<td>-2.46</td>
<td>-2.5</td>
<td>-2.64</td>
<td>-2.45</td>
<td>-2.34</td>
</tr>
<tr>
<td>Mozambique</td>
<td>-0.1</td>
<td>0.04</td>
<td>0.52</td>
<td>0.24</td>
<td>0.29</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>-1.19373</td>
<td>-1.52049</td>
<td>-1.62016</td>
<td>-1.73426</td>
<td>-1.78941</td>
</tr>
<tr>
<td>Nigeria</td>
<td>-1.86917</td>
<td>-1.81265</td>
<td>-2.12401</td>
<td>-2.08924</td>
<td>-2.00886</td>
</tr>
<tr>
<td>Burundi</td>
<td>-2.34882</td>
<td>-1.40871</td>
<td>-1.37398</td>
<td>-1.32231</td>
<td>-1.42613</td>
</tr>
<tr>
<td>Bolivia</td>
<td>-0.66578</td>
<td>-1.12622</td>
<td>-0.93542</td>
<td>-0.99129</td>
<td>-1.02304</td>
</tr>
</tbody>
</table>

Table 4.3: Political Stability and Absence of Violence Index.
Source: World Bank
HHI(C, ps) = Sum [political stability * (country concentration)^2]

= Sum [(-0.17138)*(94.13)^2 + (1.021873)*(5.02)^2 + (0.897181)*(0.50)^2 +
(-0.1061)*(0.15)^2 + (-2.45)*(0)^2 +
(0.24)*(0.08)^2 + (-1.73426)*(0.10)^2 +
(-2.08924)*(0.08)^2 + (-1.32231)*(0.02)^2 + (-0.99129)*(0.00)^2]

= -1492.45

CSRI = HHI(C,ps) – HHI©
= 8885.9466 – (-1492.59)
= 10377.5164

Table 4.4 lists the HHI©, HHI(C, ps) and CSRI values for 2008, 2007, 2006, 2005 and 2004. These values are plotted in a graph in Figure 10. Figure 11 is a line graph showing the development of HHI© and HHI(C, ps) values over the four years. The distance between the two lines gives the CSRI of tantalum and niobium. It is clear that the CSRI value for 2007 is the highest. The 94.13% production concentration in Brazil in 2007 and the lower World Bank political stability rating for Brazil and Bolivia in 2007 compared to the other years have an influence on the HHI© and the HHI(C, ps) respectively and, therefore, also on the CSRI for 2007.

<table>
<thead>
<tr>
<th>INDEX</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHI©</td>
<td>8289.596</td>
<td>8664.114</td>
<td>8790.908</td>
<td>8885.947</td>
<td>8723.626</td>
</tr>
<tr>
<td>HHI(C,ps)</td>
<td>-607.533</td>
<td>-674.1</td>
<td>-1083.23</td>
<td>-1492.59</td>
<td>-1011.75</td>
</tr>
<tr>
<td>CSRI</td>
<td>8897.129</td>
<td>9338.215</td>
<td>9874.138</td>
<td>10378.53</td>
<td>9735.376</td>
</tr>
</tbody>
</table>

Table 4.4: HHI©, HHI(C, ps) and CSRI. Source: Author.

Figure 4.2: HHI © and CSRI of Tantalum and Niobium
Source: Author
From Figure 4.2 and Figure 4.3, it is clear that the commodity supply risk in 2007 was the highest. 2004 was the year with the lowest commodity supply risk. However, using the calibration for HHI, one can conclude that the commodity supply risk was high in all four years. The commodity supply risk index (CSRI) must only be used as a source of additional information for assessing supply risk of a commodity due to political stability or instability.

B. Substitution

Substitution of a metal with other metals in any one of its application sectors can have an impact on the supply of the metal. If substitution is not possible, supply risk increases, since dependence on the metal is more. It is also an important factor that substitution of one metal for another is both cost effective and provides the same level of performance and effectiveness in the end product.

Supply stress in the case of tantalum and niobium can be reduced, since substitution of tantalum and niobium is a possibility. Aluminium and ceramics are substitutes of tantalum in the ceramic industry. Niobium, platinum and titanium are used as substitutes for tantalum in corrosion-resistant equipment whereas zirconium, hafnium, iridium, molybdenum, rhodium, and tungsten are some substitute metals that can be used in the high-temperature applications. The substitutes of niobium are molybdenum and vanadium in low-alloy steels; tantalum and titanium in stainless steel; and ceramics, molybdenum, tantalum and tungsten in high-temperature applications.

