MATERIALS AND SOCIETY, Vol. 14, No. 1, pp. 11-44 (1990)
0146-6399/90 $3.00 + .00 Printed in the USA

THE VULNERABILITY OF STEEL PRODUCTION TO MILITARY THREATS*

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ABSTRACT

Vulnerability and resilience are valuable concepts for analyzing the dynamics of technological systems. These concepts are elucidated and a procedure for investigating them is outlined. A case study of the vulnerability of the steelworks at Port Kembla in Australia to military threats is presented.

INTRODUCTION

In the study of technological systems, the concepts of vulnerability and resilience are not often a focus of attention. Most previous work has concentrated on two areas, energy and computers. The energy sector has received attention because of the repeated threats to oil imports from the Middle East (Deese and Nye 1981) and also in the course of the debate over 'soft energy paths' (Lovins 1977). This threat to oil imports from the Middle East has led to detailed analysis of stockpiling for the United States (Mikesell 1985, 1986; Plummer 1982). The U.S. energy system generally has been accused of being highly vulnerable to military attack, or more generally to any sudden shock, whether military, economic or political (Clark and Page 1981; Katz 1982; Lovins and Lovins 1982).

Vulnerability has also been assessed in relation to computers and communications, especially in relation to military contingencies. A principal concern here is the risk that malfunctions in computer-based early warning and nuclear war-fighting systems may trigger accidental nuclear war (Hoffman and Moran 1986; Morrison 1984; Borning 1987).

There are of course numerous military studies, mostly classified, which deal with the vulnerability of military facilities to attack. The focus in these studies is military effectiveness, not the issue of vulnerability per se.

Another way to approach vulnerability is through the study of risk. Here the usual aim is to determine the risk and consequences of technological failure, such as the risk of human illness or death (Perrow 1984). Again, the issue of technological vulnerability is not the main focus.

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* The authors sincerely thank the many employees at BHP Steel at Port Kembla who were interviewed for their cooperation and their valuable comments. Also providing useful comments were David Blatt, Fred Emery, Ray Markey and Stephanie Short. This research was supported by the Australian Research Grants Scheme.

What these studies lack is any systematic treatment of vulnerability and resilience of technological systems as a general issue. In this paper we aim to encourage such treatment, using steel production as an illustrative case study.

We begin by giving some rationales for the study of vulnerability and resilience, and then present some points about the concepts. Next we outline a procedure for investigating vulnerability. Our case study is the vulnerability of the integrated steelworks at Port Kembla (Wollongong, Australia) to military threats. We discuss a number of key areas at Port Kembla in relation to possible threats, consequences and responses. In the conclusion we point to different uses and potentialities of the study of technological vulnerability.

RATIONALES

There are many possible reasons for studying the vulnerability and resilience of technological systems focussing in particular on military threats. Here we present some of the more distinct rationales.

First, the study of vulnerability provides a way to probe the dynamics of technology. In the case of the steelworks at Port Kembla, military threats have played no role whatsoever in technological decision-making. Yet the steelworks is resilient to military threats in a number of significant ways. Understanding why this is so provides insight into a key question about technology: how and why is technology which was designed for a particular purpose able to serve other purposes?

The study of vulnerability brings in a wide range of issues which otherwise seem to have little connection. For example, methods of work organization can affect disruption of production due to loss of key personnel; investments in particular types of technology may result in its entrenchment and hence less resilience; government economic policies can affect vulnerability to foreign import restrictions. In addition, vulnerability provides a way to investigate the difficult issue of non-decision making (Crenson 1971).

A second and obvious rationale for the study of vulnerability is practical in nature, namely to reduce vulnerability and increase resilience. In looking at the vulnerability of steel production to military threats, a possible outcome is the provision of guidelines for improving resilience to the particular threats examined, and also improving resilience to threats of a non-military nature, such as economic collapse.

A third rationale for studying vulnerability to military threats is to analyze different defense modes. 'Defense' can be based on possession of nuclear weapons, alliance with a nuclear weapons power, non-alignment, armed neutrality, use only of defensive military weapons, guerrilla warfare or nonviolent resistance. The particular defense system used will affect the likely threats and has implications for technological decision making.

Finally, studying vulnerability to military threats can be part of a wider study of vulnerability and resilience in 'technological society', namely the study of the economic, political and social bases of stability and instability in contemporary society. Technological systems such as steel production are social systems intermeshed with physical hardware, and so the issue of vulnerability and resilience of society can be approached through the study of the vulnerability of technological systems.

The main aim in this paper is to show how the study of vulnerability can be used to probe the dynamics of technology. It should be emphasized that the aim here in studying steel production is not to see how the steel industry can produce war materiel in the event of a military contingency -- this area in Australia is the domain of the Industrial Mobilization program (Langtry and Ball 1986) -- but instead to provide a case study for delving generally into how resiliences develop and how vulnerabilities can be overcome.

VULNERABILITY AND RESILIENCE

Definitions of vulnerability and resilience can be approached using a systems perspective (Emery 1981). First, it is necessary to make a distinction between a given technological system and its 'environment'. The technological system, such as a steelworks, includes physical equipment, raw materials, workers, and relations between them including work routines. The environment is everything 'outside' the technological system and in this case can include imports of raw materials and equipment, financial markets, and the reservoir of labor skills and knowledge in the wider society. It is assumed that people are using the technological system to serve particular purposes; in this case it is producing steel, supplying customers, making profits, providing employment, etc. The main purpose can vary from one person to another, but the purposes of different people are linked to some extent. The satisfaction of purposes by the technological system can be called its 'output.'

A technological system must adapt to changes in its environment if it is to continue to serve the purposes of those who depend on it and who attempt to control it, or in other words produce its outputs. For example, if the price of a particular import increases, a choice may be made to find a different supplier. Any change in the environment is a potential threat to the continued effective functioning of the technological system. Sudden changes usually pose the greatest threats.

The vulnerability of a technological system to a specific threat can be defined as the risk or chance that a specified change in the environment leads to a disruption of the usual purposes of the system. Note that vulnerability here only has meaning in relation to specific threats. It is also possible to define a general type of vulnerability, namely, a disruption which may result from any of a variety of threats.

The resilience of a technological system to a specific threat can be defined as the capacity of the system to maintain nominated purposes in the face of specified changes in the environment. Resilience is therefore the obverse of vulnerability. These definitions will take on more meaning with the examples presented later.

Although vulnerability and resilience have been defined only in relation to changes in the environment, it is also possible for disruptions to occur within the system. Therefore it is useful to distinguish between vulnerability and resilience in relation to both external and internal changes.

ORIGINS OF RESILIENCE

There are several ways in which resilience to a particular threat can arise. First, there may be specific planning to deal with the threat. In the case of Port Kembla, there has been no specific planning to deal with military threats, so none of its resilience has this origin.

Second, there may be specific planning to deal with some other threat which helps prepare for the one in question. This may be planning for a similar contingency or a completely unrelated one. For example, on-site electricity generation which is developed (in part) to provide security against peacetime interruptions of grid supplies would also provide protection against interruptions due to military assaults.

Third, resilience may be inherent in the way technological or economic systems are organized. For example, much mechanical steelmaking equipment must be 'heavy-duty' in order to deal with the raw materials such as iron and steel; this makes the plant more resistant to the effects of bombs. By contrast, economic imperatives can foster the introduction of microelectronic equipment which happens to be highly sensitive to disruption by nuclear electromagnetic pulse.

Fourth, resilience can arise accidentally. For example, a duplicate facility may be sited in a particular place just because land is available. It is then largely a matter of chance whether this results in dispersion or concentration of facilities and hence higher or lower resilience against a bomb destroying all the facilities of a particular type.

These four categories for the origins of resilience will prove useful later in understanding the resiliences of the Port Kembla steelworks.

METHODS FOR RESILIENCE

There are several ways to promote resilience. One is to prevent any threat being realized in the first place. For example, downplaying the strategic value of a steelworks might convince an aggressor that it is not a useful target.

Protection is a second method. This might involve mechanical switches to protect against nuclear electromagnetic pulse, or in extreme cases building facilities underground to protect against bombing attacks.

Availability of spares and backup facilities is a third area of resilience, for example, in providing replacements for equipment that is destroyed in an attack. A fourth method is the capacity for reconstruction, namely the ability to rebuild facilities that are put out of action. Finally, resilience can be provided by the capacity to use different production methods, such as electric furnace minimills instead of integrated steelmaking.

