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Four Stage Scheduling of Steel Making using Earliest Deadline First Algorithm

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Abstract: Steel production (Steel Making, Rolling Process) is an extremely complex process and determining coherent Schedules for the wide variety of production steps in a dynamic environment, where disturbances frequently occur, is a challenging task. In the recent steel scenario, the heats directly sent to Rolling mills for rolling it into finished products directly after casting in continuous casting machines. In this scenario it is always important to schedule the heats from converter to rolling Mills encompassing argon Rinsing Station, Continuous casters. In this paper, authors have focused on the average waiting time, deadline deviation for each heat produced and rolled, so that all the heats will be targeted to produce with minimum waiting and without deadline time deviation. The earliest Dead line first algorithm was used to schedule the heats in each stage of the production to achieve least deviation of dead line and reduction in average waiting time. The results are compared with other conventional scheduling methods First Cum First Scheduling (FCFS), Shortest Job First (SJF) scheduling methods. Better results have been achieved with EDF algorithm.

Key Words : EDF, Steel Making, Three Stage Scheduling

Introduction:

In the steel making Industry, Steel is produced from Hot metal received from Blast Furnaces. The hot metal contains impurities like Carbon, Silicon, and Manganese etc. The Hot metal is refined in LD converters by blowing oxygen and adding scrap. The steel so produced is rinsed in Argon Rinsing stations to make clean and homogenized steel. The homogenized steel cast into blooms/billets/rounds in continuous casting machines. In the continuous casting machines the steel ladle is kept on turret and allowed to pour in a tundish. Tundish is having bottom nozzles which are submerged in bottomless moulds. The steel partially gets solidified in the copper moulds and the solidified steel is continuously drawn out. The different type of shapes and sizes are produced in the continuous casting machines and these are blooms/billets/rounds. These are further rolled in Rolling mills to produce finished products like wire rod coils/structural/angles/channels etc.

In the rolling mills the heats/jobs are heated to around 1000 deg C in the Walking Beam Furnace. The temperature depends on the grade of the steel. After soaking the blooms in the furnace the blooms/billets are rolled in the roller stands to finished products. The number of stands and rolling passes are depends on the finished products. The type of cooling (water/air) and the speed of cooling determine the mechanical properties of finished product and in turn the grade of the steel. The processing times depends on the grade of steel and product profile to be produced. In some of the steel plants there are two to three rolling mills of similar products manufacturing.

The total steel making process involves the following important steps.

1. Blowing of Hot metal in LD converter about 150 tons of steel is produced
2. In the Argon Rinsing Stations the Steel is rinsed to homogenize the steel and to kill the steel to remove the oxygen content. Sometimes temperature of the steel is raised to meet the requirement of casting. Generally about $50^{o}C$ super heat is maintained in the steel above liquidous temperature based on the carbon equivalent
3. In the Continuous Casting Machine (CCM) Liquid steel is cast into Blooms/Slabs/Billets by pouring steel into bottom less moulds and drawing the semi solidified blooms out and cut into required length in a gas cutting machine.
4. Rolling to finished products in Rolling Mills.

Steel production is an extremely complex process and determining coherent Schedules for the wide variety of production steps in a dynamic environment, where disturbances frequently occur, is a challenging task. The scheduling system of the steel processes has very different objectives and constraints, and operates in an environment where there is a substantial quantity of real-time information concerning production failures and customer requests. The steel making process, which includes steel making followed by continuous casting and rolling is generally the main bottleneck in steel production. Therefore, comprehensive scheduling of this process is critical to improve the quality and productivity of the entire production system.

Depending upon the hot metal quality and the scrap added the treatment time of the hot metal in LD converter varies. The homogenization time in Argon Rinsing time varies depends on the dissolved oxygen content and amount of slag entrapped in the steel. The time of casting in continuous casting varies with Grade of Steel to be produced and with number of strands working in caster. The rolling time depends on the final grade to be produced and product profile to be produced. The scheduling of heats to be optimized to target the timely completion of the heats / products as per the delivery dates promised to customer.

Production planning and scheduling in steelmaking-continuous casting(SCC), Rolling Mills process is of decision making about three important issues: Consolidating customer orders into charges, grouping charges into heats, scheduling the heats on to LD Converters and optimizing the order of the sequences where a sequence is a group of heats with the same chemical characteristics i.e grade of the steel. The job that are processed in LD converters are called Heats and that is assigned heat number. Customer orders are directed from Steel Melting shop. The different grades and their tonnage is decided by customer orders received. The Monthly plan is divided into daily plan which is each grade of steel and tonnage to be produced in a sequence and this is call steel order. The steel order is known well in advance. The steel order is processed in First cum first Basis without any logic. The heats are processed in a sequence in LD Converters, Argon Rinsing stations, continuous casting machines and Rolling Mills. In the steel making industry different algorithms are being used for scheduled the heats from steel making to rolling mills.

