Research on Performance of Multi-Skilled Workers for Sustainable Production Planning In Seru Production Systems

T .Venkata Deepthi, K.Ramakotaiah, K.Krishnaveni

Abstract: ***A Thriving demand of manufacturing industries causes the escalation in carbon emission and worsening the environmental conditions, to ameliorate such scenario sustainable development has attracted by countries policy makers, academia, manufacturing industry, and service industry. The primary consumers of energy i.e., production systems are the major contributors of carbon emissions and to mitigate environmental hazards sustainability factors taking part in their concerns. This paper investigates the benefits of switching to Seru production system (Cell manufacturing system) in terms of both the economic and ecological performance. A mathematical model was developed with the objectives of minimizing the total training cost of the workers which in turn will decrease the processing time and energy utilization leading to control the carbon footprint of the company. The effective scheduling of skillful workers to serus ensures the significant result on achieving the goals of the model, for this a two-stage heuristic and modified moth flame algorithm are deployed. The proposed model yields a set of alternative Pareto optimal solutions with the minimal carbon footprint on several numerical instances. The computed results will garner a sustainable manufacturing system and assure the efficacy of the suggested algorithm.***

Keywords: ***Seru system; sustainable manufacturing; ecological; training cost; Heuristic algorithm.***

I. INTRODUCTION

Sustainable manufacturing refers to those processes which are not only economically sound but also have a minimum adverse effect on the environment through the permissible application of energy and natural resources.

World commission on Environment and development explained that: "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland commission, 1987). Seru production systems implement reconfiguration of traditional assembly lines to a flexible cell system that aims at reducing the required workforce while at the same time augmenting the productivity manifold. The term efficiency of an enterprise has become anumbrella term incorporating the environmental efficiency as well as the production efficiency. Companies that improve their ecological competence will thus thrive in the long run while others will fall prey to the losses incurred as a result of improper waste disposal, high energy consumption and non-compliance with the stringent laws. The Manufacturing industry being major consumer of electrical energy in the society, contributes to the emanation of greenhouse gases of the world. The Carbon footprint of a company is taken as a major indicator of the sustainability of the company.[21] put forth a simple method to calculate the emissions of carbon dioxide by taking into account that connections between different components of manufacturing a product and the resulting wastes. Electrical consumption is generally used to identify the amount of carbon dioxide emitted and efficient production systems are adopted to minimize this energy input.Many industries have followed the path of Japanese companies and adopted seru production systems which have yielded impressive results to achieve the Double E (Ecology and Economy) standards.[22] gave the details of seru production system used in Sony and also mentioned its flow to other Japanese industries. This paper thus considers a seru production system and develops a mathematical model aimed for minimization of the total training expenditure of workers, the make-spanof the production process and finally the total carbon dioxide emissions. Seru systems, as opposed to conveyor assembly systems, focus on training of workers to make them multi-skilled which acts as the most important component of the seru systems. This training can be reflected in the decreased processing time of the products as a result of an increase in the skill level of workers. Depending on the training costs we devise a worker to seru assignment plan such that it results in a minimum make-span for the products. The paper further uses the relationship between reduced processing times and electrical consumption of the tools and machines to compute the amount of carbon dioxide that is emitted by taking various mathematical instances.

[13] presented a mathematical approach subject to certain dispatching rules which would save energy for underutilized equipment.[14] developed a model that minimizes not only the total energy of the plant but also minimized the tardiness.[5] explored different industrial activities like scheduling, dispatching and manufacturing operations to study the impacts of energy conservation on them. Seru production systems have been in use since its adaption at Sony in 1992. However, a analysis regarding the sustainability of seru production systems with a concrete numerical model is still absent from the literature. Many research articles which give a detailed explanation of this unique manufacturing system are presented in the work [10,11].

Revised Manuscript Received on August 05, 2019

T.Venkata Deepthi,, Mechanical Engineering Department K L E F, Vaddeswaram, India.

K.Ramakotaiah,, Mechanical Engineering Department KKR&KSR Institute of Technology and sciences, Guntur, India

K.Krishnaveni,, Mechanical Engineering Department KKR&KSR Institute of Technology and sciences, Guntur, India

The buildings of a seru production structure are serus or cells.[10,11] and [19] studied the 3 types of serus which are the divisional seru, rabbit-chasing seru, and perfect seru and which abides the key rule that a product and its associated activities have to be completed in the seru itself thus avoiding the transfer of material. Seru systems are a variation to the traditional assembly line, and it was first introduced in Japan in the 1980's and is widely popular in the electronic companies. The analysis of seru production systems by different researchers has highlighted the unique characteristic of multi-skilled workmanship of the system. [6], differentiated a seru system with that of manufacturing cells on the basis of the difference between the skill levels of workers in the two.[16] analyzed many industries which had implemented the system and concluded that the successful implementation of the same depends upon how much the company has invested in improving the skill level of workers and making them multi-skilled. From the literature reviewed so far, it is clear that no paper has interlinked the problems of increasing the production and ecologically efficiency at the same time. Many researchers have given individual solutions for increasing the efficiency of the plant, increasing the productivity, minimizing the throughput times, making the enterprise more environmentally sensitive, reducing the amount of waste generated and so on. All studies are focused on the individual characteristics of the company, but when we limit our vision to only a single problem we also become ignorant about the effects of our solutions on other systems. Thus a holistic model was needed when it came to increasing the efficiency of an industry as we also have to keep in mind the future of the company and help it to sustain the problems in an environment-friendly way.The remaining paper is structured as follows: Section 2 gives a description of the problem with multi-objective functions after which the mathematical model along with the constraints is formulated. A Heuristic and a Moth flame algorithm are developed to solve the model with the help of numerical illustrations in Section 3. Experimentation procedures based on the proposed models are expounded in Section 4 and 5. The results from the experimentation part are then discussed in Section 6. Section 7 finally concludes the directions for future research.

II. PROBLEM DESCRIPTION

This research evaluates the effects of production or assembly line to cell conversion by taking into account the economic and ecological execution of the new adapted seru production system. The present market scenario exhibits high fluctuations in demand where a variety of products requires a flexible and efficient production network. The novel perspective of a seru production structure is that the workers are required to be multi-skilled or fully-skilled in the assembly of a product, which enables them to perform multiple tasks on the product or to complete the entire assembly by themselves. Thus, unlike traditional conveyor system where the processing time depends on the time taken by the slowest worker, the seru system implies liability on a single worker. In this work, a seru production system is considered where a variety of products can be produced through several different serus during different stages. Initially, each seru has to be assigned with a specific worker such that there is the only one-to-one relation between the workers and the seru such that the total training cost for cross-training of workers is minimum. Each product has a number of selectable serus available such that the order quantity can be divided among them in an optimal manner. After the demanded quantity is satisfied the subsequent production cycle is initiated by reconfiguring the serus as required by the next product's operations and machinery.