These metals and ceramics can be used to make up for the supply shortage and to help keep the prices down.

The assessment of substitutability of tantalum and niobium in each of its application sectors requires high levels of metallurgical and other expertise, and is therefore not covered in this thesis. However, according to the USGS, the effectiveness and performance of the substitute metals are much lesser than that of the two original metals.

Tantalum substitutes, for example, were studied extensively during the drastic spike in price of tantalum around the turn of the century. Clinton Wood, executive chairman of Noventa, stated that, “Although a lot of R&D was done to find alternatives following the tantalum price spike in 2000, it instead proved that capacitors made from substitute material need to be about 10 times the size to achieve the same functionality” (as cited in Ruffini, 2008, p68).

Therefore, the lack of suitable substitutes, i.e. the inability of the substitute materials to deliver the same levels of effectiveness, increases the supply risk for tantalum and niobium. The dependency on the two metals increases and the supply of tantalum and niobium becomes critical.

C. Recycling

As mentioned before, recycling is a secondary source of tantalum and niobium. However, for recycling to be an important source of the two metals, it must remain an economical option for firms to venture into. However, it is to be expected that in a few years, recycling will be enforced by law, not only for environmental purposes but also for reasons of sustainability. If the rate of recycling does not
increase, the supply of metal would continue to depend largely on the primary sources (mines), thus increasing its supply risks. The rate of recycling may be calculated as the ratio of old and/or new scrap recycled, compared to apparent total consumption. Figures for the rate of recycling of niobium are not available, but estimated to be about 10%-15%. The recycling rate of tantalum is about 20% (USGS, 2009). This indicates that the supply of tantalum and niobium is not entirely dependent on the primary sources, which still remain the largest source of tantalum and niobium supply at 60% and 85%-90%, respectively (USGS, 2009).

Therefore, the existence of the option of recycling as a source of metal for both tantalum and niobium reduces the supply risk considerably.

D. Economic Significance

The scope of the supply risk of a metal is limited by its economic importance. The availability of a metal that has high supply risk but low economic importance is not very critical. However, one should also keep in mind that the economic importance of a metal is region or industry specific.

The critical nature of tantalum and niobium to the European Union (EU), for example, was reported in a study called ‘Critical raw materials for the EU’. The study was prepared for the European Commission and the work was carried out with the participation of a working group of experts and the technical support of external consultants. The economic importance of the metals to the EU and their supply risks were estimated by the expert group and plotted against each other in a graph as seen in Figure 12. Supply risk depends on political stability of producing countries, substitutability and recycling rate. The economic importance was estimated by the value added to the economic sectors relevant to the EU that use the raw material.

As seen from the graph in Figure 4.4 the supply risk is 1.1 for tantalum. Its economic importance is 7.4. For niobium, supply risk is 2.8, and its economic importance is 8.9. Both tantalum and niobium are in the high criticality group for the EU. However, these values might have been different if the study had been limited to one or a group of countries within the EU or even if countries and regions outside the EU had also been included. The values would have also differed if the study had been done on a global scale.

Figure 4.4: Criticality of Commodities. Source: European Commission, "Criticality of Raw Materials in the EU", Report to the Ad-hoc Working Group on defining critical raw materials, 2010
Foreign Exchange Risk

The fluctuations in the exchange rates and interest rates can lead to a market risk for a commodity or an organisation. This can be determined using the Value at Risk (VaR) method. VaR is a widely used statistical tool used to study the market risk of an entity (Linsmeier & Pearson, 1996). It is a measure of the possible losses that a firm could incur. VaR can be determined for a multitude of assets including stocks, bonds, stock options, bond options, future contracts, barrier options, caps, floors and many more. Companies calculate VaR for portfolios consisting of one or many different assets (van den Goorbergh & Vlaar, 1999).

Data

Prices for tantalum and niobium are instead fixed by confidential negotiations and contracts between the parties involved (Giot & Laurent, 2002). Since there is a lack of information regarding the future and forward contracts between organisations, certain assumptions have been made to illustrate this method. An Australian tantalum mining company A is assumed to have entered into a forward contract with a German capacitor manufacturing company B on June 1st 2010. The maturity of the forward contract is assumed to be 90 days. Company A delivers 10,000,000 AUD and receives 8,000,000 EUR. Historical data for the last 125 days for Euro (EUR) interbank offered rates, Australian Dollar (AUD) interbank offered rates and the AUD/EUR spot exchange rates are considered for the calculation of VaR using the historical simulation approach.