In this research, the authors have focused on developing different scheduling algorithms to sequence the heats in different stations LD Converters, ARS ,CCMs and Rolling Mills , so that Production , Productivity of the steel by reducing the waiting time in each machine, total dead line time and increasing the utilization of the machines. The authors Developed Earliest Deadline First (EDF) scheduling with different functions for the scheduling of Steel Melting and Rolling Mills scheduling to improve productivity and thereby cost of production. The metrics like turnaround time, average waiting time and deadline deviation which are used to evaluate performance of the scheduling algorithms are computed for the EDF and these are compared with Shortest Job First (SJF), First Cum First Scheduling. The metrics are computed on the heats from the steel plant production data.

These results indicated that the EDF scheduling model has shown a significant improvement of over First Come First Scheduling (FCFS), Short Test Job First (SJF). This indicated that in the steel making – Rolling Mills the model EDF has given effective utilization of LD Converters, Argon rinsing stations, Continuous Casting Machines , Rolling Mills and improvement of productivity over presently being used FCFS modeling.

Related Work:

Lixin Tang, Jiyin Liu et.al , (2001), have presented review on Planning and scheduling systems developed and methods used for SM-CC-HR production. They have also presented key issues for further research in the field of planning and scheduling systems for SM-CC-HR. Lixin Tang,Peter B.Luh et.al., (2002), they have proposed a novel integer programming formulation with a 'separable' structure is constructed considering set-up, removal times on the machines ann high job waiting costs. A solution methodology is developed combining Lagrangian relaxation, dynamic programming and heuristics. A numerical experiment demonstrates that the method generates high schedules in a timely fashion.

Peter Cowling, (2003), They have described multi objective model for scheduling hot rolling process using variety of bespoke local and tabu search heuristics. They have also described scheduling systems models, algorithms and interfaces developed to handle the instability in rolling process. Eva Schiefer (2009) has presented scheduling model for rolling high-grade-steel. The high-grade steel scheduling is reduced to job-shop scheduling problem with sequence dependent set-up-times. The objective is to minimize the idle-time of the heating furnaces and rolling units and to satisfy commercial objectives such as delivery on time. The short computing times allow the reaction to unpredictable which implies that the algorithm is very well suited for use in the daily planning procedures.

Mtteo Biondi, Dr. Sleman saliba et.al (2011), they have proposed optimization based approach using intelligent heuristics and compose these parts to fully feasible programs by solving a min-cost-flow problem. The built programs are scheduled using a mixed integer linear programming formulation in order to obtain an optimal schedule that violates as few order due dates as possible.

Yu-Wang Chen,Yong-Zai Lu et.al (2012) , have proposed to solve the Hot Strip Mill (HSM) scheduling problem using hybrid evolutionary algorithms with integration of genetic algorithm and external optimisation.The mathematical model is formulated to describe two important scheduling sub-tasks: (1) selecting a subset of manufacturing orders and (2) generating an optimal rolling sequence from the selected manufacturing orders.

Chaoun Xu,Guido Sand etal (2012) have presented an innovative scheduling coordination method to coordinate two consecutive production sections in an integrated steel plant-melt shop and hot rolling mill. The challenges and the approaches to coordinate two industrial schedulers incorporating several optimization steps, for instance mixed integer linear programming and heuristics are presented. The coordination approach is validated by testing it with real production data from a real life steel plant.

Dipl.Ing. Chaojun Xu and Shanghai , V.R.China (2013) have presented A bottom-up coordination heuristics of two large-scale flexible multi-stage batch scheduling problems is developed on the basis of an improved Bender's decomposition algorithm. An upper level coordinator is formulated as an optimization problem based on the technical constraints of the bottleneck stages within the production sections. The coordination heuristics is validated using actual production data collected from a steel plant.