The paper not only focuses on increasing the efficiency of the system but discusses holistic models to sustain the efficiency in the long run by considering the intrinsic and extrinsic factors. For the same reasons, the economic and ecological performance of the seru production system is taken as the sustainability parameters. The economic performance of the system are the intrinsic factors which are related to production costs, make-span and lead times while the environmental performance measured using the raw materials, various emissions and wastes generated, power consumption act as the extrinsic factors. To satisfy both the aforementioned parameters, the enterprise first needs to assign workers to specific serus such that the training cost is minimum followed by choosing among the available selectable serus to manufacture a product and finally assigning the optimum quantity to them to minimize the make-span and carbon dioxide emission. The paper thus considers three objective functions to achieve the Double E standards (Ecology and Economy) put forward by Japanese manufacturing enterprises which are:

- Minimization of the training cost
- Minimization of the make-span of products
- Minimization of the carbon dioxide emissions

Some assumptions that are taken into consideration while solving this problem are:

- Only one product can be processed by a seru at a time.
- The workers engaged are preferred to be multi-skilled so that they can finish the whole product by themselves
- It is ideal to have only a single worker in each seru.
- There is no work sharing and movement between serus is prohibited.
- Seru breakdowns are not considered.
- The energy consumption for completion of one product type is known and is constant.

2.1. Mathematical model

P	Workers' index (p=1, 2, ...,P).
Q	*Seru's index* (q=1, 2, …,Q).
L	Task index (l=1, 2, …,L).
t_q^l	The standard processing time of l^{th} task for q^{th} product type
c_{pq}^l	The training cost of worker p to master the skill for l^{th} task of q^{th} product type
W_q	The size of q^{th} *seru* according to workers
C	The total training cost of all workers
E_q	Overall average processing time of all workers on q^{th} *seru* .

D_q	The sum of squares of deviations from the mean processing times of all workers in q[th] *seru*
V	Product type index (v=1, 2, …, V.
U	Product batch index (u=1,2, …,U)
B_u	Size ofm^{th} product batch
T_n	The cycle time of n[th] product type
MN_n	Setup time of n[th] product in a particular cell
EFG_n	Fixed setup time of n[th] product
η_p	Upper limit of the number of tasks for p[th]workerin a particular cell. If the number of tasks assigned to the worker p is greater than η_p , worker p's average task time within a cell will be more than respective task time in the primary assembly line.
C_p	The coefficient of variation of worker p's increased task time after the conversion from a specialist to a perfectly cross-trained worker
ε_p	Multiple assembly tasks influencing coefficient of p[th] worker
β_{vp}	Worker *p's* skill level forv^{th} product type
B_m	The quantity of a product produced in a seru
S	Seru number
β_{ec}	Coefficient of carbon dioxide emission (mass of CO_2emission per kWh)
A_q	Upper limit of the carbon dioxide emission
d_t	Time limit for completion of all products

Decision variables

$$\theta^{1}_{pq} = \begin{cases} 1, \text{if the worker } 'p' \text{ is assigned to seru } 'q' \text{ and processsing taks } 'l'; \\ 0, \text{otherwise.} \end{cases}$$

$$\phi^{1}_{pq} = \begin{cases} 1, \text{if the worker } 'p' \text{ is assigned to seru } 'q' \text{ and processing taks } 'l'; \\ 0, \text{otherwise.} \end{cases}$$

$$X_{ps} = \begin{cases} 1, \text{if seru } 's' \text{ is selected;} \\ 0, \text{otherwise.} \end{cases}$$

Objective functions

$$\text{Min } Z_1 = \sum_{p-1}^{p} \sum_{q-1}^{q} \sum_{l-1}^{L} C^{l}_{pq} \theta^{l}_{pq} \quad (1)$$

$$\text{Minz}_2 = W_q \sum_{p-1}^{p} \left[\left(E_q - \sum_{l-1}^{L} t^{l}_{q} \theta^{l}_{pq} \right)^2 \right] \forall_q \quad (2)$$

$$\text{Minz}_3 = \sum_{Q-1}^{Q} B_{mQ} c_Q \beta_{ec} \quad (3)$$

Subject to

$$\sum_{q-1}^{q} \phi_{pq} = 1 \forall_P \quad (4)$$

$$\sum_{l-1}^{l} \theta^{l}_{pq} > 1 \forall p \phi_{pq} = 1 \quad (5)$$

$$\sum_{p-1}^{p} \sum_{q-1}^{Q} \theta^{l}_{pq} = 1 \forall l \quad (6)$$

$$1 \le \sum_{p-1}^{p} \phi_{pq} \le W_q \ \forall_q \quad (7)$$

$$1 \le \sum_{p-1}^{w} G_{pq} \ \forall_q \quad (8)$$

$$\sum_{q-1}^{Q} \sum_{l-1}^{U} H_{uql} = 1 \forall_q \quad (9)$$

$$\sum_{s-1}^{s_q} X_{qs} B_{mqs} = B_{mqs} \ \nabla_q \quad (10)$$

$$\sum_{s-1}^{s_q} X_{qs} B_{mqs} . C_{qs} . \varepsilon_{ec} \le A_q . B_{mq} \ \nabla_q \quad (11)$$

$$\sum_{q-1}^{Q} \max_{se\{1,2,--s_q\}} \left\{ X_{qs} . \sum_{l-1}^{L} t^{l}_{q} B_{mqs} \right\} \le d_t \quad (12)$$

The objective functions in equations. (1) to (3) represent the minimization of total training cost ,minimization of the sum of squares of deviations from mean of processing times for all workers in each seru and the reduction in the carbon dioxide emission through a decrease in the energy consumption respectively. Equation (4) ensures that a worker is allotted to only a single seru thus forbidding the movement of workers to different serus. Equation (5) represents that the worker in a seru is multi-skilled and can employ more number of tasks of a product. Each task in a seru is performed by only one worker as specified by equation (6). It is not considered that workers share their work each other. Equation (7) represents the constraint on the number of workers allotted to a particular seru.It is to be assured that total number of workers in the cell system should not exceed that of the original assembly line. Equation (8) represents cell formulation rule, which confirms that at least one worker is to be assisted with each formatted cell. Product batch is to be assigned to a cell only according to assignment rule which has been signified in Equation (9). Each seru must fulfil the demand of the product by supplying the exact quantity required. This constraint is imposed by equation (10). Constraint equation (11) imposes a restriction on the emission of carbon dioxide in each stage by fixing an upper bound emission level. Equation (12) represents the assignment rule by which product batches must be allocated sequentially and does not allow for concurrent work.

III. METHODOLOGY

The main purpose of this research is to increase the efficiency of the system by reducing the processing time of the products and simultaneously reduce the carbon dioxide emission in order to achieve long-term sustainability. The problem takes into consideration different products, each of which can be processed in a dedicated single cellular manufacturing system called as seru. Each seru has to be assigned a worker who has to be trained to make him multi-skilled. After this, a specific product quantity for each product has to be divided among the different serus optimally such that the processing times and the energy consumption are maintained as minimum as possible. The sustainability parameter related to carbon dioxide emission is directly related to the amount of energy consumed, thus the lower the energy consumption means lower is the CO_2 emission.

