Ferro Alloy Industries in the Liberalised Economy
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Optimisation of Ferro Alloy Usage in Steelmaking

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ABSTRACT

Ferro alloys constitute one of the most expensive inputs to steelmaking. Their contribution to cost depends on the type of steel. However, with respect to the product mix of a typical Integrated Steel Plant, it amounts to 7–10% of the cost of saleable steel. Optimisation of ferroalloys not only involves minimising specific cost but must also address to the issues of customer satisfaction. With the progress of knowledge in the area of material science and growing competition, subjects like residuals in ferroalloys are gaining importance. The task of optimisation is multifaceted and requires actions in a number of areas like (i) steelmaking practice – deoxidation, slag–carry over, etc., (ii) quality of ferroalloys – chemistry, size, residuals, (iii) cost affective design of steel, (iv) downstream processing of steel – heat treatment, etc., (v) Selection of ferroalloys, and (vi) Distribution and control within the plant. The paper discusses the above aspects based on information/data from real-life situations.

Keywords : Ferro alloys, Steelmaking, Optimisation, Steel.

INTRODUCTION

Ferroalloys constitute one of the most expensive inputs to steelmaking. Their contribution to the total manufacturing cost of steel depends on the kind of steel in question, viz., alloy, plant carbon, etc. Corresponding to a typical product–mix of Integrated Steel Plants, ferroalloys account for 5–10% of the cost of steel. Typical costs on account of ferroalloys for various categories of steel are presented in Table 1A. The Indian ferroalloy costs, 1995-96 are shown alongwith Table 1B for reference.

Ferroalloys are used during steelmaking for various purposes. A look at Table 2 would give a summerised picture. It may be noted that the term 'ferro alloy' in this paper includes all metallic/nonmetallic additives to liquid steel in addition to the conventional ferroalloys.

Table IA : Contribution of ferroalloys to saleable steel cost—indicative examples

Category	Cost of Saleable Product %
Low alloy steels (less than 2% alloy content)	15—30
Low, Medium and high carbon continuous cast billets	5—10
Microalloyed high tensile steels	10—15
Mild steels	3—5

Table IB : Indian ferroalloy cost, April '96

	Rs. per tonne
Low Carbon FeCr	65265
High Carbon FeCr	30820
High Carbon FeMn	19670
Med. Carbon FeMn	41110
Silico Manganese	21294
Ferrosilicon	34283
Ferrotitanium	88500
Ferrovanadium	313800

Table 2 : Additives to liquid steel

Purpose	Ferro Alloys	Unalloyed Metal/Element
Alloying	FeMn, SiMn, FeSi, FeCr, FeP, FeMo	Ni, Cu, carbon*
Deoxidation	FeSi, SiMn, CaSi, CaFe, FeAl,	Al
Reboil in open hearth	FeMn	
Micro alloying, grain refinement & other metallurgical reasons	FeTi, FeNb, FeV, FeAl, FeB	Al S (iron Pyrite)
Traceability of sale-able products	FeCr, FeV, FeMo	Cu

* Petroleum Coke

The question of 'optimisation' of ferroalloys involves minimising the specific cost of ferroalloys (i.e., cost of ferroalloys per tonne of steel) subject to the condition of satisfying the need of the customers. The customer need ranges from adherance to the chemical specification to the attainment of mechanical/metallurgical properties in the steel. Sometimes, some of the special requirements do not form a clause in the documented specification but remain as a strong parameter that influences the level of satisfaction. Any exercise on optimisation of ferroalloys must not overlook this aspect. The subject of optimisation of ferroalloys thus covers several areas from shop floor steelmaking to procurement strategy of ferroalloys; from quality of ferroalloys to meeting the stated and implied needs of the customers. The paper deals with the subject of optimisation along the following lines :

* Influence of steelmaking practices
* Quality of ferroalloys
* Design of steel
* Down stream processing of steel
* Selection of ferroalloys
* Distribution and control within the plant

INFLUENCE OF STEELMAKING PRACTICE

The process of steelmaking as well as the very practice of steelmaking adopted in a shop substantially influences the consumption of ferroalloys.

