Reconfiguration of Networked Seru Production systems in an Indian Perspective

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***Abstract*— Recent manufacturing confronted with high variety, low volume market demands, shorter manufacturing cycle times and huge fluctuations in production. In particular, developing countries like India have huge number of skilled workers but due to lack of proper training for skilled and multi-skilled workers, the manufacturing organizations not reaching their current customized requirements. The proposed Networked seru production offers great advantages to cope with the above mentioned requirements. Thus, it is necessary to reconfigure the traditional conveyor lines using in current manufacturing systems with the seru production systems where it is possible to achieve high flexibility for job shop and high efficiency of conveyer assembly lines. In this paper, we investigate the training and assaignment problem of workers on multiple reconfigured serus located on network of enterprises. Thereafter, with Ontology, knowledge has been converted into Extensible Markup Language (XML) schema of Web Ontology Language (OWL) documents to enhance the Interoperability of product data models and manufacturing resources located in a network. Moreover, a single-objective mathematical model has been developed to minimize total training cost, total processing times of each multi-skilled worker. Finally, case of Indian Electronics Company is solved with developed heuristic and multi-objective evolutionary algorithm.**

Keywords—Ontology; networked manufacturing; seru production; multi-objective.

I. *INTRODUCTION*

Recent Manufacturing systems change its trend from traditional methods to flexible production systems due to the emergence of competition between enterprises. In this paper, we highlight the weakness of traditional conveyor assembly lines and then discussed reconfiguration of traditional conveyor assembly lines in the context of networked seru production systems. Several problems encountered while performing tasks with traditional assembly lines, in particular when the market demand exhibits low in volume and high in variety. Several drawbacks reported in the literature while performing on traditional conveyor assembly lines are huge work-in-process (WIP), finished goods inventory, frequent over or under production, less skilled workers, and very long response time [1]. In order to eliminate the above mentioned drawbacks and to cater the recent manufacturing requirements the traditional conveyor assembly lines have to transform into effective production system.

However, several researchers reported many kinds of production systems with respect to conveyor assembly lines [2]. Sengupta and Jacobs [3] identified different environments and tested on a television assembly plant where the traditional conveyor assembly line outperforms assembly cells. Shmizu [4] reported that the performance of assembly cells used in Volvo has been inferior to more traditional assembly lines. Van der Zee and Gaalman [5] proposed hybrid assembly systems that includes pure cell, pure assembly line, and hybrid type of cells. A two step procedure has been adopted for conducting experiments and found that the hybrid cell does not influence the system performance.

However, a change in shift from traditional conveyor assembly line to a new production system is a very complicated decision making problem. Hence, before conversion a company must decide the number of cells required, and how many workers should assign to each cell. Liu et al. [6] and Stecke et al. [7] addressed various innovative production systems and found that seru production system has been attracting an increasing amount of attention from academic and industrial communications. A seru production is defined as a new type of work-cell-based manufacturing system, which composed of some equipment and one or several workers who produce one or more part types [8]. Various survey reports from production practices indicate that seru production is a “Double E” mode of production where it takes into consideration of both both ecological and economical performance [9].

Comparisons between seru production system and cellular manufacturing system have been investigated in the literature and are presented in elsewhere [10]. Liu et al. [11] analyzed the differences between cellular manufacturing and seru production system with five different aspects. These includes, theoretical basis of formation, practical applications, tools required, manufacturing flexibility, and formation of work cells. Sakazume [12] investigated the features of seru/cell and found the advantages and disadvantages of its implementation.

In this paper, we adopted a networked based seru production system that enables the circulation and integration of information and knowledge from product design to manufacturing and enables resource sharing between geographically distributed enterprises, thus endowing enterprises with the ability to quickly respond to the market [13]. Subsequently, for the coordination among different serus the product data has been converted into knowledge with the help of Ontology.

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In [14], researchers defined the purpose of ontology as "an entity, attribute and relationship among knowledge concepts within a specific domain using explicit descriptions and specifications that present an interoperable format which can understand by different kinds of systems there by realizing knowledge sharing and reuse". We adopt Protégé (version 4.2) as a tool for developing ontologies to identify different kinds of manufacturing knowledge. Ontologies include Resource Description Framework (RDF), RDF schema and OWL which is the World Wide Web consortium (W3C) standard semantic markup language for publishing, sharing and re-use of semantic data on the World Wide Web. Therefore, it is quite possible to transfer the ontologies to other information models through semantic relationship. The XML based information representation enables the system to be effectively adaptable to meet the emerging web technology. However, one can found the more detail information about XML files and its development with ontology are detailed in [15].