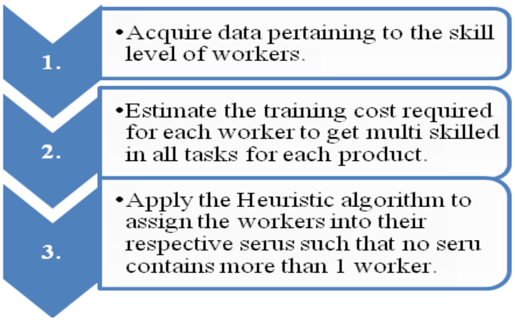


Figure 1. Flowchart Showing The Process To Get Worker To Seru Assignment Plan

The problem is then divided into two major parts; the first part includes assigning the workers to the respective serus such that the required total training cost to make multi-skilled worker is minimum. This is done by using a Heuristic algorithm which was coded using MATLAB and the key steps involved in the process are presented in a flowchart as shown in Fig. 1. After the workers are assigned, the processing time taken for each product can be calculated based on the worker's processing times.

The second part is to get a number of alternative assignments of different products to alternate serus using Moth flame algorithm based on the relation between the total energy utilization during the minimum possible processing time and the amount of carbon dioxide emission. The selection of an alternative optimal solution out of many is the one which minimizes the total carbon dioxide emission thereby making the system environmental friendly and thus enhancing the sustainable future. Figure 2, shows the process flowchart followed in order to get optimal process plans based on the modified moth flame algorithm.

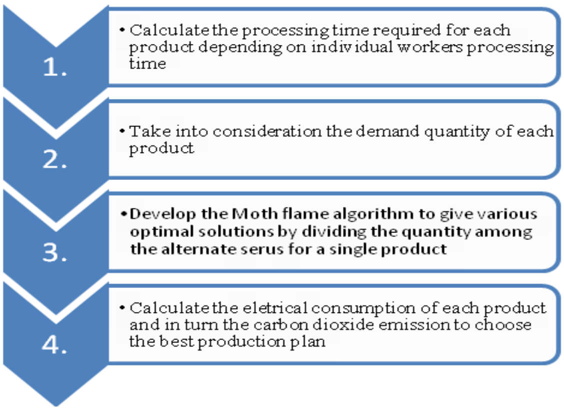


Figure 2.Flowchart Showing The Process To Get The Best Sustainable Process Plan

4. Experimentation

Standard processing time associated with each task of each product of the worker before he is trained is listed in Table 1. The sign of "/"denotes the non-existence of a particular task for the corresponding product type. The total training cost of each worker for each product in each of the alternative serus is represented in Table 2. This is cumulative of all the training costs associated with the tasks of each product.

Table 1. Worker's training cost for each task of a product in alternative serus

serus		1						2						3						4						5					
tasks		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
products	workers																														
1	1	0	30	56		20	62	/	36	113	117	/	/	11	105	9	70	/	176												
	2	62	0	158		109	92	/	54	7	80	/	/	0	179	90	106	/	6												
	3	53	1	0		50	49	/	90	17	114	/	/	167	0	64	146	/	68												
	4	102	145	151		62	87	/	96	95	47	/	/	39	23	0	123	/	433												
	5	80	90	43		0	132	/	77	21	94	/	/	109	62	55	0	/	87												
	6	15	67	67		122	0	/	118	41	0	/	/	60	60	45	86	/	78												
	7	96	146	32		167	135	/	55	0	142	/	/	176	73	83	139	/	0												
	8	49	10	101		169	123	/	0	69	163	/	/	33	18	130	167	/	76												
	9	210	100	50		16	20	/	233	0	112	/	/	183	183	34	103	/	20												
	10	0	28	55		222	156	/	87	175	45	/	/	92	74	162	158	/	56												
	11	143	17	20		185	154	/	123	154	18	/	/	193	86	189	132	/	17												
	12	21	73	88		96	177	/	98	89	76	/	/	143	1	26	124	/	68												
2	1							84	/	42	0	/	95													38	52	/	9	73	15
	2							122	/	55	55	/	94													0	65	/	72	110	62
	3							67	/	154	86	/	0													113	0	/	40	80	149
	4							8	/	117	66	/	138													80	71	/	101	0	103
	5							136	/	106	82	/	89													85	52	/	0	179	58
	6							46	/	0	167	/	61													90	31	/	60	0	118
	7							175	/	52	65	/	0													6	104	/	101	137	0
	8							0	/	60	128	/	131													12	0	/	119	21	146
	9							86	/	124	32	/	56													87	98	/	31	58	111
	10							76	/	48	154	/	0													24	23	/	56	34	65
	11							21	/	89	211	/	25													43	87	/	187	134	0
	12							165	/	58	12	/	29													231	4	/	0	24	55
3	1	14	133	23	/	59	50	/	112	173	35	/	0	161	87	0	/	179	70	14	133	23	/	59		43	/	/	111	104	0
	2	19	163	0	/	118	154	/	154	115	0	/	48	8	131	7	/	23	160	19	163	0	/	118		80	/	/	177	0	136
	3	161	87	114	/	179	70	/	97	0	174	/	118	10	78	163	/	81	0	0	4	6	/	11		81	/	/	166	63	148
	4	8	131	7	/	23	160	/	5	119	117	/	110	100	0	45	/	158	7	120	26	160	/	150		129	/	/	0	21	176
	5	0	78	163	/	81	10	/	173	40	118	/	130	0	146	12	/	24	26	5	0	104	/	35		10	/	/	128	57	105
	6	100	0	45	/	158	7	/	43	178	19	/	86	137	75	63	/	110	148	107	59	55	/	0		74	/	/	26	33	43
	7	12	146	0	/	24	26	/	0	164	164	/	38	43	73	162	/	0	62	0	177	157	/	20		127	/	/	6	163	5
	8	137	75	63	/	110	148	/	55	58	46	/	91	18	109	40	/	41	25	61	123	105	/	18		0	/	/	78	94	152
	9	211	289	7	/	0	34	/	67	87	288	/	91	198	115	191	/	67	98	277	48	19	/	67			/	/	23	67	234
	10	10	78	123	/	154	11	/	187	154	67	/	0	177	157	112	/	0	23	213	92	23	/	54		26	/	/	221	78	67

	11	0	34	58	/	82	255	/	63	87	256	/	47	159	197	128	/	45	0	45	76	176	/	21		0	/	/	34	45	289
	12	12	90	34	/	165	178	/	79	99	101	/	118	109	138	125	/	111	49	18	45	128	/	89		45	/	/	128	156	23
4	1																			0	127	/	5	74		126	61	86	/	/	134
	2																			99	0	/	116	9		58	97	112	/	/	122
	3																			72	62	/	131	165		4	160	79	/	/	165
	4																			68	116	/	0	30		44	97	36	/	/	0
	5																			163	112	/	92	0		5	137	95	/	/	80
	6																			2	23	/	161	102		159	80	7	/	/	75
	7																			30	26	/	140	106		0	46	43	/	/	56
	8																			133	128	/	167	18		141	0	14	/	/	150
	9																			231	67	/	90	87		82	12	189	/	/	87
	10																			277	23	/	83	12		89	78	60	/	/	121
	11																			45	67	/	56	0		127	62	18	/	/	45
	12																			78	0	/	87	298		178	0	111	/	/	87