Role of Dissolved Oxygen

Uncontrolled levels of dissolved oxygen in steel at tap leads to loss of deoxidisers and also oxidisable alloys like silicon, manganese, chromium, vanadium, niobium and titanium. With reference to the Basic Oxygen Converter or LD Process of steelmaking, the ways and means available to restrict oxygen level at are :

* Avoidance of reblow
* Post–blow stirring through bottom elements
* Upkeep of tap–hole/use of improved tap hole technology such as iso–jet system [1] to maintain sound geometry of stream.

The effect of controlling the above can be dramatic on the consumption of ferroalloys. For the same carbon level, say 0.05%, the dissolved oxygen can vary

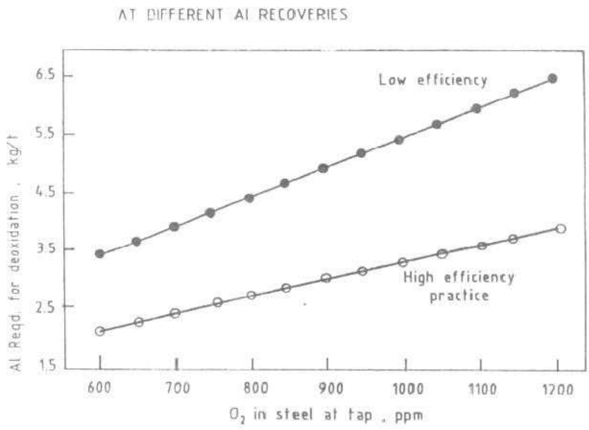

Fig. 1 : Consumption of Al as a function of desolved oxygen at tap

as much as from 600 ppm to 1100 ppm depending on the steelmaking practice (with respect to the points listed above). Referring to Fig. 1, the consumption of aluminium becomes double with a change like this [2].

The recovery of silicon and manganese while making a non–aluminium killed steel, represented in Fig. 2, also highlight the importance of controlling dissolved oxygen.

Slag Carry–Over

Slag carry–over from the steelmaking vessel into the ladle has a distinct effect on ferroalloy consumption. As in the case of LD converter, open hearth or EDF the steelmaking slag with 18 to 25% iron dissolved in it as oxides, is intensely oxidising in nature. Carry over of large amount of such oxidising slag adversely affects the recovery and hence consumption of ferroalloys in the following way:

* Influx of oxygen into deoxidised steel which eats up alloys.
* Physical entrapment of alloys in carried–over slag.

The technology of preventing slag carry over using various slag stopping mechanisms are available. Disciplined use of slag stopping system helps reducing consumption of deoxidiser and also of other ferroalloys.

Raking of slag from steel ladle is also practised in some plants. A practical method of assessing the extent of slag carry–over is the phosphorous reversal.