Methodology

Before calculating VaR, two main components of a VaR statistic need to be determined. The two components are the confidence level and the holding period. “Confidence level is a measure of the degree of certainty of the VaR estimate” (Linsmeier & Pearson, 1996). The holding period is the period over which VaR is measured. Changes in confidence level and the holding period will result in change in VaR, even when calculated for the same investment or portfolio. There are three different ways to determine VaR. They are: Historical Simulation, Variance-Covariance and Monte-Carlo Simulation.

I. Historical Simulation

The historical simulation method uses historical values to calculate VaR. On the 1st of June 2010, the date of the contract, the AUD/EUR spot exchange rate was 1.457936. The AUD interbank offered rate and the EUR interbank offered rate were 4.82810 and 0.702 respectively. As mention earlier, Company A delivers 10,000,000 AUD and receives 8,000,000 EUR. Using the data, AUD mark to market value for the forward contract on the 1st of June 2010 is calculated using the following formula:

\[
\text{AUD Mark to Market Value} = \left[ \text{AUD/EUR exchange rate} \times \left( \frac{\text{Amount received in EUR}}{1 + \text{EUR interbank rate} \times \left( \frac{90}{360} \right)} \right) \right] - \left[ \frac{\text{Amount delivered in AUD}}{1 + \text{AUD interbank rate} \times \left( \frac{90}{360} \right)} \right]
\]

On the 1st of June 2010, this value is 5,391,164 AUD. This is the hypothetical value of the forward contract on June 1st 2010.

Historical data for AUD/EUR spot exchange rate, Euro (EUR) interbank offered rates and Australian Dollar (AUD) interbank offered rates were collected for the 125 days before June 1st 2010, i.e. from December 1st 2009 to May 31st 2010. Percentage changes in the value of the three factors were calculated. Using this data and actual data for June 1st 2010, hypothetical values for the three factors for the 125 days after June 1st 2010 were determined. Using these values in the formula for AUD mark to market value, hypothetical forward contract values were determined for each of these 125 days. The difference between the forward contract value on June 1st 2010 and hypothetical forward contract values gives the profit or loss of the investment for each of the 125 days.

The profit and loss values of the forward contract investment were then sorted and plotted in a histogram as shown in Figure 4.5.
Using the daily profit and loss values for a period of 125 days, a holding period of 1 day and a confidence level of 95%, the VaR is estimated to be -96,647 AUD. The VaR is the 5% worst value in the list of 125 hypothetical profit and loss values calculated for the forward contract. This is the worst loss that the Australian mining company A could incur under the assumed conditions, i.e. the loss will not exceed 96,647 AUD. This is only an estimate of the probability of a loss. If the confidence level is increased to 99%, the VaR is estimated to be -158,424 AUD. The arrow in Figure 13 will shift to the left and lie between -150,000 AUD and -175,000 AUD. Therefore with the same data, a holding period of 1 day and a confidence level of 99%, the daily loses will not exceed 158,424 AUD. By using VaR tools for calculation of market risk resulting from fluctuations in exchange rates, tantalum and niobium mining firms will be better informed about their investment decisions.

**Safety Risk Assessment**

The safety and health risk assessment methods discussed in this section are based on the guidelines of the Natural Minerals Industry Safety and Health Risk Assessment published by the Minerals Council of Australia (MCA). Safety risk triggers are discussed to provide a perspective of possible internal risk factors, which in most cases lie within the project’s control and the need for risk assessments of these factors.

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**Data**

The identified hazard in this example is heavy rainfall. This can result in damage of property and in some cases even in fatalities. Further assumptions with regard to probabilities of occurrence and consequences have been made in the subsections. In the real business world, risk assessment teams comprising experts are involved in making the estimations and the assumptions of these values.

**Methodologies**

There are primarily three different types of safety and health risk assessment techniques: Qualitative, Quantitative and Semi-quantitative. The qualitative and quantitative methods of risk assessment are discussed in detail with suitable examples. Semi-quantitative methods shall not be discussed in this paper.