Table 2 . Worker's Total Training For Each Product In Alternative Serus

Product	Serus workers	S1	S2	S3	S4	S5
1	1	168	266	371	/	/
	2	421	141	381	/	/
	3	153	221	445	/	/
	4	547	238	318	/	/
	5	345	192	313	/	/
	6	271	159	329	/	/
	7	576	197	471	/	/
	8	452	232	424	/	/
	9	396	345	523	/	/
	10	461	307	542	/	/
	11	519	295	617	/	/
	12	455	263	362	/	/
2	1	/	221	/	/	187
	2	/	326	/	/	309
	3	/	307	/	/	382
	4	/	329	/	/	355
	5	/	413	/	/	374
	6	/	274	/	/	299
	7	/	292	/	/	348
	8	/	319	/	/	298
	9	/	298	/	/	385
	10	/	278	/	/	202
	11	/	346	/	/	451
	12	/	264	/	/	314
3	1	279	320	497	229	258
	2	454	317	329	300	393
	3	611	389	332	21	458
	4	329	351	310	456	326
	5	332	461	208	144	300
	6	310	326	533	221	176
	7	208	366	340	354	301
	8	533	250	233	307	324
	9	541	533	669	411	324
	10	483	408	469	382	392
	11	429	453	529	318	368
	12	479	397	532	280	352
4	1	/	/	/	206	407
	2	/	/	/	224	389
	3	/	/	/	430	408
	4	/	/	/	214	177
	5	/	/	/	367	317
	6	/	/	/	288	321
	7	/	/	/	302	145
	8	/	/	/	446	305
	9	/	/	/	475	370
	10	/	/	/	395	348
	11	/	/	/	168	252
	12	/	/	/	463	376

Heuristic algorithm acts as a two-stage algorithm for assigning the workers into their respective serus. In the first stage, the workers are assigned directly by taking into consideration only their training cost. Thus the worker is assigned to a seru wherein the training cost is the minimum irrespective whether the seru is already been assigned to some other worker or not. Table 3 represents this initial assignment plan. In this table symbol "/" denotes that the serus are not used for the following product while the symbol "-"denotes that the seru is empty even though it can be used for the manufacturing of the product. Thus some of the serus have been assigned with multiple workers and exceeding the predetermined size while some of them are left empty.

Table 3 .Initial Worker-Seru Allotment Plan.

SERU	1	2	3	4	5
PRODUCT					
1	W1	W2,W6,W8,W12	-	/	/
2	/	W9	/	/	W10
3	-	-	-	W5,W3	-
4	/	/	/	W11	W4,W7

The second stage of the algorithm deals with generating an adjusted-worker-to-seru assignment plan. It removes workers from the excessive filled serus and transfers them to those which are empty. This transfer is done by considering the difference of training cost of workers between the seru they are currently working and the one to which they can be potentially transferred. Table 4 represents the adjusted-worker-to-seru assignment wherein all the serus are assigned to a worker.

Table 4. Adjusted Worker- Seru Allotment Plan

SERU	1	2	3	4	5
PRODUCT					
1	W1	W2	W5	/	/
2	/	W7	/	/	W10
3	W6	W8	W4	W3	W9
4	/	/	/	W11	W12

4.1 Proposed heuristic algorithm

In this model, the concept of “optimum” is modified into “best compromise” solution for the proposed multi-objective problem. The properties of the above problem allow us to evolve a two-stage Heuristic algorithm with four steps involved to solve it. The suggested algorithm has the following three stages viz. to find a worker-to-seru assignment plan and then to get an modified worker-to-seru assignment plan.

Step 1.Determine the training cost for each worker for attaining all the skills required in all tasks of each product. That is, calculate $\sum_{l=1}^{L} C_{pq}^{l}$ for any p, q.

Step2. Assign each worker to a specific seru for which minimum training cost is maintained minimum. If there are multiple serus where a worker can be allotted, choosing the seru which has the least processing time. Still, if there is any conflict; assign that worker to the one which has the smallest index number.

Step3. Let $S_s$be a set of serus to which no workers have been assigned and set S_w form with serus having more workers than the predetermined size. Check if S_s is 0

Case 1: If $S_s = 0$.

Check whether $S_w = 0$

Sub-case 1: If $S_w = 0$, End-stage 1.

Sub-case 2: If $S_{w\_} \neq 0$.

Thus by taking into account the minimum training cost increment, one or more workers can be removed from seru$_w$ and shifted to serus belonging to S_s and make all serus of the predetermined sizes. Then stage 1 ends.

Case 2: If S_w=0,

Check if S_s =0

Sub-case 1: If S_s =0, End stage 2.

Sub-case 2: If $S_{s\_} \neq 0$

If the serus in set S_w fulfill the criteria regarding the number of workers (i.e. when S_w=0), but still there exist serus for which no workers have been assigned, shift the required number of workers from serus other than those in $S_w$to serus in S_s. This operation has to be done while simultaneously minimizing the increased training cost. For the case when there are serus which have number of workers more than the predetermined sizes (i.e$S_{w_} \neq 0$), again consider the minimization of the training cost increment and accordingly move one or more workers from serus in S_w to serus in $S_s$and continue doing so till it satisfies the constraints related to seru size and at least one worker has to be allotted in each seru. Thus after finishing this stage, we acquire the worker-to-seru allotment plan.

4.2 Reduction in Carbon dioxide emission.

Regarding the adjusted-worker-to-seru allotment plan, the workers are now assigned to respective serus, and the processing times of the products are given to each seru as shown in Table 5.

Table 5.Processing times (h/product)

	S1	S2	S3	S4	S5
P1	3	5	10	/	/
P2	/	8	/	/	5
P3	9	8	2	6	4
P4	/	/	/	7	9

In Table 5, ‘P’ represents the number of products and ‘S' represents the alternate serus for each product. Table 6 shows the energy consumption for the scheduled period of producing one unit of each product.

Table 6. Energy consumption

	S1	S2	S3	S4	S5
P1	9	2	4	/	/
P2	/	3	/	/	6
P3	3	3	10	5	6
P4	/	/	/	3	1

In the Tables, 5 and 6symbol ‘/’ represents that particular seru is not available for the product. Each of the products has a specific demand quantity which has to be met by the company. The demand quantities of four products are as shown in Table 7

Table 7.Demand quantity for products

Products	Demand
P1	38
P2	52
P3	40
P4	46

The amount of carbon dioxide emission depends upon the amount of total energy consumption as discussed by eq.3. Thus the reduction of carbon dioxide emission can only be done through the reduction of energy consumption in the serus. As a result, the demand has to be divided amongst the serus such that not only the total processing time of the products is minimized but also the manufacturing processes consume the least energy.

5. Moth Flame evolutionary algorithm

In this section, we adopted a well-known Moth Flame Optimization (MFO) bio-inspired evolutionary algorithm to find the best possible alternative solutions to the considered problem. The adopted algorithm has several applications in various diverse fields, but in this study, a modified version of moth flame algorithm is proposed, that serves the specific need of the considered problem which covers all the possible solution set to give an optimized result.