To successfully implement any kind of seru production system, reconfiguration with multi-skilled or fully skilled workers is essential. Thus, minimize the total training cost and balance the processing times of workers in each seru are the two most important issues and it is considered as single-objective functions in this paper. An heuristic and single-objective based evolutionary algorithm has been developed for solving the above mentioned objectives.

In Section 2, we give a detailed description of the problem with the basic assumptions and developed a mathematical model along with the constraints. In Section 3, we presented a framework of networked seru production environment. Section 4 explains the heuristic approach and evolutionary algorithm approach for solving the MOP. The experimentation with an illustrative example is illustrated and their results are presented in Section 5. In Section 6, the results and their discussions are detailed. The paper concludes with Section 7 suggesting the directions of the future work.

II. PROBLEM DESCRIPTION AND MODELLING

A. Problem Description

Till date, most of the manufacturing industries have been using traditional conveyor assembly lines for producing several products. But, recent manufacturing environment is exhibiting huge fluctuations in demand where meeting of production requirements is a challenging task. Moreover, one of the recently emerged manufacturing system known as networked manufacturing system have been gaining its popularity to work effectively when resources are geographically distributed. Thus, generally using traditional conveyor assembly line shown in Fig. 1 is not sufficient for the above mentioned requirements. Here, each work station corresponds to a specific task and each task can be handled by a single skilled worker. Thus achieved one-to-one correlation between task and the work, where production pace, work in process inventory (WIP), long setup time, interruptions due to absenteeism of workers are some of the major demerits.

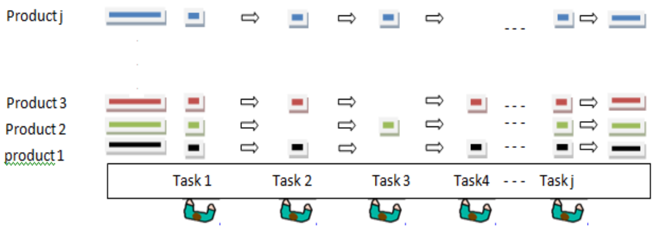

Fig. 1. Conventional conveyar assembly line.

In this study, we discussed a special case of production system in the context of conveyor assembly line i.e., seru production system shown in Fig.2 that can cater the needs of the above mentioned requirements. In seru production system, a single skilled-worker is not sufficient thus there is a need of cross-trained for making them as multi-skilled and full-skilled workers. Here, number of product types is equal to number of serus and each seru run independently without disturbing other workers. However, in the networked manufacturing, the machines are distributed geographically to perform different operations on the jobs; this can be one of the complex tasks in the present problem. We create data into knowledge for transferring data from one seru to another for enhancing the interoperability.

Where, this serus are not situated in one shopfloor due to networked environment

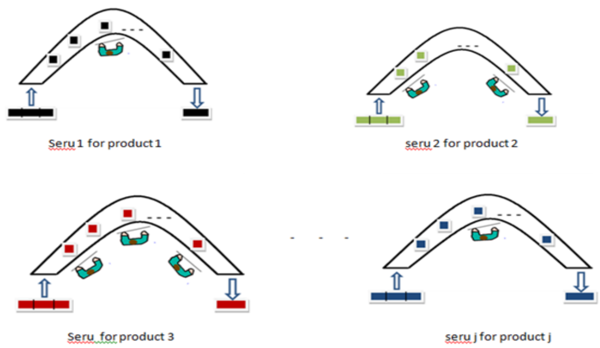

Fig. 2. Reconfigurable seru production system

In order to satisfy the above mentioned problem and its objective function effectively and efficiently, several assumptions are described as follows:

(i) Each *seru* consists of single worker where processing of only one product type is possible. (ii) A worker can have multiple-skills it is highly acceptable if a worker perform all the tasks of a product. (iii) It is assumed that for producing one product type, the processing time of each task is standard and it is same for all workers. (iv) Each seru requires at least one worker and the number of workers is proportional to number of serus. Here, each task can be performed by one worker. (v) The total number of workers is fixed and there will be no change in the reconfiguration of production line. (vi) Transportation time between the serus has been considered.