COSTS AND BENEFITS OF RESILIENCE

Vulnerability intuitively sounds like a bad thing while resilience sounds good. Likewise, prevention of threats occurring sounds better than resorting to different methods. But the assessment of the costs of vulnerability and resilience depends sensitively on the likelihood of particular threats being realized and the costs of resilience, just as the wisdom of investing in insurance coverage depends on how much it costs. If, for example, it were judged that the likelihood of a military attack on Wollongong is less than one in a million per year, this would have different implications than if inside information suggested an attack was likely in the next ten years. Cost-benefit analysis, in any event an area filled with pitfalls and value assumptions, is especially treacherous in dealing with small likelihood, high-risk contingencies.

In this paper the focus is on the origins of vulnerabilities and resiliences and on methods of responding to threats. A full cost-benefit analysis of methods of responding to potential threats would require analysis of two factors not assessed here: the likelihoods of specified threats being realized and the costs of specified methods of response.

STEELMAKING

Steel production is often used as a measure of the 'development' of an industrial society. Australia produced 6.4 million tons of steel in 1985, about 400 kilograms per head of population. The world's largest steel producers (in absolute terms) are the Soviet Union and Japan, with about 600 kilograms and one ton per head of population respectively.

BHP (Broken Hill Proprietary Limited), Australia's largest company (Trengrove 1975), produces about 96% of steel manufactured in Australia. The remaining fraction is produced by Smorgons from a minimill in Melbourne. BHP production takes place at three large integrated plants at Port Kembla, Newcastle and Whyalla. Port Kembla manufactures flat products such as slab, plate, strip and tinplate; Newcastle produces rod, bar, beams and channels; Whyalla specializes in rails, universal beams and columns. Port Kembla currently produces approximately 3.5 million tons per year; with a capacity of 4.2 million tons, it is by far the largest steelmaking plant in Australia (Lewis 1985). In the Appendix, a simple explanation of modern steelmaking is provided for non-specialists.

An examination of the vulnerability of the integrated steelworks at Port Kembla to military threats provides a way to test the general framework about vulnerability and resilience outlined above. In the following sections the possible military threats affecting the steelworks are listed and the likely vulnerabilities and methods for resilience are tabulated. Then, areas of potential vulnerability are discussed in turn along with ways of overcoming them. A useful way to begin the study of vulnerabilities in a particular technological system is to list as many potential threats as possible. A sample list for the Port Kembla steelworks is given in Table I.

Table 1 Threats Which Could Affect the Steelworks at Port Kembla

1. Nuclear war in the northern hemisphere
2. Nuclear war including attacks on U.S. bases in Australia
3. Nuclear war including attacks on Australian cities
4. Nuclear electromagnetic pulse over Australia
5. Military attack on Wollongong
6. Natural disaster (earthquake, tidal wave)
7. Invasion of Australia: fighting in the north
8. Invasion and takeover of Australia
9. Military coup
10. Terrorist attack
11. Sabotage
12. Strategic blockade of Australian ports
13. Economic collapse in the Western world
14. Major loss of steel markets
15. Strikes
16. Company shutdown

This table provides a set of triggers for thinking about vulnerabilities. Note that some non-military threats have been included in the table to suggest how the analysis could be extended.

There is not space here to give details of the implications of any particular threat for steelmaking at Port Kembla, but initially it is only necessary to get ideas about what kind of vulnerabilities there are. To start at the beginning, nuclear war in the northern hemisphere: the available literature suggests that if no nuclear weapons are dropped on Australia, relatively little death or destruction will be caused (Pittock 1987). What would happen is that the industrial capacity in the major northern countries -- the United States, Europe, Japan and the Soviet Union -- would be crippled or destroyed. Therefore one consequence for Australia would be a cutoff of most imports of raw materials and technology from the northern hemisphere.

If nuclear attacks were made on U.S. military bases in Australia, this would have little additional effect so far as Port Kembla steelmaking is concerned, since the bases are remote from major population centers. On the other hand, direct attacks on Australian cities could lead to major impacts: a nuclear bomb dropped on Wollongong could destroy part or all of the steelworks and kill many workers; nuclear attacks elsewhere could interrupt electricity supplies.

Proceeding through the threats in Table 1 in this fashion eventually leads to a set of vulnerabilities which can be characterized as consequences for steel production. A sample list is given in Table 2.

Table 2 Possible Consequences for the Steelworks at Port Kembla

A.	Destruction of parts of the steelworks
B.	Cutoff of imports (spare parts)
C.	Interruption of sea lanes (iron ore)
D.	Interruption of local transport (rail, truck)
E.	Interruption of electricity grid
F.	Interruption of fresh water supplies
G.	Interruption of computer facilities
H.	Killing of key personnel
I.	Intimidation or frightening of key personnel

Table 2 includes only consequences which provide for physical interruption of steelmaking. Economic vulnerabilities, such as unprofitability or bankruptcy, are not considered here; extension of this sort of analysis to other vulnerabilities is straightforward.

To get a feeling for the relationship between threats and vulnerabilities, it is useful to fill in points on the matrix generated by the two lists. Such a matrix is given in Table 3.

Table 3 Possible Consequences of Various Threats to the Steelworks at Port Kembla. Undesirable Consequences Are Marked by 'x', Intended Ones by 'o'

		Possible Consequences								
		A	B	C	D	E	F	G	H	I
	1		x							
	2		x							
	3	x	x		x	x	x	x	x	
	4					x		x		
	5	x			x	x	x	x	x	
	6	x			x	x	x	x	x	
	7									
Threats	8	o								x
	9	o								x
	10	x			x	x	x	x	x	x
	11	x			x	x	x	x	x	x
	12		x	x						
	13		x							
	14									
	15									
	16									

Table 3 gives an idea of patterned connections between threats and consequences which are not apparent from a consideration only of Tables 1 and 2. Several features of Table 3 are striking. Several of the threats do not lead to any of the consequences listed, such as an invasion of Australia restricted to fighting in the north. In some cases different threats lead to exactly the same types of consequences, such as threats 1, 2, and 13 leading only to consequence B. Looking at the columns A, D, E, F, G, and H, it is apparent that these consequences arise from similar sets of threats, 3, 5, 6, 10, and 11. Such convergences can provide direction for planning for a range of threats. The unusual cases in which consequences are initiated by steelworks' employees will be discussed later in the paper.

The limitations of Table 3 are worth noting. Not all possible threats and consequences are included, and there are differences in the type and impact of different threats. There are also overlaps: for example, one way to interrupt computing or electricity supplies (G and E) would be through destruction of parts of the steelworks (A). The choice of categories depends on the purpose of the analysis. Either a simpler or more elaborate and qualified table of connections could be generated if desired. This depends on what level of detail is desired in the analysis of vulnerability.

The resilience of the steelworks can be examined in terms of responses to the consequences of threats. Using a process similar to the generation of consequences from the list of threats, a list of responses can be drawn up by examining the consequences one by one. Table 4 gives some major responses.

Table 4 Methods of Providing Resilience against Military Threats to the Steelworks at Port Kembla

I. Physical protection of facilities
II. Stockpiles of spare parts
III. Backup systems (electricity, furnaces)
IV. Manufacturing facilities for spare parts and backup systems
V. Backup personnel
VI. Tighter security; job satisfaction
VII. Alternative technological systems
VIII. Decentralization

Points VI, VII and VIII warrant some explanation. There are at least two ways to guard against sabotage or terrorism. One is through tighter formal security measures. The other is through a work force which is actively alert to dangers, for example in which workers are willing to report suspicious activities. Job satisfaction is likely to produce such a work force and reduce the number of workers or ex-workers willing to aid terrorism or sabotage.

'Alternative technological systems' refers to ways of running operations. This includes being able to revert to manual rather than computer-based operation and having electric steelmaking capacity.

Decentralization here mainly refers to physical dispersion of production: rather than the bulk of Australia's steel production occurring at three locations, there might be many smaller plants throughout the country, reducing vulnerability to destruction of key facilities such as Port Kembla.

A sample matrix generated from Tables 2 and 4, showing the connections between vulnerabilities and methods of providing resilience, is given in Table 5.

Table 5 Responses Which Could Be Made to Prevent or Ameliorate Consequences of Threats to the Steelworks at Port Kembla

		Responses							
		I	II	III	IV	V	VI	VII	VIII
Consequences	A	x	x	x	x			x	x
	B		x	x	x			x	
	C								x
	D								x
	E			x	x				x
	F			x					x
	G	x	x	x	x			x	x
	H					x		x	x
	I					x	x	x	x

As in the case of the matrix given in Table 3, Table 5 provides some useful insights into the connections in the methods for providing resilience. For example, decentralization provides some resilience against every listed consequence except a cutoff of imports. The same qualifying comments apply to this table as to Table 3: there are many extra points and qualifications needed to provide a full picture. Nevertheless, this table offers a useful initial picture of the relevance of various measures for providing resilience.