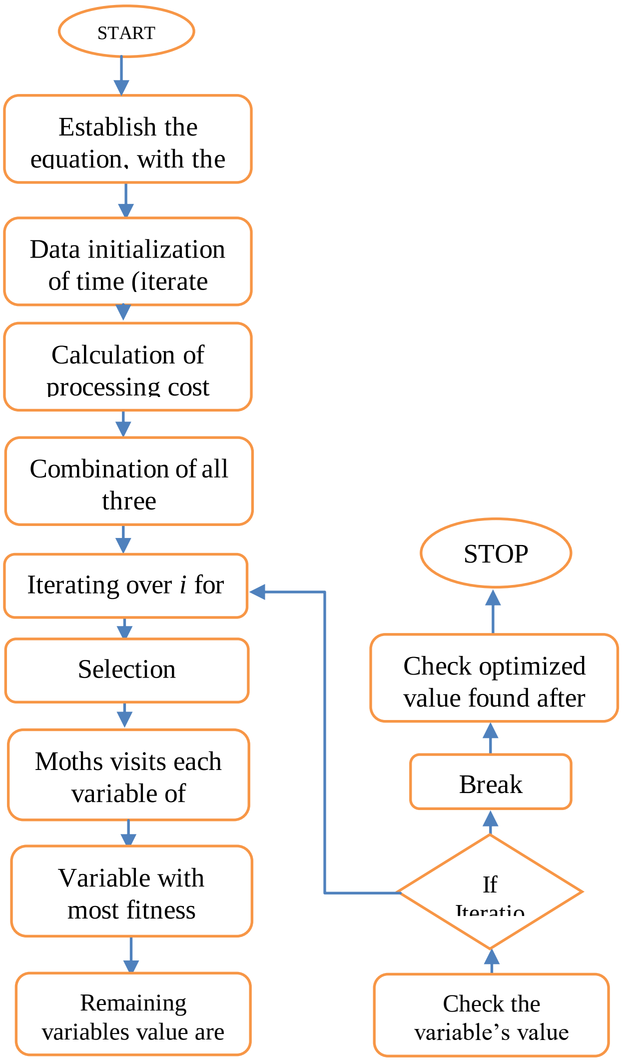


Figure 3.Flowchart of proposed MOO-HMF

Figure 3, expound the flowchart of MOO-HMFO (Multi-Objective Optimization-Heuristic Moth Flame Optimization) algorithm, a modified moth flame algorithm where the moths in the algorithm are defined as possible solutions and their position in the space are considered as variables of the problem. The basic assumption for performing the algorithm is, the moths can Fly in all dimensions together and individually or even in hyper dimensional space with changing their position vectors. The detail description of the proposed algorithm and its stepwise procedure is as follows

Step 1. Initially define the space for moths to explore in the form of time matrices and their related inputs. An encoding scheme for the initialization of processing time inthe form of a chromosome is shown in Fig 4.

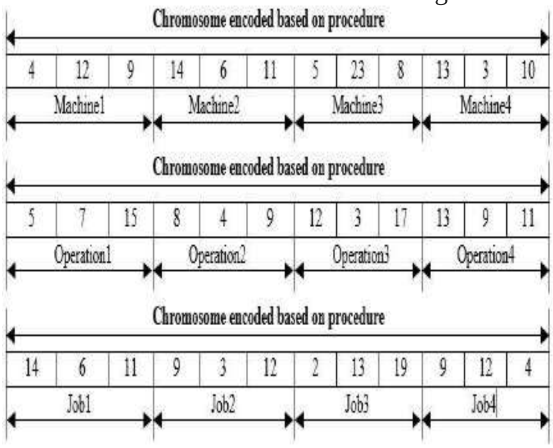


Figure 4.Encoding Scheme Of Chromosome For Initialization

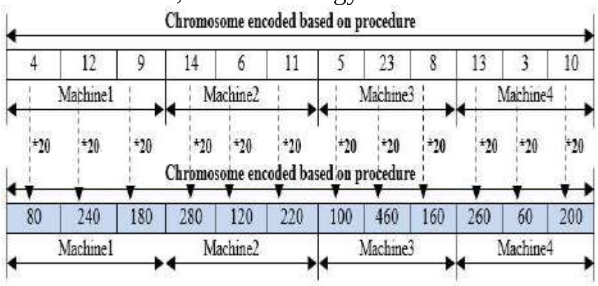
Step 2. Multiply the time matrices with our processing cost inputs and energy consumption inputs to get our remaining search spaces as energy and processing cost.

P_cost(j,k,i)=ProcessingCost(k)*time(j,k,i) (13)

Energy(j,ki)=Energyconsumption(k)*time(j,k,i) (14)

Equation (13) and (14), represent processing cost of jobs and energy consumption of machines. The procedure for the calculation of processing cost and energy consumption matrix is shown in Algorithm.

Step 3. Then convert time and energy matrices in terms of money by multiplying it by wages and cost per unit energy and add all three matrices along with their weights. This mutation is applied so as to dimensionally match the matrices of time, cost and energy.