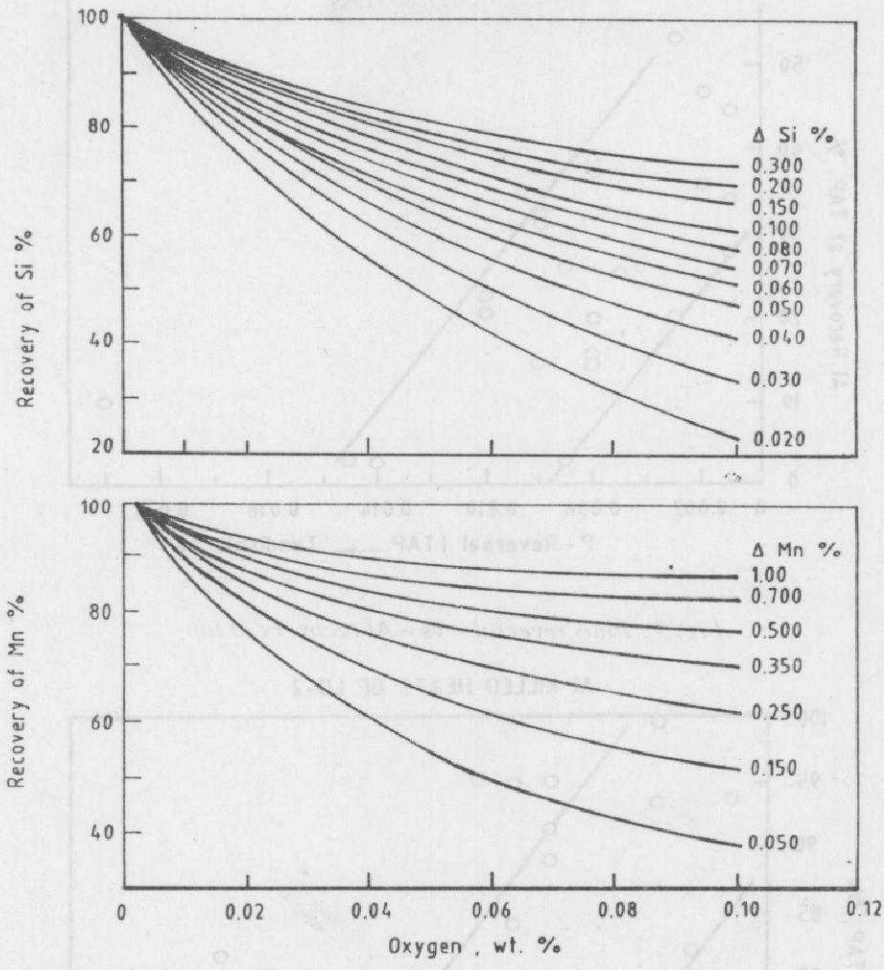

Fig. 2 : Recovery of Si and Mn as a function of oxygen content of the bath

These two are proportional to each other. Recovery of aluminium and manganese when plotted against phosphorous reversal, Fig. 3, 4 showed strong relationships indicating that slag carry–over significantly influences consumption of deoxidisers and ferroalloys. In the LD Shop No. 2 of Tata Steel where mostly aluminium killed heats are made, the aluminium consumption has been significantly brought down, (Fig. 5). This has been achieved by controlling dissolved oxygen and slag carry–over through the measures discussed above.