The feasibility or advisability of the measures for resilience is yet another matter, which could be examined through a table of requirements and cost implications.

Tables 1 and 5 are based largely on general considerations, including an awareness of the type of steelmaking operations at Port Kembla and Wollongong's and Australia's physical location and position in the world economy. To obtain a more detailed understanding of vulnerabilities and measures for resilience, it is necessary to seek a greater knowledge of technology and the work process at Port Kembla.

Two approaches are available here: direct technical examination and assessment and interviewing of informed personnel. The following discussion is based largely on interviews with key personnel.

The interviews focussed on the series of vulnerabilities listed in Table 2 and the responses listed in Table 4, with questions tailored to each interviewee's area of expertise and responsibility. People were interviewed in each of the major areas of vulnerability, and further interviews arranged by asking for further names from each interviewee (snowball sampling).

IMPORTS

The steelworks depends on a large volume and large variety of imports from overseas. How vulnerable is steelmaking to a sudden cessation of imports, for example due to economic blockade or to nuclear war in the northern hemisphere?

Imports can be put into three categories: bulk raw materials, low volume raw materials, and manufactured goods. The main bulk raw material imported is high quality limestone from Japan, about 100 000 tons per annum. Some 20 000 tons of serpentine are imported from Japan and China. Low volume raw materials now imported include alloying elements which are scarce in Australia: niobium, titanium, vanadium and molybdenum which impart toughness and strength to steel; chromium which is essential to the corrosion resistance of stainless steel. Also, about 1000 tons of tin per year are imported from Malaysia for surface coating.

A wide variety of manufactured goods are imported. Electrical equipment imported includes switchgear and machines, turbo blowers and fans. Tuyere coolers for the blast furnaces and a proportion of rolls for the mills are imported. Mechanical components imported include bearings, castings, valves, and conveyor belts. Most computer technology is imported; mainframes are supplied by IBM from the United States and Japan.

The choice between obtaining materials and goods from within Australia or overseas is almost entirely economic. When things are cheaper or higher quality elsewhere, they are imported. In most cases supply is possible from Australia but is more expensive because deposits are not rich enough or local markets are not large enough to support large-scale production. For example, specialist alloying elements could be mined in Australia, but deposits are not rich enough to be economic.

Another potential reason for importing is to cement good relations with foreign governments. For example, one BHP deal involved bartering Australian coke for Indian iron ore. This factor apparently plays only a small role in BHP's steelmaking-related imports. A potential contrary impulse would be to prefer local suppliers for military and strategic reasons, in other words, to guard against the threats that are of concern in this paper. Another pressure in this direction could come from government incentives to support local business and reduce the trade deficit. Neither of these factors appears to have played any significant role. BHP, as a private company, is driven by economic imperatives in this area, whereas a government-owned steel industry might pay more attention to strategic concerns, propping up local enterprise, or being independent of imported technology (Joseph 1984; Morris 1983; Sabel 1982, 195-205).

The major factor in recent years affecting decisions about imports has been the decline in the exchange rate for the Australian dollar. This makes imports more expensive and as a result BHP is doing more sourcing from inside Australia. Nevertheless, there remains a very large volume and dollar value of imports, creating a potential vulnerability.

If imports were cut off, production could be continued on the basis of spares, by obtaining supplies from within Australia, or by changing production or product. In any of the scenarios in which imports are cut off, the previous obstacle to local supply -- economics -- would suddenly be transformed. Previously uneconomic suppliers would become the cheapest available, or else the normal economic processes would be short-circuited by special government measures, even declaration of a national emergency. The question then would be, could steel be produced in the new circumstances, or would production be hamstrung by shortages or unavailability of previously imported goods and materials?

It is impossible to store substantial reserves of bulk raw materials because of space limitations and large usage. Therefore alternative sources of supply are required. In the case of limestone, the major bulk raw material imported, sufficient supplies could be obtained from Marulan in New South Wales, which currently supplies a proportion of limestone to Port Kembla; a rail link is available. Serpentine, used as a slag conditioner, could be obtained from within New South Wales or could be replaced by dolomite.

Some of the alloying elements might be unobtainable in Australia, at least without further mineral exploration. This might make it difficult to produce some of the more exotic grades of steel but would not hurt steelmaking in general. Small deposits of chromium exist in Western Australia and local tin, though currently uneconomical, is plentiful.

High performance refractories and components are imported. Magnesite and magnesia carbon bricks for the BOS vessels are generally made in Australia by Australian Industrial Refractories or Heat Containment, but the raw materials, magnesia and graphite, are imported. So are fireclays and binders, small but critical parts of the bricks. Components such as slide gate plates, submerged entry nozzles and shrouds, essential to the BOS and casters, are imported because local manufacturers do not have the technology necessary to produce them.

If these components and refractory imports were unavailable the continuous casters would not be serviceable, but certain mills could be recommissioned and the works revert to ingot steel production. (However, ingot steel and slab facilities will be demolished when electric steel production ceases.) Local Ardrossan dolomite bricks could replace magnesite and the old stopper rods used instead of slide gate plates.

Electrical equipment would be less of a problem. There is capacity to manufacture electrical equipment locally, though at a higher price and lower quality. Parts for turbo blowers such as turbine blades could be machined, and there are facilities for manufacturing or resurfacing most rolls, though producing the largest rolls, 80 tons, would pose a problem. Other imports such as bearings and castings could readily be produced in Australia if necessary.

In every case, the steelworks has stocks of raw materials and a supply of spare parts. By altering outputs, stocks of some raw materials such as chromium could be extended much longer than with the usual rate of consumption. The level of spares is ordinarily decided on economic grounds, striking a balance between the cost of purchasing and holding the spares themselves and the cost of loss of production should a vital component become unavailable due to breakdown or failure of delivery of new equipment. If imports were suddenly cut off, spares would keep most of the plant going for months or even years, barring a sudden run of failures. If during this time urgent efforts were made to obtain local supplies and gear up local manufacturing capability for technology normally imported, then it seems likely that production could continue without major interruption. In recent years, the steelworks has moved to a just-in-time inventory system which in many cases means a lower stockpile of spares. On the other hand, there is now more experience in fulfilling urgent orders and hence in reacting to crisis.

To be more precise about vulnerability due to dependence on imports of manufactured parts is difficult, even with more detailed study. It depends on the lifetime of existing components and spares (which could be extended in an emergency situation) and on the capability of local manufacturing to come up with alternatives. It was commonly expressed by interviewees that there is a great reservoir of ingenuity in the Australian work force and enterprises, and that an emergency brings this capacity to the fore. In World War Two Australian industry was able to 'go it alone.' Whether this would hold true in a world of greater technological integration and specialization remains to be seen.

This discussion assumes that the loss of imports is the only problem. If this were combined with some other problem, such as destruction of part of the steelworks, maintaining production would be much more difficult.

Steel production at Port Kembla is heavily dependent on computers and is becoming increasingly so. Almost all computer and electronic components are imported, and this reliance is perpetuated through sales contracts. Computer equipment is a major vulnerability in the face of a cut-off of imports. Spares provide a valuable cushion, and computer reliability is such that these might last for years. Another way to extend computer-based operations is to cannibalize old or less important computers from BHP or other companies.

Eventually, existing computers and spares would break down and the plant would be severely affected. It would be possible to revert to manual operations with a concomitant degradation of performance even in the most computerized departments such as the strip mills, the casters and the blast furnaces.

Another solution would be large-scale Australian manufacture of computer chips. Today, several companies have the designs and potential to produce chips, but there is no large-scale manufacture. It is not known whether chips suitable for industrial use could be produced quickly enough to prevent major degradation of steelmaking performance. It is clear that lack of facilities in Australia for the production of computer equipment contributes to a major vulnerability of the steel industry to a disruption of imports. Government incentives would be needed to stimulate Australian manufacture of chips in order to overcome market domination by foreign companies, if this vulnerability were to be reduced.

The following table summarizes the resilience of the steelworks to cessation of imports.

Table 6 Resiliences of the Port Kembla Steelworks against Interruption of Imports

Import	Resilience	Reasons for level of resilience
limestone	high	alternative supply locally
serpentine	high	not an essential raw material
iron ore	low	accident of location; limited rail infrastructure
alloying elements	medium	accident of location
electrical components	high	high capacity for local production
mechanical components	high	high capacity for local production
refractories	medium	limited capacity for local production
computers	low to medium	low capacity for local production; spares available

This table, while focusing on resilience or lack of it, actually emphasizes vulnerabilities, since it does not list the numerous goods and materials which are not imported, such as coal, oxygen, water and much equipment. The assessment of resilience given in Table 6 is only a rough guide; details of threats and responses would determine the resilience in an actual threat situation.