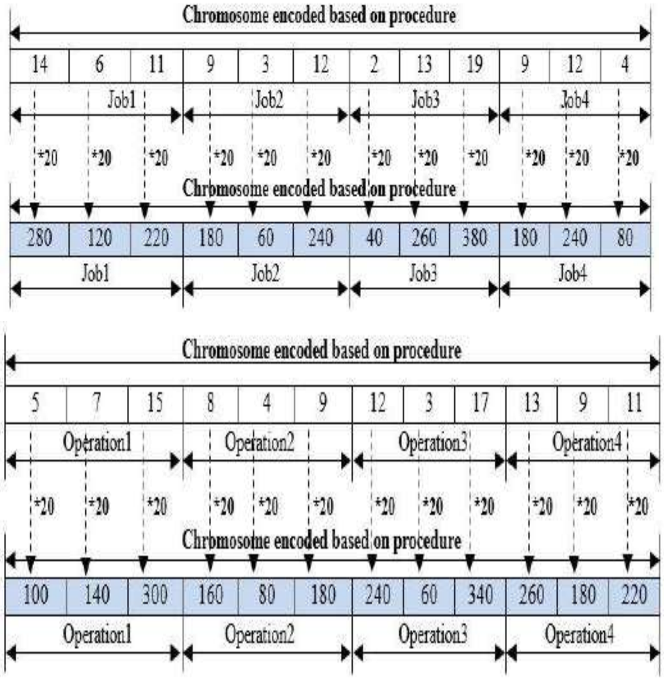


Figure5. Proposed mutation by considering operator wages

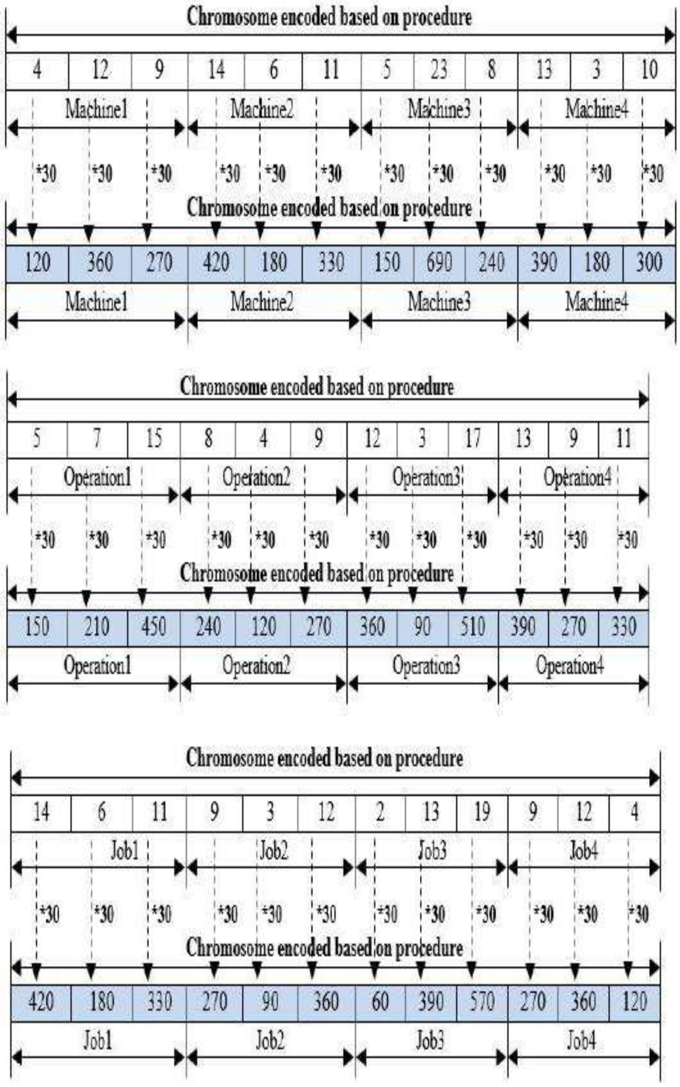


Figure6. Proposed mutation by considering unit cost of energy

A different type of mutation is proposed in this paper and this is shown in Fig 5 and 6. This was done because of the difference in dimensions of the matrices that are added to form a matrix with minimum values. Hence, we multiplied the energy by its unit cost and time with operator wages.

Step 4. All the rows are considered as individual light sources in which the minimum value is to be found.

Step 5. Then start exploring the matrices (search spaces) to find the minimum of the sum so as to obtain a Gantt chart and analyse the results.

Step 6 After the inputs are received and search area has been properly defined, then start exploring the matrices row by row in search for the minimum entry in their respective rows.

Step 7 For the same finally find the sum of all resultant matrices column-wise to gain a single-valued function after converting all ∞'s to zeros.

Step 8: Checking the single-valued function is optimized or not.

Based on the fitness values, selection of the highest probable solution is made for the defined problem. Hence, in the example shown in Fig 4, it can be seen that the second chromosome has the best fitness value and hence it is selected.

VI. RESULTS AND DISCUSSION

The problem took into consideration is related to an industry where different products are manufactured or assembled in different serus. This gave the plant's flexibility to accommodate the varying demands of the products and also the increased productivity. The different serus for manufacturing a product ensures that there was no break in the production process. Through the use of the Heuristic algorithm, workers were assigned to serus based on minimizing the training cost. In the second part, with the objective of being ecologically efficient, different process plans were suggested to attain a compromise between the processing times and carbon dioxide emission. Table 8 represents the results.

Table 8. Values of objective functions

Values of carbon dioxide emission				values of objective function	
P1	P2	P3	P4	Z2	Z3
95.77	157.785	195.465	73.79	1199	522.81
118.535	169.56	170.345	61.23	1247	519.67
153.86	204.885	144.44	54.95	1270	558.135
124.03	131.88	139.73	67.51	1235	463.15
91.845	153.075	130.31	45.53	1335	420.76
211.95	207.24	167.205	67.51	1096	653.905
164.065	150.72	164.065	53.38	1248	532.23

157.785	195.465	172.7	58.09	1202	584.04
188.4	160.14	159.355	67.51	1223	575.405
79.285	204.885	125.6	81.64	1144	491.41
124.815	183.69	168.775	67.51	1246	544.79
142.87	164.85	226.08	48.67	1116	582.47
108.33	150.72	138.16	106.76	1176	503.97
145.225	190.755	153.075	97.34	1117	586.395
146.795	190.755	167.99	78.5	1085	584.04
187.615	131.88	171.915	76.93	1175	568.34

In the table, total processing time required for manufacturing a batch of each product is denoted as 'Z2' while 'Z3' represents the total carbon dioxide emission. It clearly demonstrates that a compromise has been achieved between the processing time and carbon dioxide emission in order to achieve the goal of sustainability. Focusing more on either one of the objectives leads to failure in achieving the other. For instance, taking steps to minimize the processing time may drastically raises the carbon dioxide emission of the plan. This is because there is a possibility that heavier and advanced machinery which consumes more energy is used to get shorter cycle times. On the contrary, restricting production processes or following too many laws preventing the use of advanced machinery might be sustainable ecologically; however, the increased costs and cycle times may prove precarious in the long run.

Scenario 1, consist of four different products produced on four serus with all necessary input data is listed in Table (9) for solving the objective functions as minimum processing time and carbon emissions. The solutions' have been attained with reference to the system performance measures and that has depicted in Figure (7). In the above-characterized figure, processing time is represented on X-axis, which is referred to as a essential criterion of the presented algorithms and carbon emissions are represented on Y-axis . It is reflected in Figure (7) that the MOO-HMFA achieves better performance results than NSGA-II.

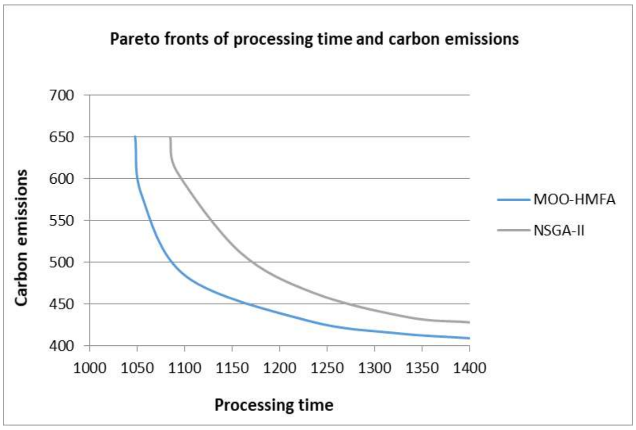


Figure7. Pareto optimal results for four products, four serus scenario

Table 9.Worker's Training Cost For Each Operation Of A Product

Product	Worker	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	Operation 8
1	1	0	/	88	128	86	168	175	/
	2	143	/	156	137	177	119	147	/
	3	111	/	0	175	173	107	91	/
	4	133	/	159	0	59	130	171	/
	5	99	/	141	150	0	126	139	/
	6	99	/	66	65	123	0	121	/
	7	59	/	125	158	114	59	0	/
	8	71	/	71	130	129	167	141	/
2	1	/	187	182	/	169	153	119	162
	2	/	0	197	/	113	142	135	166
	3	/	91	0	/	74	101	127	161
	4	/	88	167	/	100	133	86	163
	5	/	91	157	/	0	197	157	128
	6	/	174	172	/	127	0	77	119
	7	/	82	199	/	168	70	0	52
	8	/	197	138	/	111	92	152	0
3	1	0	119	/	/	121	137	56	69
	2	132	0	/	/	168	51	196	157
	3	121	60	/	/	87	186	106	107
	4	99	131	/	/	178	190	93	194
	5	165	111	/	/	0	80	129	130