1. Qualitative Risk Assessment

Qualitative risk assessment is a technique based on the estimation of the probability or the likelihood of events and their consequences. To illustrate the functionality of a basic method of qualitative risk assessment, the following assumptions have been made. An event or hazard can be classified as having low, medium or high likelihood. In this example, the likelihood of flooding due to heavy rainfall is assumed to be high. The consequence of this heavy rainfall in mines can be fatality, equipment failure or delays. The consequences are also classified as events having low, medium or high consequence. In this example, the event is assumed to have medium or moderate consequences. A basic risk matrix tool is shown in Table 4.5. Based on the risk matrix in Table
14, the risk of heavy rainfall is estimated to be ‘HIGH’.

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>High Consequence</th>
<th>Medium Consequence</th>
<th>Low consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Likelihood</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Medium Likelihood</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Low Likelihood</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 4.5: Risk matrix – A basic example. Source: NMISHRAG, 2005

II. Quantitative Risk Assessment

The quantitative technique is more reliable than the qualitative assessment method, which may be regarded as an informal approach. The quantitative risk assessment approach is detailed, and specialists and experts are required in most cases to carry out the processes involved. The efficiency of this approach depends on the accuracy of available data.

There are many approaches to quantitatively assess the risks of a hazard. Fault Tree Analysis is one of the most widely used quantitative tools. Fault Tree Analysis - In a fault tree analysis, the flow starts from the initiating event and continues with a series of events that could follow. The initiating events are the end events of the fault tree diagram. They are determined by the risk assessment team. Events and the probabilities for each event should also be determined by a team of experts. Figure 4.6 illustrates the fault tree analysis as an example.

Figure 4.6: Fault Tree Analysis – An Example. Source: Author
The undesirable event in this example is an electric fire. The possible events leading to an electric fire are shown. The probability for each event in the last layer is assumed. OR & AND logic gates are used to depict the relationship between an event and the underlying events. Boolean algebra calculations are used to arrive at the likelihood of all other intermediate events and finally for the topmost event, which in this case is an electric fire. When there is an OR relationship, the probabilities are added, and when there is an AND relation, the probabilities are multiplied. The probability of the electric fire, calculated using a fault tree analysis as shown in Figure 18, is ‘0.0728’. The events leading up to this undesirable event are also shown in the Fault Tree Diagram. Therefore when the final risk is too high, it becomes simpler to identify the underlying cause and develop tools to reduce or eliminate risk at the specific points.

Chapter 5
Impact of Technology

Impact of Existing Technology

One important factor that has major influence on the availability of raw materials is technological growth. On the one hand, restrictions to the supply of one or more raw materials may hinder the technological growth of economies. On the other hand, if a particular technology becomes obsolete, there might be an excess supply of materials due to decreased demand. The impact of existing technology on demand is further discussed in this section. Technologies have different life cycle stages and, corresponding to each stage in the life cycle, the demand cycle thus varies. This in turn is related to the demand and supply cycle of the raw materials in use.

Capacitor Technology

To illustrate the impact of technology on demand and availability of raw materials, the trend in capacitor technologies was examined (Zednicek, 2006). A comparison between four notebooks manufactured in 2003 and six notebooks manufactured in 2005 was made, and it showed a changing trend in use of capacitors. Figure 5.1 illustrates the changing scenario of the technology used in capacitors in PCs and notebooks. Use of tantalum MnO₂, tantalum polymer, niobium oxide and aluminium polymer capacitor technologies were analysed. The total count of capacitors in 2003 was 19. In 2005, the total count of capacitors was 28. The share of aluminium polymer capacitors had reduced from 14% in 2003 to 4% in 2005. The share of tantalum MnO₂ capacitors in PC notebooks had decreased to 2% in 2005 from about 39% in 2003, whereas the share of tantalum polymer capacitors had increased from 47% in 2003 to about 70% in 2005. Tantalum MnO₂ capacitors had been replaced by tantalum polymer capacitors and niobium oxide capacitors in 2005. The huge reduction in tantalum MnO₂ share can be attributed to a few performance related issues. From this study, one can infer that with the introduction of the technology for tantalum polymer capacitors and the technology for niobium oxide capacitors in 2005, the technology for aluminium polymer capacitors and the technology for tantalum MnO₂ capacitors reached their declining stages.

It is therefore clear from the above example that technology has a timeline. The life cycle of technology influences the demand for product and the raw materials used in the product. The availability of the raw materials is thus critical for further growth.
and development of economies that are seeking to gain technological excellence.