It is worth noting that resiliences against import interruption stem from a variety of sources. The carrying of spares can be interpreted as planning for the contingency of import interruption for reasons other than military threats and is motivated on economic grounds. The capacity for local production of electrical and computer equipment and strengths and limitations of the transport infrastructure reflect the social structural factors of technology and economics. In other words, evaluation of the resilience of steelworks manufacture at Port Kembla to interruption of imports cannot be divorced from wider evaluation of the Australian technological infrastructure and economic relationships. Finally, some resiliences and the lack of them are accidental, mainly due to the location of raw materials. The only major source of resilience not playing a role is that due to direct planning for military threats.

TRANSPORT

As well as imports from overseas, the Port Kembla steelworks obtains materials and goods from elsewhere in Australia. Iron ore from Western Australia is brought in by ship, some 5 to 6 million tons per annum; this is the most vulnerable of Australian-sourced materials. Shipments could be cut off by a naval blockade or mining of Port Kembla harbor. An alternative route would be overland by rail, but to provide the volume of iron ore required, such a solution would strain the existing rail capacity and be incredibly expensive. Even so, it would depend on getting the iron ore from Pilbara (or possibly from Iron Knob, South Australia) either by truck or by a newly constructed rail line. It can be concluded that the steelworks is highly vulnerable to a restriction of coastal shipping.

Supplies of other goods and materials currently brought in from elsewhere in Australia are less vulnerable to disruption. Some alloying materials such as ferromanganese and ferrosilicon are processed at Bell Bay in Tasmania, but supplies of the ores could be obtained from the mainland. Coal is readily available from mines in the Wollongong region, and other minerals and goods can readily be transported by rail, road or even air.

Wollongong is bounded by the ocean on the east and mountains on the west; there are only a limited number of access roads and rail lines. Even so, it would be difficult to block all of these simultaneously, and makeshift truck routes could be quickly restored. The city's airport handles light aircraft only, and these could land on a road if necessary.

Transport is vital to the operation of the steelworks not only to and from the works but also within the works. Internal transport is mainly by road and rail. Damaged rail lines could be readily repaired, while the internal road system has a high redundancy.

Table 7 Resiliences of the Port Kembla Steelworks against Interruption of Transport

Transport Mode	Resilience	Reasons for Level of Resilience
foreign shipping	medium to high	depends on import; air alternative
coastal shipping	low	rail sourcing of coal, limestone; surface transport capacity for iron ore severely limited
rail	low to medium	limited number of lines; trucking alternative
truck	medium to high	limited number of roads into region; ease of repair or detour
air	high	many places for small craft to land
internal rail	high	ease of repair
internal truck	high	ease of repair; multiple routes

DESTRUCTION

By its very name, an integrated steel plant can be expected to be vulnerable to destruction of particular parts. This is the case at Port Kembla, where the dropping of a large bomb on any number of key facilities would have a drastic effect. Yet, within this general vulnerability, the steelworks has some surprising resiliences to destruction. In this section the effects of destruction of some of the key facilities are described. Discussion of three especially important services, electricity, water and computing, is reserved for later sections.

Elimination of any one of the following major facilities would normally cripple an integrated steelworks: coal washery, coke ovens, blast furnaces, oxygen supply, BOS vessels, continuous casters and rolling mills.

The coke ovens, in order to run, must have washed coal. Port Kembla has one coal washery. If it were put out of action, washed coal could be bought from somewhere else. For example, there is additional washing capacity in the Wollongong area, used for coal export, and washed coal also could be obtained from Queensland. Port Kembla steel production therefore could continue even after destruction of its coal washery.

The coke oven batteries are crucial to iron and steel production. There are four batteries at Port Kembla comprising hundreds of ovens. If a battery were wiped out, it would be perhaps two and a half years before it could be rebuilt and be producing coke again.

The coke ovens are all in a row in one part of the plant. Vulnerability to destruction is therefore higher than if some had been located in a separate location. Even so, the ovens spread out over an enormous area extending hundreds of metres, and they are solidly constructed facilities, basically being metal and brick. Anything short of a nuclear explosion would be unlikely to destroy them all simultaneously.

If some ovens were put out of commission, this would not halt production. Port Kembla could stop exporting coke, and could get some from the nearby company Kembla Coal and Coke.

The sinter process was originally devised so that fine iron ores could be utilized in the blast furnace by agglomerating them and fusing them into lumps. The production of sinter has become essential to modern-day ironmaking at Port Kembla because, for economic reasons, the blast furnaces have been tuned to use sinter. If the main sinter plant were disabled, there is a backup plant which could possibly be brought on line. If no sinter production were possible, the blast furnaces would have to be reprogrammed to accommodate fines, a difficult process.

Port Kembla has five blast furnaces, of which only numbers 4 and 5 are operated today with ironmaking capacities for producing 1.05 and 2.45 million tons of steel per year, respectively. Numbers 1, 2, and 3 are smaller than number 4, and would not be economic in normal circumstances. Blast furnaces can be temperamental and it is not unusual for one of these two operating furnaces to be out of action for weeks at a time.

Blast furnaces are very large metal constructions, and a bomb would not necessarily put them out of commission. Numbers 4 and 5 are over 100 metres apart. It would take a very large bomb to destroy both in one hit. Numbers 1 to 3 are located in another part of the plant. Number 2 has been reconditioned for production but never fired. Therefore, even if numbers 4 and 5 were put out of commission, capacity would exist for iron-making, at reduced output.

Large volumes of oxygen are essential for BOS steelmaking. Port Kembla gets oxygen both from its own plant, which can supply 100% of its requirements, and from the company CIG, located literally across the street, which can supply up to 75% of its requirements. Destruction of both plants would terminate steel production, but such destruction is unlikely because they are separated by considerable distance.

The duplication of oxygen production capacity developed for economic reasons. CIG basically produces argon from air for welding and other purposes. Oxygen is easily produced as part of the process, and therefore it is profitable to take a site next to a steelmaker, the only major consumer of oxygen, even if the oxygen has to be sold at a very low price.

The BOS plant could not be easily incapacitated by bomb attack due to the solid steel construction of the vessels. Although they are not widely separated, a direct hit on each of the three furnaces would be necessary to render them inoperative.

The continuous casters and rolling mills are similarly constructed and, like the coke ovens, cover quite a large area so that complete destruction would be unlikely. But the rolling mills are set up for sequential operation, so that destruction of one part would halt production. On the other hand, rapid repair would be possible.

Table 8 Resiliences of the Port Kembla Steelworks Against Destruction of Facilities

Facility	Resilience	Reason for Level of Resilience
coal washery	medium to high	other sources of washed coal
coke ovens	medium	physical strength and scale of ovens; alternative sources of supply
gas holders	high	not essential for production
sinter plant	medium	backup plant; possible reprogramming of blast furnaces
blast furnaces	medium	physical strength and scale of furnaces; backup furnaces
oxygen	medium	two separated plants
BOS	medium	physical strength and scale of vessels
continuous casters	medium	physical strength and scale of casters
rolling mills	medium	physical strength and scale of mills
laboratories	high	separated labs; not essential for basic production

ELECTRICITY

A continuous supply of electricity is essential to steelmaking at Port Kembla, especially for powering computers, fans, pumps, machinery and producing oxygen.

A sudden interruption of electricity could have serious consequences. Some parts of the steelworks, such as the rolling mills and the coal washery, would simply shut down without major problems if electricity were cut off. In a few areas there is greater risk of damage, especially in the coke ovens, blast furnaces and BOS. Manual procedures would be adequate to shut down most coke ovens without permanent damage. A proper shut down of a blast furnace takes days. Without electricity the turbo-blower would not work, and there would be some danger of metal solidifying in the furnace, causing massive damage. Similarly, a sudden total loss of electricity to the BOS could result in solidification of steel in a vessel or casting machine, causing serious damage.

Gas mains run throughout the steelworks, carrying both natural gas and gas produced in the works itself (coke ovens and blast furnace gas). Loss of electricity to produce steam could cause loss of pressure in the gas mains, causing air to be sucked into the mains. The resulting gas-air mixture can be, depending on composition, highly explosive. Electricity thus is necessary to avoid explosions in the gas mains.

The vital importance of continuous supplies of electricity is well recognized at Port Kembla and has influenced the development of its power system. The steelworks uses a maximum of about 175 MW power, an average of about 145 MW and at low load, typically during the night or on low output, the requirement is about 100 MW. The load varies considerably in time. For example, short bursts of power of say 30 MW are drawn by the rolling mills.