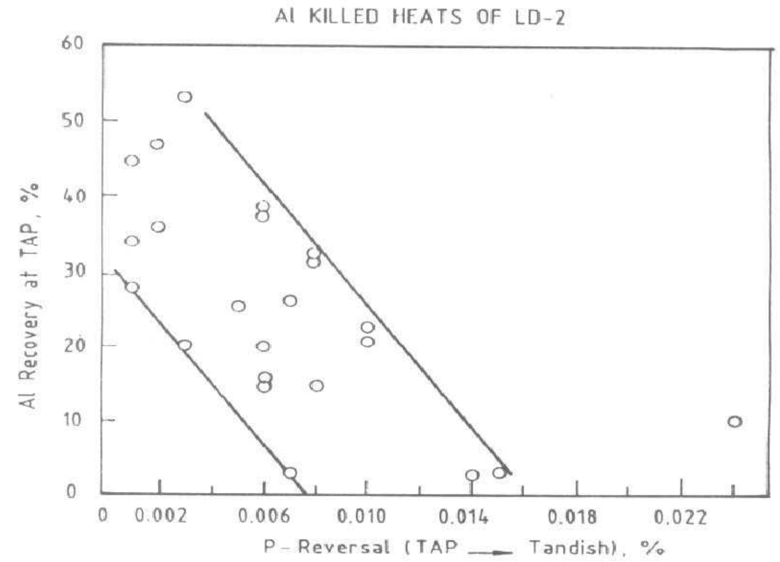

Fig. 3 : Phos reversal – vs – Al recovery at tap

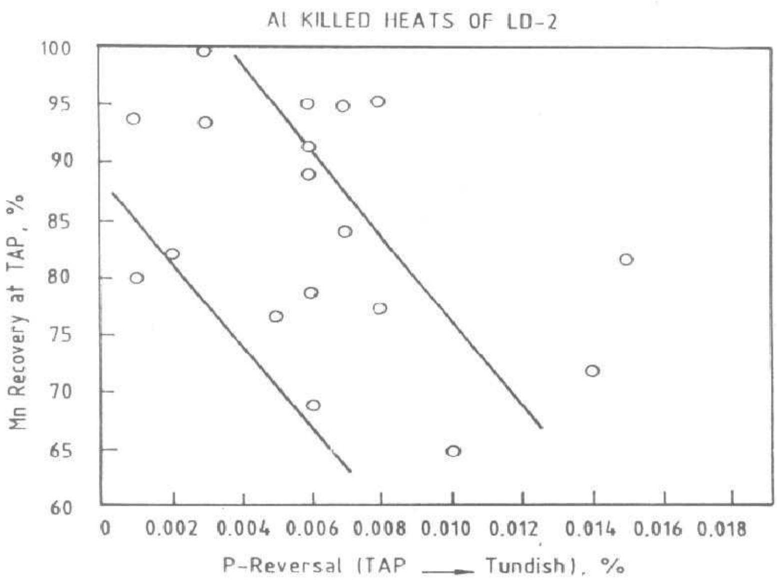

Fig. 4 : Phos reversal – vs – Mn recovery at tap

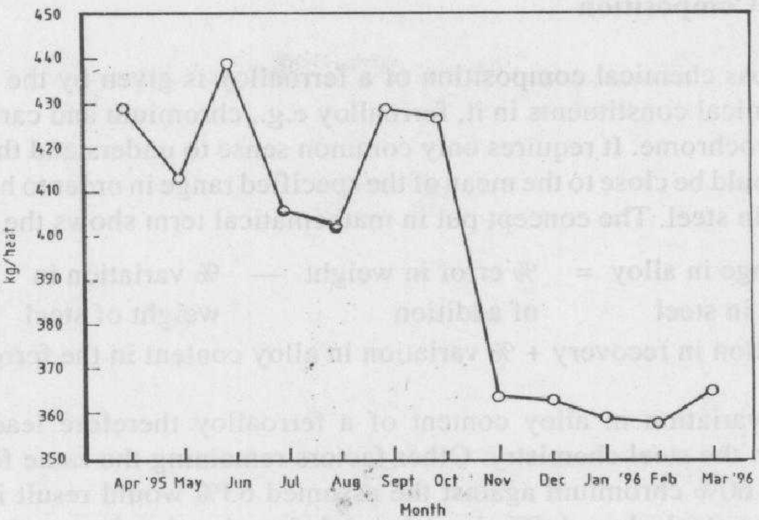

Fig. 5 : Decrease in aluminium consumption in LD Shop No. 2 Tata Steel

Practice of Ladle–Addition

The producer of addition of deoxidiser and ferroalloys into the ladle during tapping has a bearing on their recovery and consumption. Years of experience suggests that the highest and most consistent recoveries are obtained when the additions are completed during the time the filling of ladle is 33 to 66%. The number 33 and 66 are somewhat approximate, but it means that any addition made initially when the gush of stream first falls or when the last bit of liquid is emptied out into the ladle, the recovery is poor and erratic. Ladle degassing facilities are available in most of the steel shops having special steels in their product–mix. The recovery from additions made in the ladle while it is in the degasser is consistent and free of the above mentioned variations.

QUALITY OF FERROALLOYS

The quality aspect of ferroalloy is gaining more importance than ever, mainly because of stringency in the specification of steel. Also, quality of ferroalloy, as it will be seen during the discussion, has lot to do with its specific consumption. The quality parameters of a ferroalloy can be classified under the following heads.

- Chemical composition, gross
- Chemical composition, residuals
- Size

Chemical Composition

The gross chemical composition of a ferroalloy is given by the contents of major chemical constituents in it, ferroalloy e.g., chromium and carbon in high carbon ferrochrome. It requires only common sense to understand that the alloy content should be close to the mean of the specified range in order to hit the aimed chemistry in steel. The concept put in mathematical term shows the following :

% Change in alloy content in steel	=	% error in weight of addition	—	% variation in weight of steel

+ variation in recovery + % variation in alloy content in the ferroalloy

A 5% variation in alloy content of a ferroalloy therefore leads to a 5% variation in the steel chemistry. Other factors remaining the same ferrochrome containing 60% chromium against the assumed 63% would result in a 7 point variation in a steel where 1.4% chromium is being aimed at. In a grade where, say hardenability is to be guaranteed, this can lead to off chemistry/defective steel. Closeness of chemical composition of ferroalloy directly helps to comply to the steel order in case of primary steelmaking. Where secondary steelmaking facility is available (like ladle furnace or vacuum furnace) such a ferroalloy helps the steelmaker to avoid the trouble of multiple trimming addition and sampling before casting.

Residuals in Ferroalloys

The residuals in ferroalloy which are important under the present steelmaking scenario are sulphur, phosphorus, silicon, titanium, chromium and nitrogen. The problems with sulphur and phosphorus are easy to understand because the allowable limits have become quite low in almost all types of steel. For instance, high phosphorus content in ferromanganese often results in downgrading in manganese bearing restricted phosphorous steels.