Notation	Description
i	The index of worker ($i=1,2,\ldots, I$).
j	The index of seru or product type ($j=1,2, \ldots, J$).
k	The index of task or workstation at the conveyor assembly line ($k=1,2, .., K$)
t_j^k	The standard processing time of task k of product type j.
C_{ij}^k	The cost for training worker i to master the skill for task k of product type j
W_j	The size of seru j regarding workers.
C	The total training cost spent on all workers.
E_j	The average processing time over all workers in seru j.
D_j	The sum of squares of deviations from mean of processing times over all workerd in seru j.

Decision varibles

$$\alpha_{ij}^{k} = \begin{cases} 1 & if \text{ worker } i \text{ is assigned to seru } j \\ & \quad \text{and processes task } k \\ 0 & otherwise \end{cases}$$

$$\beta_{ij} = \begin{cases} 1 & if \text{ worker } i \text{ is assigned to seru } j \\ 0 & otherwise \end{cases}$$

B. Mathematical Formulation of the Problem

Minimize

$$Z = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c_{ij}^{k}.\alpha_{ij}^{k} \tag{1}$$

Subjected to

$$\sum_{k=1}^{k} \alpha_{ij}^{k} > 1 \qquad \forall_{i,j}\ \beta_{ij} = 1 \tag{2}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} \alpha_{ij}^{k} = 1 \qquad \forall_{k} \tag{3}$$

The objective function consists of minimization of makespan i.e., minimization of the total training cost spent on all workers, and minimization of the sum of squares of deviations from mean of processing times for all workers in each *seru*. They have been represented in equation (1) and (2). Constraint (4) ensures that only one worker can only be assigned to one seru i.e., the shifts of workers among serus is not allowed. Constraint (5) suggests that each worker can operate maore than one task of a product in the seru. This reflects that workers in serus have multiple skills, which is different from that in the original conveyor assembly line. Constraint (6) ensures that a specific task in seru is only processed by one worker. Work sharing among workers is not considered. Constraint (7) assures that there is atleast one worker and at most *Wj* workers in seru *j*.

III. FRAME WORK FOR THE PROPOSED NETWORK BASED SERU PRODUCTION SYSTEM

The above presented problem is complex in nature and it requires systematic approach to assign workers into the required serus. Thereafter, with the assigned workers and their tasks for the above mentioned objective function, the optimal solution is to be found. First, we proposed a heuristic approach and it is mentioned in the below Fig. 3.

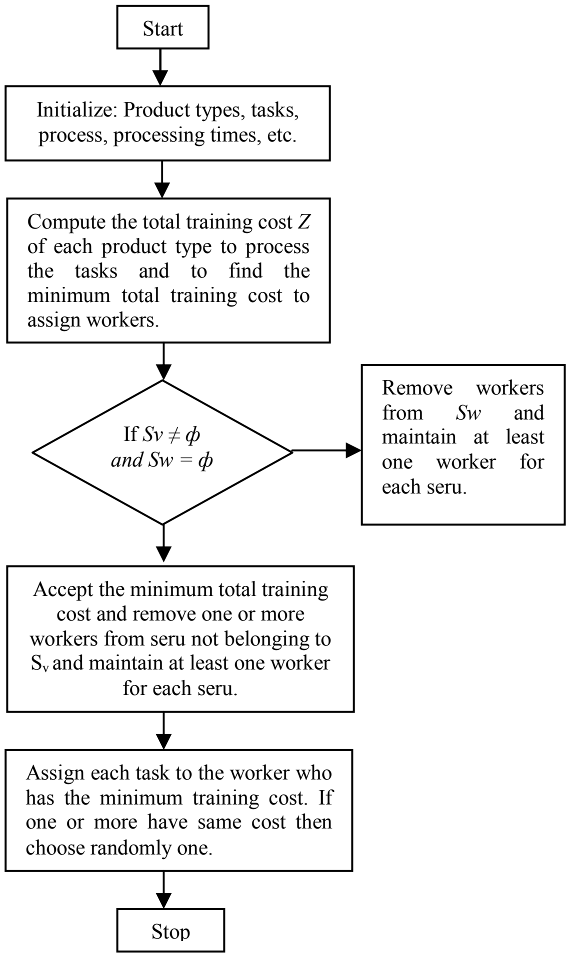

Fig. 3. Heuristic approach for the assigning tasks to workers

Fig.3 starts with the initialization of number of product types, tasks, processing times and the machines required for the processing of operations and it is shown in Table I.