The steelworks has about 60 MW of its own generating capacity, of which 55 to 57 MW is potentially available at any given time and some 45 MW is typically generated; the remainder of power requirements is drawn from the New South Wales Electricity Commission (Elcom) grid. Much of the steelworks capacity is a by-product of production; for example, high-pressure gas from the blast furnace is used to turn an alternator, producing 9 MW. The steelworks also has some diesel generators for emergency use.

The steelworks runs its own internal electricity grid. It has three buses: most secure, secure and general purpose. The most-secure bus powers those functions which are definitely not to be shut down quickly, such as the coke ovens and computers. The secure bus powers functions which, if possible, should not be shut down quickly, while the general purpose bus powers functions which can be shut down immediately with no damage, such as the arc furnace. The steelworks' own electricity supply services the secure and most-secure buses. External electricity from Elcom services the general purpose and secure buses. The steelworks' electricity supply system has a priority order for allocating power. If power supplies are suddenly reduced, the least sensitive users are cut off first, and so on.

One threat to the steelworks would be loss of Elcom power, for example, due to destruction of major generating plant or of the Springhill sub-station through which power to Port Kembla is shunted. For this contingency the steelworks is well prepared through its own power generation capacity and its secure-bus system. Even a sudden interruption of outside power would pose little threat of permanent damage to production facilities.

Whether much or any steel could be produced over an extended period of time using only internally generated power is difficult to say. It would be necessary to supply continuous power to at least some coke ovens and a blast furnace. On top of this it would be necessary to produce oxygen, run the sinter and BOS plants, the continuous casters and strip mills or rolling mills. Several measures could be taken to reduce electricity load: careful load management (scheduling of peaks in usage), cutting out production of stainless steel, and not running auxiliary services such as air conditioning. Steel production might depend initially on reorganizing production so that different electricity-requiring processes were run in series rather than in parallel as usual. One idea would be to return to production of ingots rather than using the continuous caster. But ingot reduction is power-intensive, so this may not be a useful idea. (Returning to open hearth production might not help since it also has high energy requirements, and in any case the open hearth facilities at Port Kembla are no longer available for use, having been gutted.)

Another approach, feasible over a period of months, would be to increase generating capacity. Old generators from elsewhere could be obtained and powered by natural gas, for example, if supplies were still available.

A more serious vulnerability is found in the plant's own electricity grid, but even here there is considerable protection against failures and destruction. Most electricity lines are duplicated for security purposes, and in some vital areas triplicated. The main danger is not in the power lines but in the nodes, namely, where the lines come together. There may be parallel circuits for taking electricity into a blast furnace, but if all the parallel circuits enter the furnace through the same switchboard, the board represents a vulnerability to destruction. On a larger scale, there are two main substations in the steelworks grid. So while the five lines from Elcom to the steelworks grid provide resilience against breakdown in transmission, the two substations themselves become crucial nodes. The substations are located far apart (several kilometres) to better service the load and also to provide security. If internal distribution lines were interrupted, the internal grid network would be likely to provide an alternative route for provision of electricity to key areas. The combination of more than one substation plus the internal network provides considerable resilience against attack or breakdown.

Superficially, electricity might seem one of the areas through which it would be easiest to disrupt steel production. It is precisely because continuous supply of electricity is so crucial that so much effort has been put in to provide a secure system.

One of the two main reasons for the steelworks setting up its own power generation was security of supply. In decades past, supply from Elcom was far less reliable than today. In 1949, the steelworks had plans to build an 80 MW power station to provide additional power, but in the event the newly formed Electricity Commission was able to provide this coal-powered electricity at less cost to BHP. Not only was there a saving on cost per megawatt-hour, but the Commission, with the Public Works Department, also assumed the capital outlay. In the 1950s, on-site electricity generation was increased as a security measure. As the works expanded and more internal sources of power became available, generating capacity was upgraded. The importance of internal power production was apparent in the 1970s when there were a number of blackouts on the New South Wales grid; these outages also pointed to deficiencies in the steelworks' secure bus coverage. Since then Elcom power has become much more reliable. The power shortages in the early 1980s led to predictable power shortfalls, well handled in the steelworks by careful scheduling. Since the mid 1970s the primary driving force behind additions to the steelworks grid has been the economics of saving energy. As the price of fuel oil increased and awareness of energy costs became widespread, efforts were made towards energy savings. Second-hand generators have provided a relatively inexpensive way to use this energy to produce power. For example, coal 'middlings', a normally useless high-ash fraction, have been used to help generate an extra 9 MW. But there has been no deliberate move towards self-sufficiency in power since the steelworks cannot compete in cost terms with Elcom, which supplies very cheap electricity by world standards.

In the steelworks electricity distribution system, parallel lines and built-in duplication of functions through the network are motivated by security consciousness, which ultimately is about economics, namely preventing costly failures. Continuous production processes dictate the existence of parallel lines and switches so that maintenance can occur without interruption of production. Much of the generating plant at Port Kembla is old plant acquired on retirement from Elcom. A watch is kept on BHP generating plant elsewhere in Australia, such as at Kwinana, for possible use in case of emergency.

The evolution of resilience in the electricity supply system at Port Kembla can thus be traced back to two dimensions of economics: the economic advantage of having a secure supply of electricity to service continuous production processes whose interruption would be very costly and the economic advantage in saving energy which would otherwise be wasted. Both these economic pressures have led to considerable resilience against threats which were never planned for, namely, destruction of electricity production or distribution facilities due to military attacks.

Table 9 Resiliences of the Port Kembla Steelworks against Destruction of Electricity Generation and Distribution Facilities

Facility Destroyed	Resilience	Reason for Level of Resilience
Elcom grid	medium	steelworks grid (economics)
Springhill substation	medium	steelworks grid (economics); no alternative supply from Elcom
steelworks substations	medium	steelworks grid and other substations (economics)
steelworks lines	high	maintenance and security requirements (economics)
individual plant central circuits	low to medium	cost of duplication

WATER

Both fresh water and salt water are used extensively in the steelworks; their most vital function is cooling, for example, in the blast furnaces and coke ovens. Cooling water is recycled in many parts of the works, but new supplies are required regularly to replace losses.

Salt water supplies could be interrupted by destruction of pipes and pumps but, since Port Kembla is next to the sea, it would be easy to rig up replacement equipment. The steelworks is much more vulnerable to interruption of supplies of fresh water which are required for boilers, quenching of coke and cooling of the BOS, continuous casters and rolling mills. If all fresh water supplies were cut off suddenly -- for example, through destruction of the reservoir supplying Port Kembla -- it might be possible to use salt water in some of the relevant cooling circuits temporarily, for example, in the coke ovens. But this stop-gap would eventually break down due to corrosion, perhaps in a matter of hours in the case of the continuous casters.

The steelworks is relatively vulnerable to restriction of fresh water because supplies have been highly reliable over the years, so there has not seemed to be any need to provide alternative supplies.

Table 10 Resiliences of the Port Kembla Steelworks against Destruction of Water Supply and Distribution Facilities

Facility Destroyed	Resilience	Reason for Level of Resilience
salt water pipes/pumps	high	seaside location; simple technology
fresh water pipes/pumps	medium to high	simple technology; ample supplies
fresh water reservoirs	low	usual reliability of supply

COMPUTING

Twenty years ago computing was a luxury at the steelworks, something that was peripheral to the main production processes. Today, computerization is highly advanced and continues to penetrate into every aspect of steel production. Central computing facilities work out details for operations at least daily and often more frequently; information dealt with includes volumes of materials, scheduling and chemical composition. Most major facilities have their own process computing facilities, monitoring physical and chemical quantities and providing automatic or semi-automatic control over production. Programmable logic controllers (PLCs) are used extensively, for example, in the rolling mills to quickly reprogram production patterns. Computers are also used extensively for accounting, payroll, ordering and archival functions.

Computing can be seen as just one type of technology which deals with information; others include the telephone network, radio communications and printing and photocopying equipment. Of these technologies at the steelworks, computing is undoubtedly the most important and the most vulnerable and therefore deserves special attention here.

Computer equipment could be destroyed by direct attack; computing facilities come to a halt when electricity is cut off; or a nuclear electromagnetic pulse from a very high altitude nuclear explosion could interrupt and possibly destroy many microcircuits without affecting any other part of steelworks operations (Lerner 1981; Wik et al. 1985).

The vital role of computing is well recognized at the steelworks. Computing equipment is itself expensive. The main computer building is the only one where regular security checks are made of workers and visitors, though the daily duration of this checking was reduced a few years ago for financial reasons. Backup tapes are saved in case of a crash of the central computer; transaction logs ensure that as much as possible of previous information can be reconstructed. These and other standard computer security approaches are used to limit damage caused by computer failure.