Retrieval Number J91720881019/2019©BEIESP
DOI: 10.35940/ijitee.J9172.0881019

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

	6	176	140	/	/	111	0	52	136
	7	136	168	/	/	143	145	0	81
	8	71	166	/	/	188	50	173	0
4	**1**	0	62	128	90	/	65	/	127
	2	171	0	120	53	/	100	/	182
	3	130	103	0	99	/	176	/	148
	4	65	132	190	0	/	126	/	149
	5	84	122	58	73	/	59	/	140
	6	60	170	63	137	/	0	/	86
	7	165	167	56	149	/	135	/	148
	8	150	162	183	142	/	50	/	0

In scenario *2*, the above problem is broadened by taking the four products and five serus. The complete necessary input data of the problem is listed in Table (1). The processing time and carbon emission plots illustrate the achieved Pareto optimal fronts of the mentioned algorithms, which have been shown in Figure (8). Here, MOO-HMFA performs better than NSGA-II in all defined performance criteria.

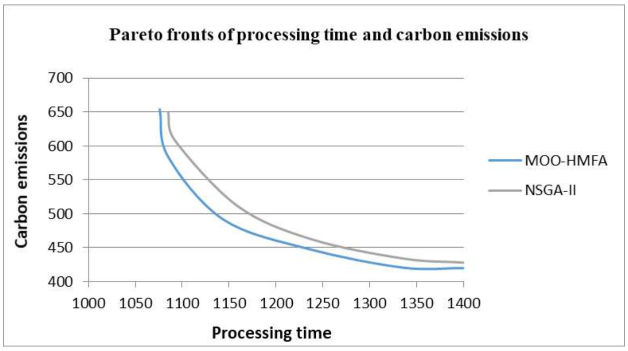


Figure8.Pareto Optimal Results For Four Products, Five Serus Scenario

Scenario *3* comprises six different products and eights serus. Table (10) incorporates the complete data of the problem. Convergence curves of algorithms for processing time and carbon emissions are shown in Figure (9). Hence, it has resulted that The MOO-HMFA shows better results when compared to the NSGA-II algorithm.

Table 10. Worker's Training Cost For Each Operation Of A Product

Product	**Worker**	**1**	**Operation 2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	1	0	30	56	/	20	62	/	36	113	117
	2	62	0	158	/	109	92	/	54	7	80
	3	53	1	0	/	50	49	/	90	17	114
	4	102	145	151	/	62	87	/	96	95	47
	5	80	90	43	/	0	132	/	77	21	94
	6	15	67	67	/	122	0	/	118	41	74
	7	96	146	32	/	167	135	/	55	100	142
	8	49	10	101	/	169	123	/	0	69	163
	9	147	136	23	/	83	104	/	132	0	99
	10	61	81	31	/	140	161	/	105	25	0
B											
	1	0	11	105	9	70	/	176	84	/	42
	2	48	0	179	90	106	/	6	122	/	55
	3	63	167	0	64	146	/	68	67	/	154
	4	110	39	23	0	123	/	133	8	/	117
	5	130	109	62	55	0	/	87	136	/	106
	6	86	60	60	45	86	/	78	46	/	144
	7	103	176	73	83	139	/	0	175	/	52
	8	91	33	18	130	167	/	76	0	/	60
	9	60	64	56	12	55	/	85	50	/	68
	10	55	153	120	2	13	/	10	21	/	0
	1	0	/	95	71	53	/	134	141	115	93
	2	55	/	94	125	107	/	79	60	161	53

C	3	86	/	0	38	52	/	9	73	15	71
	4	66	/	138	0	65	/	72	110	62	62
	5	82	/	89	113	0	/	40	80	149	54
	6	167	/	61	80	71	/	101	106	103	24
	7	65	/	1	85	52	/	0	179	58	3
	8	128	/	131	90	31	/	60	0	118	11
	9	73	/	2	6	104	/	101	137	0	78
	10	131	/	169	12	31	/	119	21	146	0
D											
	1	0	132	117	/	14	133	23	/	59	50
	2	49	0	94	/	19	163	71	/	118	154
	3	112	173	0	/	161	87	114	/	179	70
	4	154	115	77	/	8	131	7	/	23	160
	5	97	113	174	/	0	78	163	/	81	10
	6	5	119	117	/	100	0	45	/	158	7
	7	173	40	118	/	12	146	0	/	24	26
	8	43	178	19	/	137	75	63	/	110	148
	9	3	164	164	/	43	73	162	/	0	62
	10	55	58	46	/	18	109	40	/	41	0
E											
	1	0	/	4	6	11	/	2	112	88	10
	2	120	/	26	160	150	/	126	64	32	146
	3	5	/	0	104	35	/	121	130	136	14
	4	107	/	59	0	5	/	76	77	67	0
	5	139	/	177	157	0	/	127	29	169	27
	6	61	/	48	105	18	/	112	154	47	5
	7	5	/	17	63	91	/	0	72	6	87
	8	80	/	123	111	104	/	21	0	6	163
	9	81	/	25	177	84	/	128	57	0	94
	10	129	/	20	166	63	/	26	33	50	0
F											
	1	0	130	74	/	131	80	/	129	172	3
	2	136	0	127	/	5	74	/	126	61	86
	3	148	99	0	/	116	9	/	58	97	112
	4	15	72	62	/	131	165	/	4	160	79
	5	105	68	116	/	0	30	/	44	97	36
	6	43	163	112	/	92	0	/	5	137	95
	7	5	2	23	/	161	102	/	159	80	7
	8	152	30	26	/	140	106	/	0	46	43
	9	141	133	128	/	167	18	/	141	0	14
	10	21	61	146	/	57	145	/	29	60	0

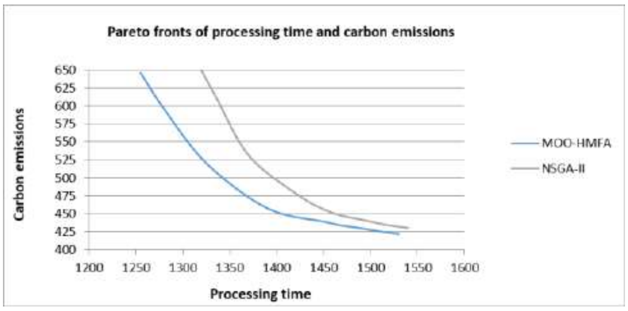


Figure9. Pareto Optimal Results For Six Products, Eight Serus Scenario

An algorithm which accounts less number of generations to encounter termination criteria will be able to converge fast in comparison of other algorithms. Though, it is not assured that the least computational time is to be associated with less number of generations because of variation in complexity incorporated for one single run of different algorithms according to their operational performance. Hence, computational time emerges as one of our key performance criteria. MATLAB software is used to code the algorithms and the problem is assessed on Intel® Core™2 Duo CPU T7250 @2.00GHz, 1.99 GB of RAM. Ultimately, from the experimental outcomes, we perceived that the presented MOO-HMFA performs better than NSGA-II to achieve better performance measures effectively accounting less computational time and less number of generations.

