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Review on the Inspection Allocation Problem (IAP) in Different Manufacturing Systems

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Abstract— the quality of products in different manufacturing systems has received lots of studying and attention. The aim is how to reach the required quality level on the way to meet customer requirements by using available resources. Applying a proper quality plan at industries is vital to cope with competitive markets and verify customer satisfaction. This paper reviews and classifies the inspection allocation problem (IAP) at different manufacturing system from 1981 to 2018. Numerous approaches have been investigated and classifications are given according to the inspection strategy, and techniques followed. Emphasis is devoted to minimize the cost of inspection and its related components.

Index Terms— Inspection allocation, Manufacturing systems, Optimization, Quality control, GA, Assembly line , serial manufacturing system .

1 Introduction

Quality is a term of excessive importance to both manufacturers and consumers. Nowadays, in the highly competitive market, many organizations realized that their survival in the market depend mainly on producing high quality products and services. Quality is one of the goals organizations pursue to achieve. But sometimes, this goal might be difficult to achieve due to some challenges (Oliver 1981).Quality control is responsible for defining quality purpose. The fundamentals for effective quality control are elimination of deficiencies and their causes in addition to minimization quality related costs such as; scrap, rework, rectification and inspection costs. All these costs are due to manufacturing problems that should not only be detected and corrected at the earliest time, but prevented if possible. Usually, quality defects are discovered during inspection (Willis et al. 2006). Inspection is an organized continuous assessment application. Inspection involves the examination, measurement, testing, gauging, and comparison of equipment, materials or parts (WHO 2011). Because of non-ideal manufacturing conditions and inherited variability of the production stages, deviations from design specifications results in low level of products quality (Rezaei-Malek, Mohammadi, et al. 2018). Inspection can be performed either after each operation or after several operations depending on the feasibility of location of the inspection station. This paper reviews the Inspection Allocation Problem (IAP) for quality inspection stations as it is proven to be an important topic in production/manufacturing systems both economically and technically. Solving the IAP enhances the product quality level and satisfies customers. Several researches have studied the IAP to enhance the quality inspection system and mathematical models have been applied to industrial systems to improve the efficiency and productivity through these attempts. The aim of solving the allocation of inspection stations problem is to allocate an economical number of stations which accomplish a certain level of quality and make the correct balance among different cost components. Researches are reviewed about the inspection allocation problem in different types of manufacturing systems in addition to the several techniques used to solve the problem.

The structure of this paper is organized as follows: Section 2 describes the inspection allocation problem classification, section 3 includes the IAP smart manufacturing system. While section 4 includes the conclusions. Figure 1 summarizes an outline of the search and selection criteria covered in this article.

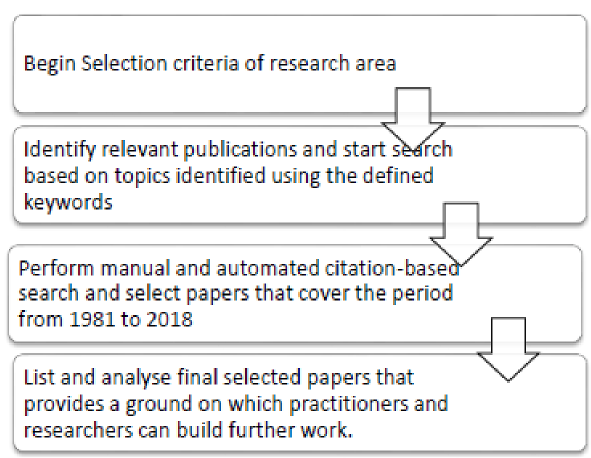

Fig.1. An outline of the search and selection criteria

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2. Classification of IAP

The chosen articles for this study are the ones that are the most recent when discussing the topic of inspection allocation problems in the period from 1981 to 2018 which covers a considerable time interval. Moreover, according to the literature, those articles concentrate mainly on the manufacturing systems characteristics, method of application and optimization. They discuss and present 3 problems that are commonly faced by practitioners and researchers concerning the IAP. The aim of allocation of inspection stations, which is schematically represented in figure 2, is to allocate an economical number of inspection stations ISi after operations in stations $wsi,;i=1,\ldots n$ which accomplish a certain level of quality and make the correct balance among different cost components. The most effective models are the ones that considered the most realistic assumptions as possible, so the system is characterized by the input data, relations and outputs. To monitor the system efficiently and optimize the number of inspection work stations, several factors should be recognized. The first factor is the production line configuration whether serial or non-serial should be identified. The second one is the inspection type used at the production line whether 100 % inspection or sampling inspection. Finally, the external and internal costs that will affect the system should be stated. All the mentioned factors are needed to evaluate the difficulty of the system and how to deal with the formulation of the problem.