If computing facilities were suddenly unavailable, there would be two lines of action. First, replacement facilities could be brought in. If the main computer building were destroyed, a replacement computer could be brought in and installed in the basement of the nearby administration building, new wiring put in and computer operations recommenced in perhaps as little as a month.

If replacements could not be obtained, for example, due to interruptions of imports, it would be necessary to revert to manual operation. This would be difficult and costly in many cases, but it was standard practice until computers were introduced. As computerization proceeds, the skills for manual operation are gradually being lost, and so reversion will become more difficult.

In the mid 1970s there was a major fire in the control room of the BOS which destroyed its computer. In the space of a few days, with great initiative, it was possible to get production going again through ad hoc wiring and controls.

An important trend is decentralization of computing functions, and this contributes to resilience of the computer network. The move away from dependence on a single mainframe is prompted by the better response time and higher service level available with a distributed system. Computing costs are higher with decentralization, and security grounds have been secondary in this development.

If the central computer were lost, steelmaking could continue in simplified form, namely, without special grades of steel or sophisticated production planning. Even if local computers were put out of commission, production could continue. For example, the slab caster could run as long as PLCs were available, while the hot strip mill could run if restricted to basic grades of steel. In short, computing currently makes it possible to reduce prices, provide quality control and produce specialty steels in a way impossible otherwise without vastly increased labor, time and expense. In an emergency, basic steel production could continue without many existing computing facilities. The trend is towards ever more dependence on computing. Whether lower costs and increased social availability of computers, plus decentralization at the steelworks, provides sufficiently increased resilience to compensate for the dependence on computing remains to be seen.

Table 11 Resiliences of the Port Kembla Steelworks against Destruction of Computing Equipment

Facility Destroyed	Resilience	Reason for Level of Resilience
computer centre	medium	economics
local computers	medium to high	alternative systems; spares
all microcircuits	low	economics (high dependence, no day-to-day threat)

SKILLED LABOR

The vulnerability of industrial enterprises to loss of skilled labor is routinely displayed in the form of strikes. Because it is essential not to interrupt operation, the steelworks management has ensured that there are staff who can operate key facilities should waged workers go on strike. Military threats pose a different threat to the availability of skilled labor. The main danger here is killing of key personnel, for example, by a bomb dropping on a group of workers with vital skills who happen to be together in the workplace, at a meeting or on a bus.

The Port Kembla steelworks has high resilience against loss of skilled labor in this fashion for three reasons. First, the plant operates around the clock; at any given time typically some two-thirds of workers are away from the premises. Second, the plant is geographically dispersed, so that it is unlikely that a single bomb would kill all workers in a particular area of expertise. Third, there is a considerable degree of skill diversification among the work force. Many workers have experience in a variety of areas, for example, engineers, electricians, chemists, and metallurgists. In addition, in many trade areas, ranging from fitters and turners to computer programmers, outsiders could be brought in if necessary.

Perhaps the only exception to this general resilience in the area of skilled labor lies in blast furnace operators. Operating a blast furnace is a difficult operation requiring much experience and a sensitive feel for a complicated process with many degrees of freedom. Poor operation can result in a chilled hearth and major interruption to operations. It was estimated that loss of half a dozen key people would put blast furnace operations at serious risk and loss of 25 key people would mean the blast furnaces could not be run. For the reasons outlined above it is very unlikely that 25 key people would be killed by a military attack. Even in this case, operators could be brought in from Newcastle. Even in this most sensitive area of blast furnace operation, the resilience of the steelworks to loss of skilled labor is quite high. This goes to show that physical facilities rather than labor provide the key vulnerabilities to military threats at Port Kembla.

CENTRALIZATION

We have mentioned that most steel production in Australia takes place at one of three locations: Port Kembla, Newcastle and Whyalla. Such centralization of production at these integrated plants increases the vulnerability of the industry to military threats. Carefully targeted or placed bombs in the three centers would have the potential to cripple steelmaking in Australia for a considerable period. Therefore, it is valuable to examine the factors which have led to centralized, integrated steelmaking.

Steelmakers around the world have traditionally experienced cost benefits from operating large production units. Integrated steelworks, by coordinating the preparation of raw materials, ironmaking, steelmaking and the shaping of the product all on one site, were seen to achieve greater efficiency. This coordination of the essential stages of production concentrates expertise and facilitates the organization of human resources as well as enabling a more economic use of natural resources and by-products.

Vertical and horizontal integration entails the supply and transportation of raw materials, and the production, distribution and marketing by the same company. The company may own the mines and quarries, and the road, rail and sea facilities which carry the raw materials to the steelworks and then transport them to market. Such control of raw materials and transport gives the producer independence, organizational efficiency and thus economy.

So-called jumbo mills are extremely expensive to build, so full output must be maintained for economic viability. "Unless these mills stay at high activity levels, the burden of unrecovered interest charges can soon condemn the mill to a life in which it can never make an adequate return on the investment." (Hewitt 1980, 180)

The tenuous position of large steelworks was seen during the oil price rise of 1973. This, plus high inflation rates, has been blamed for the stagnation of world steel markets. Some of the newest high-technology mills are carrying capital cost charges which more than outweigh the operating cost, yield and quality advantages when compared to older mills.

One alternative to large integrated works is the 'minimill' which evolved in the 1960s (Barnett and Crandall 1986; Goldberg 1986). A minimill can be defined as "a small steelworks, melting and refining cold metal (usually but not invariably cold scrap) in an electric arc furnace and casting it into billet or slab in a continuous casting machine." (Gale 1983, 2)

The electric arc furnace has certain advantages over the basic oxygen furnace. For example, during a recession there is an abundance of scrap at a price depressed by the poor market. The electric furnace can also accommodate pig iron or molten metal if necessary. Its capacity may be up to one million tons per annum but is more often around 50 000 tons. The electric furnace can produce anything that the basic oxygen furnace produces, and is suited for small batch production.

The minimill is cheaper and easier to build, taking around 18 months compared with several years for an integrated works. Mini works can be adapted more easily to market demands, for example, by being sited near major consumers. On the other hand, minimills are restricted to a narrower range of products than integrated plants, and typically concentrate on wire, rods, and tubes. But with increasing development of the technology, it seems that minimills will begin to compete even in the areas of plate and slab (Barnett and Crandall 1986, 60-64). However, the focus here is not on economics or product range but on the resilience of minimills.

If Australian steel production, instead of being concentrated in three major integrated plants, were decentralized in 10 or 20 minimills (perhaps accompanied by smaller integrated plants), steel production would be more resilient to attacks on plants. In addition, minimills provide some added resilience against a loss of imports, since spare parts could be obtained by cannibalizing some of the mills to keep others going. By relying on scrap, minimills are less dependent on transport of iron ore, a key vulnerability of steelmaking at Port Kembla in the event of a blockade of coastal shipping.

In Australia, the decision to invest in a large integrated plant or a minimill is largely economic. In the case of Port Kembla, the decision to build there was originally influenced by the convenience of port facilities, nearby coal and limestone and a work force. Once a large integrated works has been built, it makes economic sense to continue investment in the site rather than duplicate facilities elsewhere. In other words, the physical infrastructure, representing economic investment, provides an ongoing incentive towards centralization. This can be interpreted as a form of 'entrenched technology' (Collingridge 1983).

Specialization is another factor which affects vulnerability. At Port Kembla there are plans to close the existing electric furnace, eliminate the production of steel from ingots and to import stainless steel. This measure is being taken for economic reasons; it will result in a further specialization of production at Port Kembla and in Australia, thereby reducing resilience to a range of threats.

Another influence is politics. With the rise of environmental awareness since the 1960s, there has been much more frequent opposition to industrial projects, especially in urban areas. To build a new large steelworks in an area such as Port Kembla today would be much more difficult and expensive due to environmental objections and constraints. Although there are continuing pressures to reduce pollution at Port Kembla, the baseline for objections is given by past patterns of land use and pollution rather than what is required of new developments. This provides another reason for continued investment at Port Kembla rather than in new works.

These factors are apparent in BHP's attempts to build a minimill in western Sydney. Although the motivation for this mill is primarily economic, it would at the same time be a step towards greater resilience against military attack. Siting has been vigorously opposed by local residents.

A serious program of decentralization would undoubtedly increase the resilience of the steel industry but at the expense of major economic, political and social dislocations. In present circumstances BHP could not be expected to pursue such a program by itself. Substantial government incentives or a drastically restructured economic environment would be required to bring about significant decentralization.

VOLUNTARY SLOWDOWN

There are some special cases in which it might be considered desirable to halt production of steel. If an invader conquered Australia, one aim might be to exploit its industrial capacity. Steelworks might be used to produce weapons, for example. One possible form of resistance to the invader could take the form of subtly sabotaging industrial production (Boserup and Mack 1974).