Similarly, the ferrochrome used in titanium restricted grades like ball bearing steel must have very low levels of titanium. Titanium is often restricted to 30 ppm in ball bearing steels in order to keep it resistant to roll–contact fatigue. Steels used for deep drawing or for electrode quality wire rods require restriction on silicon level. Aluminium or ferromanganese used in such heats, therefore, must have low silicon content. Several special steels are, now–a–days, have an upper limit on nitrogen and thus the nitrogen level in ferroalloys have become important. For instance, chrome–moly based creep–resistant steels used in power plants, require a nitrogen limit of 70 ppm to be observed. One has to select the proper source of low nitrogen ferrochrome. In several other grades of steel, like steels for wire drawing of Extra Deep Drawing grades, nitrogen has to be restricted to levels as low as 30 ppm to satisfy the customer because nitrogen affects wire durability as well as deep durability. The steelmaking operation for such grades are controlled to keep nitrogen levels very low. The relative contribution of nitrogen from ferromanganese, petroleum coke, etc., in such a case is substantial. Hence nitrogen content of these additives becomes an acceptance criterion. Recently, the allowable nitrogen content of petroleum coke has been stipulated in order to guarantee low nitrogen levels in high carbon wire rods made at Tata Steels. Uncontrolled residuals in ferroalloys cause downgrading of steel and adds to the specific cost of ferroalloys.

Size Specification

Size of ferroalloys is an important physical characteristics to be considered. Whist the fines are oxidised easily or entrained in slag, oversize pieces of ferroalloy may stop the flow through the chute. Also, large pieces of ferroalloy, as common sense suggests, requires longer time of dissolution. However, a deeper understanding in this area is needed to arrive at the correct size specification of ferroalloys. A relaxed specification leads to problems in steelmaking whereas an unnecessarily narrow size specification raises the cost of ferroalloys.

Mechanism of Dissolution

The ferroalloys can be divided into two broad categories depending on whether the melting range of the alloy lies below or above the freezing point of liquid steel. Ferroalloys like ferromanganese, silicomanganese, ferrosilicon, etc., are included in Class I because the melting ranges of these are below the freezing point of steel. Ferroalloys like ferrovanadium, ferroniobium, ferromoloybdenum have melting ranges above that of steel and hence categoried in Class II ferroalloys, Table 3 [3].

The mechanism of dissolution of Class I and II ferroalloys are totally different. As a cold piece of ferroalloy is immersed in liquid steel, a frozen layer of steel forms on its surface. The layer than melts and exposes the piece. In case of Class I alloys, the dissolution process is rapid. In case of Class II, however, the process of dissolution is slow and controlled by the rate of mass transfer between solid and liquid. It is thus obvious that larger sizes can be afforded in case of Class I ferroalloys whereas the size has to be restricted in case of Class II ferroalloys. Since the dissolution of Class II ferroalloys is essentially a mass transfer controlled process, stirring in the liquid steel bath accelerates the process of

Table 3 : Class – I and Class – II ferroalloys

Class – I Ferro Alloy	Class – II Ferro Alloy
FeMn	FeNb
SiMn	FeV
FeCr	FeW
FeSi	FeMo
Cu	
Ni	
Al	

dissolution. A larger size of Class II ferroalloy can only be afforded, if the Melt shop has adequate facilities for stirring in ladles. Mathematical models are available for Class II ferroalloys [4,5]. Supported by some plant–scale validation studies, these can form the basis of size specification.

DESIGN OF STEEL

Often the customer requires a steel with a very wide or even open ended chemical composition but insists on closely controlled mechanical/metallurgical properties. For instance, a customer catering to automobile industry may require a steel corresponding to SAE 8620 grade which has a liberal chemistry latitude but specifies that RC 35 hardness is attained at 6 mm from the quench end in the Jomminy test. The steel therefore has to be specially designed and while designing one must take into account the cost of ferroalloys and work out the least expensive chemistry.

In many microalloyed steels the customer does not specify the levels of microalloying but requires guaranteed metallurgical properties like grain size, or cupping value, impact properties, etc. Flexibility is often available to use a combination of microalloys or a cheaper microalloy and economise on ferroalloy cost. As for example, a conventional niobium bearing steel for seamless tube making has been successfully made with titanium + vanadium. Steels for high strength reinforcing bar has been successfully made with vanadium during shortage/high price of ferroniobium.