Bai-linwang,tie-ke et.al. [2013], they have represented the constraints and dynamic scheduling of steel making and continuous casting by hybrid knowledge with frames and production rules. They have solved the dynamic scheduling by a tree hierarchy architecture and real time rule based reasoning dynamic scheduling strategy is implemented by inference mechanism. Patrick A.P. Carter, (2015), they have developed several mathematical batch scheduling models that use different modeling paradigms in an effort to compare their computational complexity. With the selection of an appropriate model, model extensions are added to replicate an industrially relevant steel mill scheduling problem for a finishing line using data from a facility located in Ontario, Canada

In the literature, very little work on Scheduling of Steel Making and Continuous Casting (SCC) reported. In the available literature researchers have focused on genetic algorithms, heuristics, lagrangian relaxation, linear programming to solve the Steel Making and Continuous Casting (SCC) scheduling problem. Due to dynamism of machines involved in Steel making , no scheduling model is perfectly models the scheduling problem. Lot of research is still going on to find best algorithms for SCC scheduling by using different mechanisms. No author reported the research on SCC Scheduling using Earliest Deadline Concept. Deadline aware Scheduling concept is most important concept being used in all industrial scheduling activities. Hence authors have chosen EDF methodology for scheduling of heats to LD converters, ARS stations , continuous casting and Rolling Mills of steel making.

Earliest Deadline First Algorithm:

In the Earliest dead line algorithm the heats or jobs are listed with processing times. The model randomly determines a factor for each job/heat and finds out a *deadline time* for each job/heat. After deadline times are arrived for each heat / job the jobs are ordered based on the *deadline function* in ascending order. The scheduling model considers for each 4 jobs/heats it sequences on one stream of LD converter (M1) , Argon rinsing station (M2) , Continuous Casting Machines (M3) and Rolling Mills(M4) .

Deadline time for each job/heat is calculated based on the total time it takes to process each heat in the LD converter (M1), Argon Rinsing Station (M2), Continuous casting Machines (M3) and Rolling Mills (M4) and multiplied with random number α. The *deadline function* is defined as β (M1+M2) + γ * deadline time where β, γ are factors decided based on the best optimization and β+ γ = 1. The schedule sequence is arranged in ascending order as per *deadline function* value. The ordered sequence is split into sets of sequences and each set shall have 4 jobs/heats. In each set start time, waiting time and deadline variation is computed. The best optimized sequence is decided based on minimum dead line variation.

Methodology:

In this paper authors have considered for four machines of steel making namely LD Converter, Argon Rinsing Unit, CCMs and Rolling Mills. It is considered that there are 'm' number of LD converters, n number of ARS , o number of CCMs and p number of Rolling Mills parallelly operating and processing heats.

In this paper the authors took 64 jobs with Processing Times on M_1,M_2, M_3, M_4 i.e LD Converter Blowing time (t_1) ,Argon Rinsing time (t_2) , Continuous Casting Machines (t3) , Rolling Mills(t4) as shown in table 4.1.The deadline time for each job is calculated using function $\alpha*(t_1+t_2+t_3+t_4)$ where t_1,t_2,t_3,t_4 are processing times and α is random number varies between 1 and 3. The scheduling at LD converter, ARS stations , CCM and Rolling Mills is done using EDF methodology on the data presented in Table 4.1 and it is compared with FCFS and SJF. Various Performance metrics like Average Turnaround Time (ATT), Average Waiting Time (AWT), Total Elapsed Time (TET) and dead line deviation is computed and compared. Java simulation programme is developed to compute all scheduling methods. Out of 64 jobs, it is considered that each 4 jobs/heats will run on one stream of machines M1 , M2 , M3 , M4 accordingly the computations are done. So that starting times after four jobs / heats will become zero for the first job/heat in that stream.

Waiting Time of a job request is the time elapsed between the arrival time of job request and when the job request starts its work on Machine of type-1, plus the time elapsed between the time it completes its work on M1 and starts its work on M2 and so on. The Total Elapsed Time of the entire schedule is the time when all job requests completed their work on M1,M2,M3 and M4 respectively. Total Elapsed time of this schedule is the c_k , where k is the last request in the schedule given by the scheduling algorithm. The performance metrics can be computed by the following computations for a given scheduling sequence. Average Waiting Time (AWT), Average Turn-around Time (ATT), Total Elapsed Time (TET) of all job requests can be computed as follows.

$$AWT = \sum_{i=1}^{i=n}\left((c_i - t_{i2}) - (s_i + t_{i1})\right)/\, n$$

$$ATT = \left(\sum_{i=1}^{i=?}\right.$$

Where
n : Number of jobs.
i : Job Request Number
: The time required on Machine of type-1 (M1) for job request ii.
: The time required on Machine of type-2 (M2) for job request ii.
: Completion time of job request i Machine of type-2.
TET = , where k is the last job request in schedule.