**Impact of Emerging Technology**

The supply of raw materials should be able to keep up with changes in demand resulting from emerging technological innovations, since they have an impact on the future demand for raw materials. For example, in Figure 16, the outdated tantalum MnO₂ technology was replaced by niobium oxide capacitor technology in 2005, resulting in decreased tantalum MnO₂ demand and increased niobium oxide demand. To analyse the impact of emerging technologies on the supply of raw materials, a study that will be used up in 2030 by the emerging technologies. The figures were updated by BGR in April 2010 and are based on the most recent amounts of tantalum and niobium produced. The demand from emerging technologies in 2030 is estimated to change by a factor of 3 for niobium and by a factor of approximately 2.55 for tantalum. The projected increase in demand for tantalum and niobium due to emerging technologies highlights the importance of the need for a secure supply network. Any restriction to supply will therefore have an impact on technological growth.

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Production in 2006 (t)</th>
<th>Demand 2006 (t)</th>
<th>Demand 2030 (t)</th>
<th>Indicator 2006</th>
<th>Indicator 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tantalum</td>
<td>1,384</td>
<td>551</td>
<td>1,410</td>
<td>0.40</td>
<td>1.02</td>
</tr>
<tr>
<td>Niobium</td>
<td>44,531</td>
<td>288</td>
<td>1,410</td>
<td>0.01</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 5.1: Demand due to emerging technologies. Source: BGR, 20

Table 5.1 was commissioned by the German Federal Ministry of Economics and Technology (BMWi) and updated by BGR in 2010. A list of raw materials including tantalum and niobium were studied. For tantalum, the emerging technologies of micro capacitors and medical technology were studied. For niobium, the emerging technologies of micro capacitors and ferroalloys were studied. This indicates the predicted importance of these two metals in future technological growth. The result of this study for the two metals is as shown in Table 5.1. The demand for tantalum and niobium in the coming years will be greatly influenced by emerging technologies.

In Table 5.1, the figures in the column titled ‘Demand 2006’ are based on the amounts of tantalum and niobium produced in 2006 and the amounts of raw material used in 2006 by the emerging technologies under consideration. The figures in the column titled ‘Demand 2030’ are the projected values of the amounts of raw materials that will be used up in 2030 by the emerging technologies.

It is also interesting to observe that new innovations in technology might render the existing technologies obsolete. If, for example, the use of aluminium in capacitors proves a more cost-effective and performance-effective alternative, demand for tantalum and niobium will decrease. This might lead to the shutting down of mining projects, as in the case of the Wodgina mine in Australia that was shut down due to decreased demand for tantalum.

The impact of both existing and emerging technologies on the demand for tantalum and niobium, further stresses the importance of a steady supply that must be able to meet their changing demand levels. Demand level fluctuates with technological innovations and changes, and therefore the availability of the raw materials should also be sufficiently elastic to satisfy the demand at the right time. However, in recent years, the market has witnessed demand changes at such great paces that supply sources have been unable to keep up.

**Timelines of Products and Mines**

The demand for tantalum and niobium must be met with a steady supply. In the recent years, due to the speed of technological development, products have
shorter life cycle durations than before. The timeline of a mine, on the other hand, has increased due to the number of rules and regulations that mining firms are now required to follow. This can result in a poor fit between the product life cycle and the mine life cycle. A gap between the supply and the demand is created and this impacts the availability of the material in the market. In order to understand the implications of the mismatch between the life cycle of a product and the timeline of a mine, it is essential that the reader understands these concepts first.

**Product Life Cycle**

Products have limited lifelines. The significance of analysing the product cycle is to determine the position of the product in the market. The sales and profits a firm makes mirrors the life cycle stage of its product. Product life cycle is applicable to all products ranging from PCs to automobiles and from capacitors to IT products. However, the actual timeline of the product life cycle varies from one product to another. In the last decade or two, the pace of development of technological products has been tremendous. This creates a pressure to the supply of materials. Changes in the underlying technologies of the product have an impact on demand in the market. Therefore the supply, demand and price of a product vary from one stage to another.