Inside, voluntary sabotage of steelmaking would be very easy. At the best of times it can be difficult to continue producing steel. Without appearing to do anything different, it would be easy for blast furnace operators to make 'mistakes', for bugs to enter computer programs or for short circuits to occur in the electricity supply. The issue here is not whether it is possible to voluntarily slow down or stop steel production in the face of military rule; it is certainly possible. The challenge would be to do this in a way that did not cause massive damage, so that steel production could be started again as soon as desired. The evidence available suggests that this also could be accomplished.

The ease with which steelmaking could be interrupted by inside sabotage or simply poor work performance -- such as 'accidentally' puncturing gas mains -- points to the key role of loyalty and commitment of workers. In normal times, workers have nothing to gain by sabotaging production, since their jobs depend on the continued viability of the steelworks. In a time of military threats, even a few workers prepared to act for the enemy could wreak havoc. It is not too much to say that potentially the single greatest vulnerability in steelmaking lies in the loyalty of the work force. Protecting against inside saboteurs would be extremely difficult and would involve elaborate security measures, which themselves might be compromised.

In practice, there has been almost no evidence of politically motivated sabotage either in peace or wartime in Australia. Steel production continued without problem during World War Two. The evidence for non-state terrorism in Australia is slight. Even in the case of the highly publicized bombing at the Hilton Hotel in 1978, no group claimed responsibility. Whatever political differences have existed in Australia, struggles over them have been nonviolent.

Maintaining or improving worker morale is important in ensuring the present low risk of insider disruption. Moves in recent years to flatten the job hierarchy may help promote worker satisfaction. Such changes have been adopted in a number of industries around the world as the technical organization of manufacturing changes (Hirschhorn 1984). Commitment at Port Kembla may be higher with the leaner work force since the major layoffs in 1982-83. On the other hand, it is hard to improve morale when, as at present, further reductions in employment are in the offing.

CONCLUSION

A study of the vulnerabilities and resiliences of steelmaking at Port Kembla provides not only information about this particular plant but also insights about technological systems in general. The approach used here is to enumerate possible threats (military threats in this case) to the steelworks and then focus on specific areas of potential vulnerability and ways to overcome likely consequences of the contingencies considered.

The value of considering a set of threats for which no preparation has been made is that it shows the extent to which integrated steelmaking technology at Port Kembla serves purposes for which it was not designed. This provides a way of approaching the question of the neutrality of technology.

The answer to this question is bounded by two extremes. On the one hand, a technology could be 'neutral' in the sense that it can be used for any purpose, or equally for good or evil. No technology fits this idealized picture: the Port Kembla steelworks, designed for flat products, could readily be adapted to produce rails, would have great difficulty casting 80-ton work rolls, and, of course, would not be able to produce aluminum. On the other hand, a technology could be so totally the product of its design that it is unable to have any other use. Few if any technologies fit this picture either: the Port Kembla steelworks, through its plants and workshops, can produce oxygen and electrical equipment, for example, though that is not its primary purpose.

The study of the origins of vulnerabilities and resiliences provides a means of going beyond these two simplistic notions about technology. The steelworks is resilient to military threats in a number of important respects even though it was not designed for this purpose. The resiliences of the steelworks to military threats arise from an overlap of purposes between the requirements for such resilience and the requirements for producing steel in Australia in the context of the Australian and world market. Economics is a key factor linking these two domains. For the continuous process of steelmaking, in which sudden shutdowns can be exceedingly costly, it makes economic sense to develop highly secure services. For example, electricity, which might in other circumstances be a highly vulnerable feature, is relatively resilient even to major military threats.

The study of the vulnerability of steel production reported here is necessarily incomplete, because the vulnerabilities of interacting technological systems are interconnected. In order to assess fully the vulnerabilities in integrated steelmaking, it would be necessary to carry out studies of related systems, in particular computing, electricity and manufacturing in Australia. For example, the vulnerability of the steelworks to an interruption of imports depends on the corresponding vulnerability of manufacturing capacity elsewhere in Australia, which might produce equipment for Port Kembla, to interruption of imports. Conversely, a study of vulnerabilities of non-steel manufacturing in Australia would require the results such as reported here, since steel is such a fundamental material in manufacturing.

A full understanding of the vulnerability of steel production would also require a better knowledge of some of the threats. For example, it is unclear whether a nuclear electromagnetic pulse would permanently damage many microcircuits.

Finally, a full assessment of vulnerability of steel production also requires more knowledge of what responses would be taken in the wider society. In particular, what would steel be used for in the circumstances? It would be necessary to know how much steel was needed and exactly what types. This would depend on the state of the surviving population and industry.

As mentioned earlier, high resilience is not necessarily an important goal in itself, since the benefits it provides may not warrant the costs of achieving it. But if it is desired to move in a direction of greater resilience -- and resilience to economic disruptions could prove more important here than resilience to military threats -- then there are quite a number of implications that could be drawn from this study. Aside from specific points raised in the text, an important general point is that resilience is not achieved by completely eliminating threats; this is impossible anyway. The greatest preparations have been made in areas such as electricity where interruptions have occurred. Other areas where there have been no notable problems, such as water supply and coastal shipping, are potentially quite vulnerable since no contingency plans have been made. The general implication is the familiar one that learning requires experience and failures.

APPENDIX: STEELMAKING

Steelmaking is fundamentally a process which reduces iron ore to metallic iron by smelting (melting and extracting impurities) at about 2000°C in a blast furnace. The iron is then refined using oxygen in the Basic Oxygen System (BOS) furnace to further remove impurities and carbon. Alloys are added according to the grade or type of steel required. At a specified chemical composition and at about 1600°C, the furnace is tapped: the metal is drained out. The steel is then ready to be rolled or shaped to suitable dimensions.

The main raw materials used for ironmaking are iron ore, coal and limestone. Iron is rarely found in its natural state but in the form of iron ore is quite common, comprising approximately 5% of the earth's crust. Iron ores are mainly oxides, namely chemical compounds of iron and oxygen, often mixed with other oxides of phosphorus, silicon, manganese and sulphur. Ores such as hematite, magnetite and limonite have different compositions and combinations of oxides and the proportion of iron varies considerably, but the predominately hematite ores of Australia are high grade at around 60% iron.

The ore is usually drilled and blasted from the surface of 'open cut' sites, crushed, screened and blended and then shipped by bulk carrier to the steelworks. The ores are not always suitable for direct use in the blast furnace: if too fine, they will tend to restrict the flow of air and gases through the furnace charge or burden. Therefore, only lumps of 6mm to 30mm size are used. Smaller-sized particles, called 'fines', are roasted with coke, limestone and millscale to form an aggregate or sinter which can be used in the blast furnace.

Coal is the main source of energy in the manufacture of iron and steel, but for greater efficiency it must be converted to metallurgical coke. After removing non-combustible matter by washing, the coal is blended and pulverized, then heated in the absence of air for about 16 to 20 hours at 1000°C. Gases, liquors and tars are driven off leaving a strong porous residue of coke with 80% to 90% carbon content. The by-products are quite valuable. They contain tar, ammonia, naphthalene, benzol and a gas which may be used throughout the works for heating purposes.

This metallurgical coke produces heat for smelting, provides carbon monoxide for ore reduction, and also is strong enough to help support the furnace contents or burden, thereby allowing free flow of air and gases.

Limestone helps remove impurities from the ore by acting as a 'flux.' A flux is a scavenger, chemically combining with impurities such as phosphorus and assisting in their transfer from the metal in the blast furnace to a liquid slag floating on top.

To make 10 tons of iron requires about 16 tons of ore, 6 tons of coke, 1.4 tons of limestone and 20 to 30 tons of preheated air. The process is virtually continuous as the raw materials are introduced or 'charged' by skips (conveyors) into the top of the furnace while a hot air blast is injected near the bottom.

Temperatures of around 2000°C are achieved in the melting zone of the furnace by the combination of hot air blast and the burning coke. This heat plus carbon monoxide from the coke reduces the iron oxides to metallic iron which sinks to the furnace hearth along with the molten slag. Every few hours the molten metal is run off at about 1500°C into ladles for transfer to the steel furnaces.

Impurities such as phosphorus and sulfur are only partly removed in the ironmaking operation and the carbon content of the iron is usually around 3%, but during steelmaking these impurities are almost completely eliminated and the carbon is adjusted to within specified limits for specific purposes.

The BOS (Basic Oxygen Steel) process uses high purity oxygen to oxidize (combine with) the impurities as well as the relatively high percentage of carbon in the iron. The furnace is a barrel-shaped vessel open at the top and lined with thick refractories (heat-resistant materials which do not react with the iron). The furnace is tilted and charged with 15% to 25% scrap before the molten iron is added, then, back in the upright position, a water-cooled tube or 'lance' is lowered to just above the surface and oxygen is blown at high velocity onto the metal.