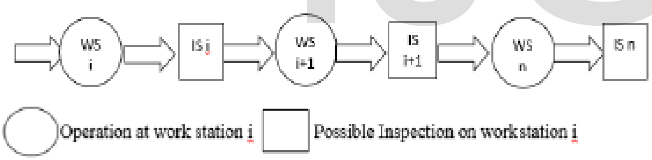

Fig.2. Inspection allocation problem schematic

2.1 Production line configuration

There are different types of manufacturing line depending on the produced products in a serial production system where the raw materials go through successive work stations and get processed in a sequential way, but when the raw material can be converted into finished products taking one or more paths through the system, it is called non-serial production system. However, the difficulty arises due to assembly stages at which multiple serial lines join to form a single serial line such as the case presented by (Carcano and Portioli-Staudacher 2006); they worked on assembly line and built up a mathematical model using stochastic simulation approach with two stages optimization technique; the objective was how to minimize the total balancing loss which defined in terms of the efficiency of the line by taking in consideration how to maximize the product reliability. The decision variable was how to allocate the optimal number of inspection stations after balancing the line by nearly equal distribution of the work elements on the available work stations to avoid slackness. The researcher distributed 21 elements at five work stations after the solution of assembly line balancing problem they added inspection station after each stage on the manufacturing line to meet the product quality and gain customer satisfaction. (Lqh and Zlwk 2015) recommended a new model to find the optimum assignment of quality inspection stations by solving the assembly line balancing problem, they studied a case study from a polish factory and the results from the proposed model is compared with different quality performances such as the efficiency of the line, smoothness index and the quality of the line. The model is built by adding only two inspection stations at the assembly line; they depended on the fact that stations that will produce a considerable number of defective parts will be followed by inspection station. After adding inspection points on the manufacturing line to minimize the total idle time there was a slight different in efficiency, smoothness index and quality of the line.

(Liu, Du, and Xi 2018) dealt with transient state analysis of quality system unlike many researches practiced steady state quality processes. They used the Markov model to achieve their goal at a two stages manufacturing system with the objective of developing the quality of produced products.

2.2 Solution techniques used in IAP

A variety of optimization approaches have been used to solve optimization problem that is formulated with different constraints and components. According to the massive review conducted on the IAP literature, a considerable amount of studies dealt with the problem as an optimization problem using exact and heuristic and meta- heuristic methods and few considered simulation.

2.2.1 **Exact optimization approaches**

The concept of exact optimization methods is based simply on enumerating the full solution space. Some of the most popular exact methods are the Complete Enumeration Method, Integer Programming, Linear Programming, Non-linear Programming, Branch and Bound and Dynamic programming which can be used to solve small size problems.

2.2.1.1 **Dynamic programming approaches**

Dynamic programming methodology enables solving the optimization problem by breaking it down into simpler sub-problems, solving different parts of the problem and then combining the solutions of the sub problems to find an overall solution. If the studied problem can be broken down into smaller sub problems, and these sub problems can still be broken into smaller ones then a dynamic programming problem is encountered. Some researchers proposed a dynamic programming model to solve inspection allocation problem. (Carcano and Portioli-Staudacher 2006)solve inspection allocation

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problem at serial production system with the objective of minimizing the inspection cost using imperfect inspection with inspection time should be less the process time as a constrain. (Wang 2005) proposed another dynamic programming model to solve the problem with offline inspection stations (Wang 2007) solve the problem but this time dealing with off line inspection stations and maintenance stations requirements with minimization objective function for the total cost of the manufacturing line.

(Wang 2009) solve the problem with on line inspection station approach. (Yang and Cho 2014) developed a model to minimize inspection cost at on line inspection stations. (Cudney, Qin, and Hamzic 2016) proposed two models to determine the optimal sampling levels for lots entering a multi-product production system, the main objective of these models is to minimize the total cost which will include the appraisal cost. They achieved their goal by determining an appropriate inspection size for each product with limited resources of labor time.

2.2.1.2 **Integer programming approaches**

Integer programming is a linear program in which all variables must be integers. The aim of integer programming is to find optimal decisions for problems. Integer programming models arise in almost every area of application of mathematical programming, it has played an important role in Capital Budgeting, Warehouse Location, and scheduling it has a great models supporting managerial decisions (Hamzic 2013). Some researches solved the IAP with mixed integer linear programming MILP, and mixed non-linear integer programing; (Hossain and Sarker 2017) worked on a new mixed integer linear programming model solved with branch and bound algorithm applied on a serial production system with no parallel work stations considered, they aimed to create an optimal decision from their model whether the defective parts should be scrapped or rework at online work station or at offline work station to improve the quality of the produced product with minimum total production cost per unit. Their research helped to minimize the wasteof productive time and waste of material as well as production cost. (Ouzineb et al. 2018a) developed a mixed non-liner integer programing model solved by standard shortest path algorithm to find the optimal buffering plan and get the optimal inspection strategy. The proposed model created new theoretical results which solve the buffer size bound and stationary. The objective of this research was minimizing the total cost and maximizing the productivity to get the customer satisfaction by maintaining a higher level of quality through optimizing the inspection station distribution which will affect the inventory on the manufacturing line. (Eger et al. 2018) used integer programing to reduce scrap, minimize time and quality cost by using a new strategy called zero defect manufacturing by enhancing the process control without additional process and inspection stages. It was applicable at three main engineering industries aerospace, railway and medical devices. They developed a new strategy that reduce scrap generation and prevent transmission of defects cross multi stage manufacturing system. (Hossain and Sarker 2016) Used mixed integer non liner programming to optimize rework stations with on line and off line inspection stations at flexible production system. (Ouzineb et al. 2018b) Dealt with Integer non liner programming to minimize the total cost by optimizing the buffer size and allocation of inspection stations at multi stage manufacturing system. (Mohammadi et al. 2018) Proposed a model with bi- objective function solved by mixed-integer linear programming to optimize the inspection plan at serial multi stage production system.