The authors have considered 64 Jobs on 4 types of Machines by considering 16 instances are available for each machine type. The dead line time is calculated using simulation programme for each heat or job id as (M1+M2+M3+M4) * Alpha. This is shown in Table 4.1 and algorithm used for EDF scheduling is shown in Algorithm 3.1.Where Alpha is the random number between 1 and 3. The dead line indicates the job to be completed within that time otherwise dead line deviation which is shown in Table 4.1.

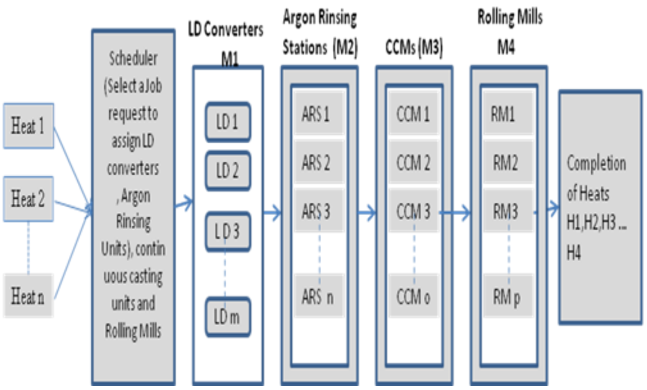

Fig:4.1 Depiction of scheme of scheduling activity in LD Converters, Argon Rinsing Stations, Continuous casting Machines and Rolling Mills in a Steel Melting Shop

TABLE: 4.1 The Job Id, M1 , M2 , M3, M4, Alpha and Dead Line values

Job_id	**M1**	**M2**	**M3**	**M4**	**DL**	**Alpha**
0	24	25	94	120	394	1.5
16	16	12	96	158	564	2
32	23	23	99	158	606	2
48	25	12	80	125	605	2.5
63	27	16	105	158	612	2

Algorithm : Pseudo-code for EDF Four Stage Scheduling Algorithm

Input : n number of job requests with processing times t_{i1}, t_{i2}, t_{i3} and t_{i4} on Four types of Machines M1, M2, M3 and M4. p number of instances are available for each Machine

$d1_i$ is deadline of i^{th} job request = Alpha * ($t_{i1} + t_{i2} + t_{i3} + t_{i4}$)

$1 \leq Alpha \leq 3$

(Beta + Gama) = 1

Output : Optimal Scheduling sub sequences Seq_1, Seq_2, $Seq_{3, \ldots}$ Seq_p

1. begin
2. i=0;
3. solution vector = empty;
4. for each job request r_i with minimum (Beta*dl_i + Gama*((t_{i1} + t_{i2} + t_{i3} + t_{i4})) among all unprocessed jobs do add the job request r_i to the solution vector at index i;
5. i=i+1;
6. end for;
7. for i=0 to n-1 do
8. j = i % p;
9. append solution vector[i] to the scheduling sub sequence Seq_j;
10. end for;
11. for i=1 to p do
12. calculate performance metrics for each scheduling sub sequence Seq_i;
13. end for;
14. calculate aggregate performance metrics for the entire scheduling sequence;
15. end;

The Algorithm- I shows the methodology in computing performance metrics using EDF, FCFS and SJF scheduling and the results are shown in Table I.

V. ANALYSIS AND COMPARISION OF RESULTS

Using the Java simulation programming the FCFS, SJF and EDF scheduling results are computed and they are tabulated below.

5.1 FCFS Scheduling Results:

Sixty four jobs/Heats of different grades are scheduled using First Cum First Basis and there are scheduled on LD Converters First (M1), Argon Rinsing Units (M2), Continuous Casting Machines (M3) and Rolling Mills (M4) . The start time of Job/ Heat on M1 finish time of job on M2, M3 , M4, Waiting Time (WT) and dead line and dead line violation are computed using computer programming as per the formulas mentioned above. In the set of heats below every four heats are scheduled on one set of M1, M2 ,M3 and M4 . Total 16 LD converters, 16 Argon Rinsing units , 16 Continuous casting machines and 16 Rolling Mills are used and parelley processing the heats. The elapsed time for each set of machines processing calculated. The results are shown in Table 5.1.