Oxygen combines chemically with the carbon and the impurities in the metal and facilitates their removal as gases and/or their absorption into the slag. Burnt lime helps control this violent heat-producing reaction and assists in slag formation, which helps to remove impurities.

The 'oxygen blow' (blowing of oxygen into the iron) is continued for about 20 minutes until the charge is homogeneous at about 1600°C and the carbon and impurities are at acceptable levels. The vessel is then tilted to tapping position so that the molten steel flows into a ladle below, where ferro-alloys are added to specification. Alloying additions such as ferromanganese and ferrosilicon along with carbon in specific quantities impart certain characteristics to the finished steel such as hardness, toughness and tensile strength.

BOS furnaces range from a few tons to 400 tons capacity and are capable of steelmaking cycles of about 30 to 40 minutes. They are ideally suited to produce low carbon steel, especially for flat products such as plates and hot or cold strip.

The electric arc process is another way to produce carbon steel. Because this method permits extremely close control of temperature and oxidation it is ideally suited to the production of high alloy and stainless steels. The charge usually comprises 100% scrap of a composition compatible with the required specification.

In the electric arc furnace, heat is generated by passing an extremely high current through carbon electrodes suspended above the metal. The gap is only a matter of centimetres and voltage around 200 V to 700 V. The enormous current of between 50 000 and 150 000 amps produces a temperature of 7000°C within the arc. In this way, the scrap is melted and carbon and other elements are oxidized into the slag, assisted by burnt lime and fluorspar, and driven off as gases with the aid of oxygen.

Alloying elements are added to the furnace to bring the steel to the desired composition before being tapped into ingot molds of the appropriate size for rolling. Furnace capacities range from a few tons to 360 tons and production cycles vary between 2 and 6 hours depending upon grade.

The steel may then be teemed into ingots of up to 30 tons in weight and heat-soaked in pit-type furnaces for a few hours to achieve a uniform rolling temperature. At about 1130°C the ingot is passed between a pair of rolls and reduced in thickness, correspondingly lengthened, and shaped as it passes through. This process not only shapes the steel but also improves its internal structure giving greater toughness and tensile strength.

This stage, from teeming to primary rolling, may be eliminated by continuous casting where the steel passes from a tundish through a water-cooled mold of the appropriate dimensions, and then cut to length ready for final shaping. By eliminating the primary steps, continuous casting represents substantial cost savings in time, materials and energy as well as a superior surface finish and homogeneity inherent in the technique.

Steel products may be in the shape of plate or strip, rod or wire, beam or pipe, each having a distinctive chemical composition but all derived from the same raw materials and passed through similar stages of reduction and refining.

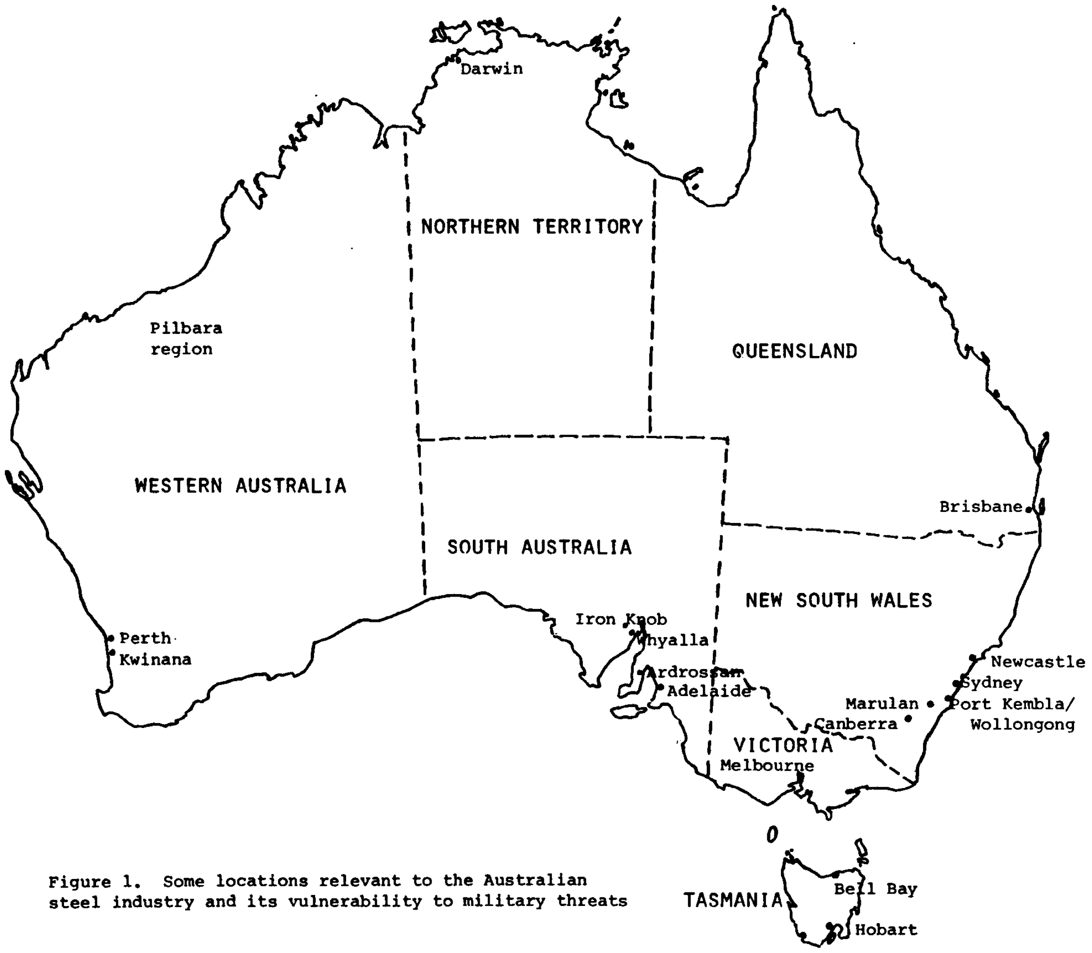
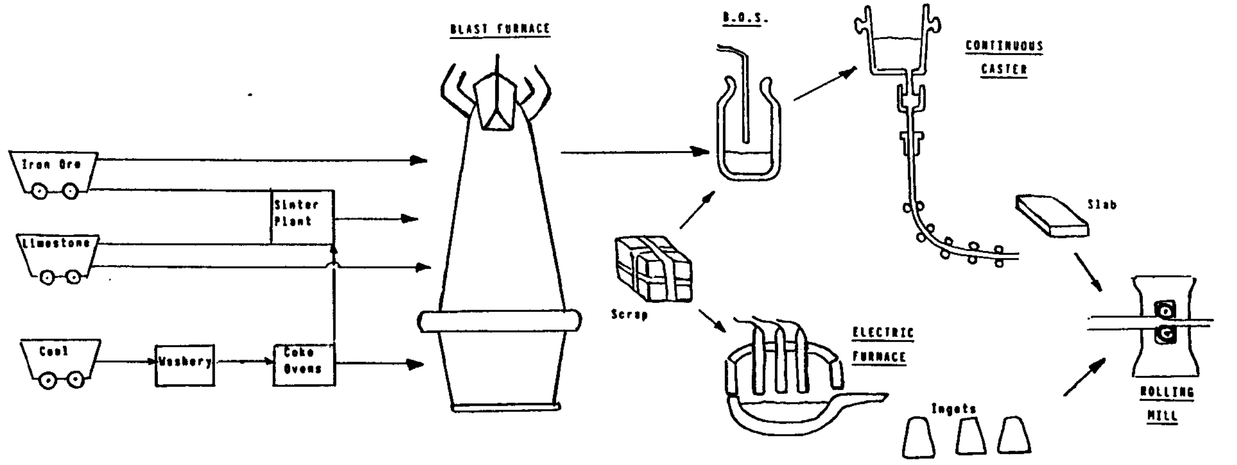


Figure 1. Some locations relevant to the Australian steel industry and its vulnerability to military threats



COKE OVENS	SINTER PLANT	BLAST FURNACES	BASIC OXYGEN STEEL	ELECTRIC FURNACE	CONTINUOUS CASTERS
(3A, 4,5,6,7A batteries)		(Nos : 4 & 5)	(3 Vessels)	(50 tonnes)	(Nos : 1 & 2)
Annual Capacity	Annual Capacity	Annual Capacity	Annual Capacity		Annual Capacity
	6.3 million tonnes	3.14 million tonnes	4.2 million tonnes		4.1 million tonnes

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