**Time Cycle in the Mining Industry**

This unavailability of raw materials metals creates opportunities for the development of new and upcoming projects. However, due to the recent trends in the regulations for sustainable mining, the opening up of a new mine project takes several years. Mining firms are now required to follow a number of rules and regulations that did not exist in the past. Extensive time periods are needed as they are under pressure to follow standardised procedures in order to satisfy the project stakeholders. The total time period for a mine to reach the mineral development and mineral exploitation stage could be anywhere between 5–15 years.

**Chapter 6**

**Timelines of Products and Mines**

On the one hand, due to the speed of technological development, products have shorter life cycle durations than before. The life cycle of a product, which in turn creates a corresponding change in demand for the raw materials used. Therefore, a short product life cycle implies that the demand for its raw materials will also be short-lived. On the other hand, the timelines of mines have increased due to the number of regulations and rules that mining firms are required to follow. For the supply to meet the demand there is a need for a proper fit between the life cycle of a product and the life cycle of a mine producing the raw materials that the product requires.

**Implications**

The relation between the product life cycle and required supply of raw materials from mines is illustrated in Figure 5.2. From Figure 5.2, one can infer that the demand conditions of a product in the market will have an impact on the product life cycle. Appropriate product life cycle management tools are then used to determine the market strategies and product requirements at each stage. The changes in the requirements of the market and the product will in turn impact the production design for raw materials. This gives us the demand for raw materials. The change in demand needs to be met by the supply of the raw materials from mines. When the supply from mine production is unable to meet the demand changes, there is an increase in the supply risk of the material. For example, during the dot com boom, the demand for mobile phones was extremely high. This increased the demand for tantalum, which was one of the raw materials used in the manufacture of mobile phones. However, the increase was so drastic that the mine production was unable to quickly adapt to this change, resulting in a shortage of tantalum in 2000. This poor fit between the product life cycle and the mine life cycle results in a gap between the demand and the supply of raw materials. This gap impacts the availability of the material in the market. To deal with the disparity, steps such as the building up stockpiles or inventories of essential raw materials become extremely necessary. For example, in the case of tantalum supply, the DSLA stockpile for tantalum was depleted in 2007 (USGS, 2009). This led to a major reduction in the quantity of tantalum available in the market, thereby widening the gap between the supply and the demand for tantalum.
Exploration companies enter into joint ventures or partnerships in the early exploration stages as a way to share risks of the project. Apart from risk sharing possibility, the joint ventures allow the company to obtain funds and finances for the project.

The procurement departments have, so far, been purchasing the required raw materials based on the demand of production. For certain commodities the market has changed and this kind of purchasing may no longer work. An assured supply of raw materials is necessary. So, in addition to the possibilities discussed, i.e. building up of stockpiles and risk sharing, there is the possibility of the participation of middle and end level members of the supply chain, in the project of the mining firm. In exchange for the participation, the customers of the mining firm are given assurance of the supply of the wanted material when availability of the material in the market is critical. This possibility of participation has already been recognised in the market, but most companies still hesitate to change their strategies with respect to assuring the supply of specific natural resources via participation since this procedure will be expensive for the participating firms. However, in the long run, the non-availability of the required raw material for production can prove to be more expensive and harmful.

It is clear from the discussion above that the supply of material to meet world demand of tantalum and niobium could come under pressure, not only because of risk factors, but also due to technological innovations and, more interestingly, due to a likely gap between the life cycle of products and the timelines of mines that supply the raw materials for those products, resulting in a gap between the demand and the supply.

Chapter 7
Conclusion and Remarks

Tantalum and niobium are significant metals. They render unique properties to the end products and have low substitutability. Resources of tantalum and niobium exist in abundance. Therefore, the risk of the geological availability of tantalum and niobium is not a matter of concern. Of greater relevance are the factors that affect the supply and demand of these two metals. The supply of niobium is sufficient to meet the projected increases in its demand, and its price is therefore expected to increase at a steady pace. The supply of tantalum, on the other hand, is under stress. There is a shortage in supply because of the depletion of the DLA stockpiles, the reduction in demand due to the world financial crisis and the shutting down of operations at the Wodgina mine in Australia. The availability of tantalum, therefore, is critical.