With various measures taken in steelmaking (as discussed before) and quality control of incoming ferroalloy, it has been possible to bring about marked improvement in the consistancy of recovery. Once consistency is achieved, it becomes possible to shift the aimed alloy content to lower values. Recently, a substantial saving has been accrued at Tata Steel by lowering the aimed manganese level in structural steels and lowering the aimed niobium level in micro alloyed LPG steel.

DOWNSTREAM PROCESSING OF STEEL

Improvement in the downstream processes sometimes result in reduced consumption of ferroalloys. Silicon bearing electrical sheets are produced at Tata Steel through the conventional 'open hearth – ingot casting – primary rolling – finish rolling – annealing' route. With the help of Quality Improvement Project taken up in the annealing operation at Sheet Mills, the watt loss characteristic of annealed sheets underwent a favourable change. Consequently it was found that to maintain a particular grade or grades (with respect to watt loss characteristics) less amount of ferrosilicon requires to be added in the steelmaking stage. Upto 20% reduction in ferrosilicon addition could be achieved with this improvement in the annealing process. Similarly, refinement brought about in the Thermo Mechanical Treatment (TMT) line for reinforcement bars, The ferromanganese consumption in steelmaking could be reduced.

SELECTION OF FERROALLOYS

Flexibility often exists in selecting a set of ferroalloys to make a particular grade of steel. For instance, a steel containing silicon and manganese can be made with a combination of (a) ferromanganese and ferrosilicon, (b) ferromanganese, silicomanganese and ferrosilicon, (c) ferromanganese and silicomanganese. Out of these three combinations (c) become the least expensive because silicon from silicomanganese is significantly cheaper compared to silicon from ferrosilicon. There are many examples where expensive low carbon ferroalloys like low carbon ferrochrome or low carbon ferromanganese has been replaced partly or fully by medium/high carbon ferroalloys. Incidentally, silicomanganese which contains about 2% carbon (same as other medium carbon ferroalloys) can be, in certain cases, an economic replacement of medium or low carbon ferromanganese.

Sometimes, the form in which the alloy is commercially available has a bearing on the cost–effectiveness. For example, aluminium ingots weighing 10 to 12 kg is about 10% less expensive than aluminium notch bars of 1 kg weight. With a slight modification in the handling and addition procedures, switching over to aluminium ingots from aluminium notch bars gives rise to handsome savings.

DISTRIBUTION AND CONTROL WITHIN THE PLANT

Ferroalloys are the most expensive raw materials which have to be handled in bulk within the boundary of the steel plants. Generally, there is a central ferroalloy stores from where these are issued to the steel Melt Shop(s) on a daily/weekly basis. Within the steel shop, the ferroalloys are kept in a strong room/bay and taken out for additions. A poor handling and storage practice leads to losses due to spillage and contamination. Also, ferroalloys are prone to pilferage. System improvement and investments in these area can result in recurring savings and reduction in gross specific consumption of alloys.

CONCLUSIONS

1. Optimisation of ferroalloy usage involves minising the specific cost of ferroalloys per tonne of steel subject to the condition of meeting the stated and implied needs of the customers.

Table 4 : Routes to optimisation

Broad Area	Specifics
Steelmaking	Control on dissolved oxygen at tap
	Control on slag carry–over. Practice of ladle addition
Quality of Ferroalloys	Gross chemical composition, Residuals size.
Selection of Ferroalloys	Combination of FeMn, FeSi and FeSiMn. Partial/full replacements of low carbon ferroalloys.
Design of steel	Least–cost chemistry to meet hardenability specification.
	Least–cost microalloying
	Lower aim–chemistry (taking advantage of improved consistency)
Downstream processing of steel	Improved heat treatment e.g., annealing, quenching leads to reduced consumption.
Distribution and control	Elimination production of spillage, contamination and pilferage.

2. The task of optimisation is multifaceted and requires actions in a number of areas from steelmaking proper to improvement in downstream pro-

cesses. The table presented below summarises the discussions on such areas made in the paper (Table 4).

The points discussed are some of the essentials of the game. There is no end to inncvations and therefore by no means should the paper be considered to have frozen the scope of optimisation.

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