TABLE I. STANDARD PROCESSING TIME OF EACH TASK OF EACH PRODUCT TYPE

Product type	Task1	Task2	Task3	Task4	Task5	Task6
1	6	6	8	/	/	/

2	4	3	3	2	3	5
3	9	8	9	/	/	/
4	7	6	9	/	/	/
5	5	/	4	3	/	/
6	4	6	6	7	/	/

The symbol "/" represents no task is assigned on the corresponding product type, and there is no need to train. There are six product types, and maximum six operations for each product type. Each operation with its processing time for required product type and the training cost of each worker is shown in Table II. In Table II, the number "0" represents the worker has already acquired the skill for that task means the training cost for that particular product type does not exit.

TABLE II. TRAINING COST OF EACH TASK OF EACH PRODUCT TYPE FOR EACH WORKER

Product 1

worker	Task1	Task2	Task3	Task4	Task5	Task6
1	0	/	56	89	125	96
2	152	/	112	86	94	156
3	123	/	0	163	98	78
4	88	/	74	0	93	135
5	72	/	101	141	0	139
6	133	/	111	156	107	0

Product 2

Worker	Task1	Task2	Task3	Task4	Task5	Task6
1	/	94	158	75	142	96
2	/	0	152	147	88	101
3	/	82	0	123	111	89
4	/	135	142	0	89	114
5	/	120	147	109	0	136
6	/	100	129	120	141	0

Product 3

Worker	Task1	Task2	Task3	Task4	Task5	Task6
1	0	120	105	114	89	/
2	102	0	112	104	99	/
3	132	152	0	142	78	/
4	85	125	147	0	56	/
5	91	100	128	148	0	/
6	126	148	109	103	81	/

Product 4

Worker	Task1	Task2	Task3	Task4	Task5	Task6
1	0	119	121	/	137	112
2	132	0	171	/	188	130
3	111	60	0	/	77	163
4	178	51	92	/	101	166
5	136	100	185	/	0	93
6	100	66	124	/	113	0

Product 5

Worker	Task1	Task2	Task3	Task4	Task5	Task6
1	0	90	/	59	61	84
2	124	0	/	73	110	96
3	105	84	/	99	114	101
4	99	79	/	0	80	70
5	108	89	/	82	0	115
6	119	75	/	69	119	0

Product 6

Worker	Task1	Task2	Task3	Task4	Task5	Task6
1	/	132	148	156	98	/
2	/	0	112	92	77	/
3	/	148	0	114	84	/
4	/	113	122	0	135	/
5	/	120	93	118	0	/
6	/	74	89	165	105	/

Form Table II, after assigning the task to each worker of each product type the total training cost of each product type for each worker has been calculated and it is shown in Table III.

TABLE III. TOTAL TRAINING COST ON EACH PRODUCT TYPE

Worker	Product type 1	Product type2	Product type3	Product type4	Product type5	Product type6
1	366	565	428	489	294	534
2	600	488	417	621	403	281
3	462	405	482	411	503	346
4	390	480	413	588	328	370
5	453	512	467	514	394	331
6	507	490	567	403	382	433

IV. META-HEURISTIC TO SOLVE THE OBJECTIVE MODEL

In this section, we propose a meta-heuristic based evolutionary algorithm i.e., genetic algorithm is used to find out the feasible process routes. The genetic algorithm is a stochastic search based evolutionary algorithm that copies the operators such as roulette wheel selection, crossover, and mutation to solve the above complex problem to find out the feasible process routes. The initial parameters for the GA is depicted in Table IV where the probability of crossover is varying between 0.65 to 0.9 and the probability of mutation between 0.001 to 0.015. Here, the roulette wheel selection has been implemented to find out the feasible solutions from the population.

The flow chart of the GA is depicted in Fig. 4 and its basic idea is described as follows: The initial step of the algorithm starts with assigning initial basic feasible solutions generated randomly called the population. Evaluate the population by evaluating each solution and sorting the value of the best. There after the operators such as selection crossover and mutation is performed to find out the feasible sequence of the process plans. This process has been continued until low substance improvement is made.