To ensure a reliable supply of raw materials at competitive prices, and at the required time, risk assessment is essential. To assess the risks of the availability of tantalum and niobium, a number of different risk triggers can be taken into account. Commodity supply risk can result from the political and the economic situation of the producing countries. The production concentrations of the tantalum and niobium producing countries and the point estimates of the ‘political stability and absence of violence’ component of the World Bank governance indicators are incorporated into the HHI to arrive at the ‘Commodity Supply Risk Index’ (CSRI). The CSRI can vary from 0 to 10,000.
The CSRI of tantalum and niobium, as calculated in this paper, varies from 8,890 – 10,400. This implies that tantalum and niobium have a high supply risk due to the political instability in the producing countries.

In the case of tantalum and niobium, the supply stress can be reduced since substitution of tantalum and niobium is a possibility. However, the effectiveness and the performance of the substitute metals are found to be lesser than that of the two original metals. Therefore, the lack of suitable substitutes, i.e. the inability of the substitute materials to deliver the same levels of effectiveness, increases the supply risk for tantalum and niobium.

Recycling is a secondary source of tantalum and niobium. Figures for the rate of recycling of niobium are not available, but estimated to be about 10-15%. The recycling rate of tantalum is about 20% (USGS, 2009). Supply of tantalum and niobium is, therefore, largely dependent on the primary sources. However the existence of the option of recycling as a source reduces the supply risk of both tantalum and niobium.

The scope of the supply risk of a metal is limited by the economic importance of the raw material, which is region or industry specific. In a study prepared for the European commission, the supply risk and economic importance of tantalum and niobium to the EU was assessed. The supply risk is 1.1 for tantalum. Its economic importance is 7.4. For niobium, supply risk is 2.8, and its economic importance is 8.9.

Apart from the risk factors such as political instability that have a direct influence on supply, there exist other factors whose influence on supply cannot be ignored. Foreign exchange rate risk and safety risk are two such risk factors. Foreign exchange rate fluctuations result in market risk. Hedging tools such as options and forward contracts are usually employed by firms to protect the business against interest rate and exchange rate volatility. The risk that these instruments are exposed to due to changes in interest rates and exchange rates need to be measured. The VaR is an important risk assessment tool used by firms to assess market risk. Using an example of a forward contract between a tantalum producer and a capacitor manufacturer, a measure of the possible losses that the forward contract can suffer can be arrived at by using the ‘historical simulation’ approach of calculating the VaR.

Safety hazards such as improper maintenance of machinery or poor safeguarding of workers against workplace accidents are factors that, unlike exchange rate fluctuations, can be under the control of the project. These hazards may result in the shutting down of production for days, weeks or months at a time. Qualitative and quantitative methods of safety risk assessment can be applied to arrive at risk values for possible unfavourable events, for example, in a tantalum mine, using estimations of probabilities and consequences. Safety hazards cannot be neglected for any mining project including that of tantalum and niobium. Therefore the risk assessment of the safety hazards will help identify the probability that a risk exists and the point of existence of the risk. Mitigation of risk then becomes easier.

There are some other factors which have an impact on the supply of a raw material by greatly influencing its demand. The demand of the raw material is driven by the growth of the existing and the emerging technologies. The existing technology has a life cycle. In correspondence with each phase of the technology cycle, the demand of the used raw materials also varies. For example, technology for tantalum polymer capacitors replaced the technology for tantalum MnO2 capacitors in PC notebooks between 2003 and 2005. Share of tantalum MnO2 capacitors decreased from 39% in 2003 to about 4% in 2005, whereas share of tantalum polymer capacitors increased from 47% in 2003 to 70% in 2005.

The emerging technologies will influence the demand of raw materials in the future. According to a study conducted by BGR, the demand for tantalum in 2030 is expected to increase by a factor of 2.55 and the demand for niobium in 2030 is expected to increase by a factor of 3.0. The projected demand is the result of emerging technologies. The supply of these two metals should be able to meet the changes in demand resulting from growth in the existing and the emerging technologies. Any restrictions to the availability of raw materials will restrict the economic and technological growth of a nation.

The supply from mine production should be able to adapt quickly to the changing demand needs. The gap between the supply and the demand can be overcome by taking actions such as the building up of stockpiles or risk sharing via joint ventures and partnerships. Apart from this, there is also the possibility of the participation of middle and end level members of the supply chain in one or more specific projects of the mining firm. In exchange for the participation, the
customers of the mining firm are given assurance of the supply of the wanted material when availability of the material in the market is critical. Most companies hesitate to take this step and change their strategies with regard to assured supply via participation, since it can be very costly. However, in the long run, the non-availability of the required raw material for production can prove to be more expensive and harmful.

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