Table 5.1 The FCFS scheduling computation results

Job id	**ST**	**FT**	**WT**	**Dl**	**DL Violation**
0	0	263	0	394	0
16	0	282	0	564	0
32	0	303	0	606	0
48	0	242	0	605	0
63	68	745	39	612	133
					6447

5.2 SJF Scheduling Results:

In this jobs/ heats are arranged in the order of Shortest Job i.e. total time of processing on LD Converters (M1) , Argon Rinsing Units (M2) , Continuous casting Machine (M3) and Rolling Mills (M4) together. After arranging the heats in Shortest Job First basis, each set of four heats are processed on one set of M1 , M2 ,M3 and M4. The Start Time, Finish Time, Waiting Time, dead line and dead line violation is computed for each heat and shown in Table 5.2.

Table 5.2: The results of SJF Scheduling

Job id	ST	FT	WT	Dl	DL Vio
0	0	263	0	394	0
16	25	400	118	564	0
32	34	566	263	606	0
48	0	242	0	605	0
63	39	600	294	612	0
					4182

5.3 EDF Scheduling Results:

The model randomly determines a factor for each job/heat and finds out a *deadline time* for each job/heat. After deadlines are arrived for each heat / job the jobs are ordered based on the *deadline function* in ascending order is sequenced. The scheduling model considers for each 4 jobs/heats it sequences on one stream of LD converter (M1) Argon rinsing station (M2) , continuous casting Machine (M3) and Rolling Mills (M4). The start time of Job on M1, Finish Time of Job on M4, Wait Time , Dead Line and Dead Line Violation is computed for each Job ID / Heat Id and tabulated in Table 5.3. The Dead Line Time (DLT) is computed with (M1 + M2 + M3+M4) * Alpha and Alpha is a random value between 1 to 3. The Dead Line Function is computed based on the formula β * DLT + γ * (M1 + M2 + M3+M4). Where Beta and Gamma are chosen randomly such that Beta + Gamma = 1.In this research β is taken as 0.05 and γ is taken as 0.95. Based on the Dead Line Function the sequence is ordered in ascending form. The dead line variation is difference between dead line and finish time of job on M4. If it is negative the dead line violation is zero otherwise it is same positive value. This indicates that the job/heat is completed within the dead line time then there is dead line violation.

Table 5.3 EDF Scheduling Results

Job id	ST	FT	WT	Dl	DL Vio
0	0	263	0	394	0
16	25	435	153	564	0
32	44	595	292	606	0
48	0	242	0	605	0
63	37	552	246	612	0
					2732

The algorithm for generating scheduling sequences and calculation of the above results is
shown below.

5.3 Comparison of Results

Java simulation programme is developed for computation of average waiting time and deadline violation. In the table 5.1 sixty four jobs are listed with M1, M2, M3, M4 timings. The deadline time is calculated based on the (M1+M2+M3+M4) timings and alpha is randomly chosen between 1 to 3.

The Average Elapsed Time, Total Dead Line Violation of the EDF scheduling model when compared with FCFS and SJF is shown in Table 5.4. The graphical comparison of Scheduling Model and Average Elapsed Time and total dead line violation is shown in Figure 5.1. These values indicates that EDF (731) scheduling model is comparable with FCFS (743) and SJF (732) in terms of Average Elapsed Time . The total deadline violation values indicates that the EDF (2732) scheduling is giving much better results when compared with SJF (4182) and FCFS (6447).

Scheduling Model	Average Elapsed Time	Total Deadline Violation
FCFS	743	6447
SJF	732	4182
EDF(4 Stage)	731	2732

Table 5.4 Model vs AET & TDV

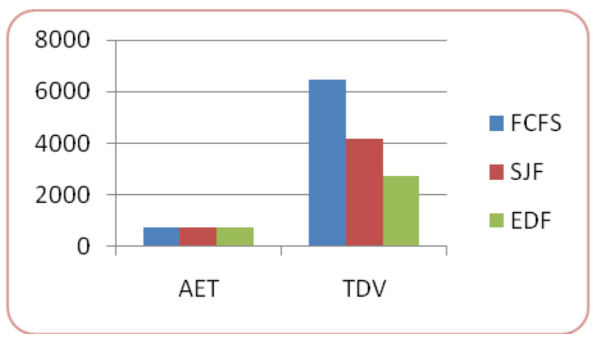

Fig 5.1 : Depicting AET, TDV for each Algorithm

VI. Conclusion

In this research EDF model is used for scheduling the heats at LD converter, ARS Stations , continuous casting machines and Rolling Mills. The scheduling results are compared with other conventional models viz FCFS and SJF. The result shows that EDF Model performance in terms of total deadline violation is much better than other FCFS and SJF, this implies that the deviation from deadline time is much less and better than others. The average elapsed time for a job in the case of EDF is comparable with FCFS and SJF.

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