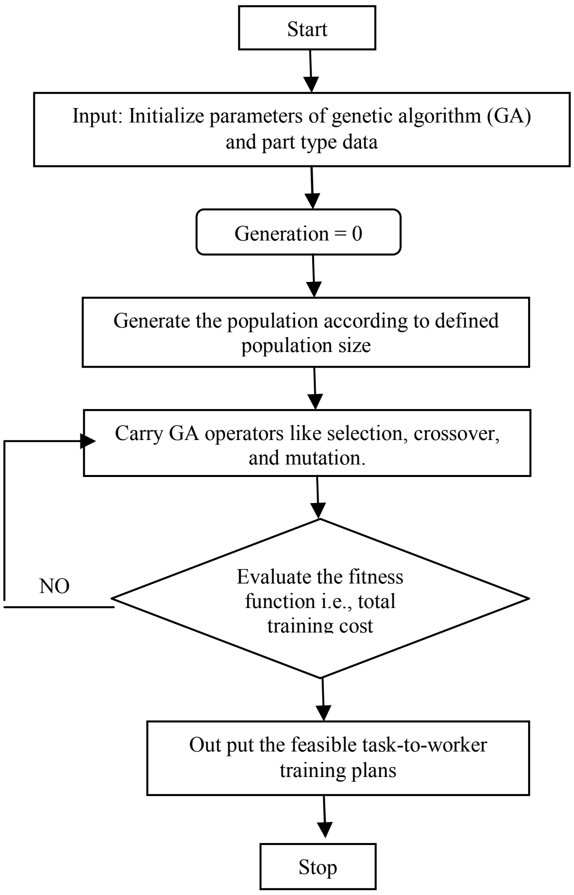

TABLE IV. WORKER-TO-SERU ASSIGNMENT PLAN

Worker	Seru1	Seru2	Seru3	Seru4	Seru5	Seru6
1	0	0	0	0	1	0
2	0	0	0	0	0	1
3	0	0	0	0	0	1
4	0	0	0	0	1	0
5	0	0	0	0	0	1
6	0	0	0	0	1	0

The worker to seru assignment plan shown in table IV where "1" signifies the corresponding assignment exists and "0" represents the assignment does not exist. Here we follow two conditions while assigning the workers.
Condition 1: If $Sv \neq \phi$ *and* $Sw = \phi$.
Accept the minimum total training cost and remove one or more workers from seru not belonging to S_v and maintain at least one worker for each seru otherwise, Remove workers from *Sw* and maintain at least one worker for each seru.

TABLE V. DIFFERENCE OF TOTAL TRAINING COST

Worker	Seru1	Seru2	Seru3	Seru4
1	72	271	134	195
2	319	207	136	340
3	116	59	136	65
4	62	152	85	260
5	122	181	136	183
6	125	108	185	21

TABLE V. ADJUSTED WORKER TO SERU

Worker	Seru1	Seru2	Seru3	Seru4	Seru5	Seru6
1	1	0	0	0	0	0
2	0	0	1	0	0	0
3	0	1	0	0	0	0
4	0	0	0	0	1	0
5	0	0	0	0	0	1
6	0	0	0	1	0	0

According to Table V and VI compute the total processing times of each worker and find out the maximum total processing time of the worker and the minimum total processing time.

TABLE VII. INITIAL TASK-TO-WORKER TRAINING PLAN

seru	Work er	T1	T2	T3	T4	T5	T6	Total cost (TC)
1	1	1	1	1	0	0	0	56
2	3	1	1	1	1	1	1	541
3	2	1	1	1	0	0	0	214
4	6	1	1	1	0	0	0	290
5	4	1	1	1	0	0	0	178
6	5	1	1	1	1	0	0	331

The process routing of six type of products are 1-2-3, 1-2-3-4-5-6, 1-2-3, 1-2-3, 1-2-3, 1-2-3-4 respectively, where the number denote the indexes of tasks. This computational case been coded in MATLAB software and the problem is tested on Intel Core^{TM}2 Duo CPU T7250 @2.GHz, 1.99 GB of RAM. In Table VII the TC represents the total training cost for all workers in the corresponding seru of the task-to-worker training plans.

V. CONCLUSIONS

Out of many new kind of conveyor assembly line, seru production system proves its capability due to its adaptability for merging with mass, job shop, and flexible manufacturing kind of environments. Although, the seru production system has been implemented on cross-training and assignment problems in a single shop floor environment still lots of issues have not been solved on distributed environment. In this paper, we have considered flexible job shop system where the resources are distributed geographically. To deal with the distributed manufacturing system it is necessary to have an effective mechanism for proper information sharing. Thus, first we have converted the data into knowledge and then an Ontology based

Protégé software has been used for generating knowledge into XML based files. Where transferring of information from one source to another is possible thus interoperability is achieved.

Second, we have investigated a cross training and assignment problem of multi-skilled works in the context of networked seru production system. Thereafter, a case of Indian manufacturing Industry is taken; a mathematical model has been formulated and found that it is a clear case of NP-hard problem. Later, with the developed heuristic and evolutionary algorithm the above mentioned problem is solved. Future work may include investigation of some more objectives that can be benefit to the distributed seru production systems.

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