VIII. CONCLUSION

Seru production systems were introduced in Japan to manage with the fluctuation and alterations experienced in the present market, which involves the reconfiguration of the traditional assembly lines to self-sufficient cell systems. It has proved its effectiveness in the market by its high efficiency and flexibility while reducing the job floor space. This system uses the worker's capabilities to the highest extent, thus improving product quality. In this chapter,we had considered the problems of cross-training of workers, making of a worker to seru allotment plan and finally distributing the order quantity between the alternate serus in order to achieve a consensus between the processing time and carbon dioxide emission. A mathematical model for multi-objectives was developed incorporating the economic and environmental factors, which solved in a two-stage approach using the heuristic and moth flame algorithm. This proposed approach was applied to a numeral example and the computational results were noted and their effectiveness was verified. Although this chapter successfully achieved results on sustainable manufacturing, it only achieved a compromise between productivity and sustainability. Also, the mathematical model was subjected to various assumptions which make it a bit rigid for practical purposes. Thus there is scope for future work which would actually consider the dynamic system. Secondly, the mental attributes of the workers have to be considered while assigning them to multi-task involved serus as well. One of the assumptions taken while solving the problem makes it imperative to follow a sequential production system. However, the scope of the problem can be expanded to consider the simultaneous processing of products.

REFERENCES

1. Dormer, A., Finn, D. P.,Ward, P. Cullen, J. (2013)." Carbon footprint analysis in plastics manufacturing Research article", Journal of Cleaner Production,51,p.p133-141.
2. Giret, A., Trentesaux, D., Salido, M.A., Garcia, E. (2017). "A holonic multi-agent methodology to design sustainable intelligent manufacturing control systems", Journal of Cleaner Production, 167, p.p1370-1386.
3. Gimenez, C., Sierra, V., Rodon, J. (2012). " Sustainable operations: their impact on the triple bottom line", Int. J. Prod. Econ, 140,p.p 149-159.
4. Latif, H. H., Gopalakrishnan, B., Nimbart , A., Currie, K.(2017). "Sustainability index development for manufacturing industry",Procedia Manufacturing, 24,p.p 82-95.
5. He, Y., Liu, F.(2010). "Methods for integrating energy consumption and environmental impact considerations into the production operation of machining processes", Chin. J. Mech. Eng,23(4),p.p428-435.
6. Isa, K., Tsuru, T.(2002). "Cell production innovation in Japan: toward a new model for Japanese manufacturing? "41,p.p 548-578.
7. Shankar, K. M., Kannan, D., Kumar, P.U.(2017). "Analyzing sustainable manufacturing practices – A case study in Indian context", Journal of Cleaner Production, 164,p.p1332-1343.
8. Karthik, T., Murugan, R.(2017). "*Carbon footprint in denim manufacturing*", Book chapter, Sustainability in Denim, p.p125-159.
9. Liu, C.G., Li, W.J., Lian, J., Yin, Y.(2012). "Reconfiguration of assembly systems: from conveyor assembly line to serus", J. Manuf. Syst, 31,p.p312-325.
10. Liu, C. G., Lian, J., Yin, Y., Li, W.J.(2010). "Seru seisan an innovation of the production\ management model in Japan", Asian J. Technol. Innov, 18,p.p 89-113.
11. Liu, C.G., Stecke, K.E., Lian, J., Yin, Y.(2014). "An implementation framework for seru production", Int. Trans. Oper. Res,21,p.p 1-19.
12. Jin, M., Tang, R., Ji, Y., Liu, F., Gao, L., Huisingh, D. (2017). "Impact of advanced manufacturing on sustainability: An overview of the special volume on advanced manufacturing for sustainability and low fossil carbon emissions", Journal of Cleaner Production, 161,p.p69-74.
13. Mouzon, G., Yildirim, M.B., Twomey, J.(2007)." Operational methods for minimization of energy consumption of manufacturing equipment", Int. J. Prod. Res, 45, p.p4247-4271.
14. Mouzon, G.C., Yildirim, M.B., 2008. "A framework to minimize total energy consumption and total tardiness on a single machine", Int. J. Sustain,1,p.p105-116.
15. Sakikawa, T.(2005). "HRM practices and operational/financial performance: evidence from cell production at Japanese electronics manufacturers", Ann Rep Econ, Nigata University,29,p.p17-45.
16. Sakikawa , T.(2006)." HRM practices for Japanese cell production", Ann Rep Econ, Nigata University,30,p.p1-29.
17. Shirai, K.(2001). "Cell production and managing human resources. In: Tsuru, T (ed) Innovation and evolution of production systems: diffusion of cell production among Japanese firms",p.p 87-121.
18. Smith, L., Ball, P.(2012)." Steps towards sustainable manufacturing through modelling material, energy and waste flows", Int. J. Prod. Econ, 140 ,p.p227-238.
19. Stecke, K.E., Yin, Y., Kaku, I., Murase, Y.(2012)." Seru: the organizational extension of JIT for a super-talent factory", Int J Strateg Decis Sci, 3(1),p.p106-119.
20. Yang,M.G.M.,Hong, P., Modi, S.B.(2011). "Impact of lean manufacturing and environmental management on business performance: an empirical study of manufacturing firms", Int. J. Prod. Econ, 129,p.p251-261.
21. Zhang, X.F., Zhang, S.Y., Hu, Z.Y., Yu, G., Pei, C.H., Sa, R.N.(2012). "Identification of connection units with high GHG emissions for low-carbon product structure design", J. Clean. Prod,27,p.p118-125.
22. Iwamuro, H. (2002)," Cell Manufacturing System. Nikkan Kogyo Shimbun Tokyo (in Japanese)".

AUTHORS PROFILE

T.VENKATA DEEPTHI, received B.Tech in the Department of Mechanical engineering from Sir.C.R.Reddy college of engineering and M.Tech With Computer Integrated Manufacturing in Department of Mechanical from KLUniversity and Research scholar in KLEF.

Dr.K.RAMAKOTAIAH, received PhD from SCSUMU University. He received under graduation and post graduation degrees in the mechanical and manufacturing engineering respectively. His current research interests include machine tool vibrations, micro machines and condition monitoring of machines. He has published several papers in reputed International journals.

Mrs.K.KRISHNAVENI, received B.Tech in the Department of Mechanical engineering from Bapatla Engineering College and M.Tech in Department of Mechanical engineering with Machine Design as a specialization from Nova College of Engineering, JNTU Kakinada. Currently working as Associate Professor at KKR & KSR Institute of Technology& Sciences.