2.2.2 **Heuristic and Meta heuristic approaches**

A progressive method of solving an optimization problem, Heuristic and Meta heuristic algorithms refers to involvement techniques for problem solving that gives a solution which is not guaranteed to be optimal. Heuristic and Meta heuristic methods are used to speed up the process of finding a reasonable solution by a random way but intelligent at the same time to provide the researchers by innovation models to enhance the research. So, Researchers devoted their efforts to heuristics. Several of them built meta-heuristic algorithms such as Simulated annealing SA, Genetic algorithms GA obtaining near optimal solutions.

2.2.2.1 **Simulated annealing approaches**

Simulated annealing is a global optimization technique which distinguishes between different local optimal solutions. It is a memory less algorithm as it doesn’t use any gathering data during the search. It can deal with arbitrary systems and cost functions to find near optimal solution, it is relatively easy to code even for complex problems.

(Van Volsem, Dullaert, and Van Landeghem 2007) used simulated annealing to solve the inspection allocation problem in serial manufacturing system by applying sampling inspection plan with on line inspection strategy. (Nahas, Ait-Kadi, and Nourelfath 2006) improved the efficiency of the system by suggesting buffer allocation plan through distributing the buffer space between the intermediate buffers of the production line, then the size of buffer for each machine was provided optimally. This research dealt with homogeneous and non-homogeneous production lines with different processing times. The objective of the model was to maximize the total line throughput with suitable planning of the buffer size by estimating the performance of the line. Themodel has been built by using a meta-heuristic technique called the degraded ceiling method and the results were compared with simulated annealing approach. (Azadeh and Sangari 2010) proposed a simulated annealing model with a case study from a serial multi stages manufacturing line. The objective of the proposed model was to minimize the total cost taking in consideration non-inspection, sampling inspection and full inspection. They applied the penalty cost the cost of delivering defective products to the customer as an input; due to its important for any manufacturing company. (Chu 2005)proposed a new model to

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solve inspection allocation problem for serial production system with two types of work stations, work stations with attribute data and work stations with variables data which is more practical at the most industries. The model was applied in a printed circuit boards manufacturing facility by building a profit model to optimize the inspection allocation problem. The model concerned the capability of the inspection and the route of the defective part after inspection process.

2.2.2.2 **Genetic algorithm approaches**

A genetic algorithm is a Meta heuristic strategy inspired by Darwin's principle of natural selection. Genetic Algorithms are search algorithms based on the mechanics of natural selection and natural genetics (Sastry, Goldberg, and Kendall 2005).Some researchers used Genetic Algorithms to build their models; (Raviv 2013) used genetic algorithm with a profit maximization objective function at serial multi stage manufacturing system using off line inspection strategy. (Shiau, Lin, and Chuang 2007) considered inspection planning which dealt with the selection of the number and location of the inspection stations. They proposed a genetic algorithm model applied on advanced manufacturing system with a realistic cost plan taking in consideration internal and external costs. The generated model was compared with the enumeration method that generated an optimal solution for the problem. They concluded that GA saved time when compared with a complete enumeration method; the model was built with the flexibility to change to keep with the rapid variation of customer opinion from time to time. (Rau and Cho 2009) proposed a genetic algorithm model for a reentrant production system to optimize the allocation of inspection stations for maximizing the total profit with proposed proper parameters that will suit with various production systems. Manufacturing at reentrant production system is very difficult as the produced products are manufactured layer by layer. This complicates the identification of the source of defects. The researchers applied ANOVA analysis on the generated results from the genetic algorithm model at different mutation and cross over rates and compared the results with complete enumeration method that generated optimal solution. (Heredia-Langner, Montgomery, and Carlyle 2002) suggested a genetic algorithm model to solve inspection allocation problem to achieve their objective to maximize the average quality level and minimize the inspection cost for inspected produced products. This paper introduced several important factors; flexibility, variety and complexity of the parameters of the problem so the model can be modified at any time, it will depends only on how to the problem be formulated. They claimed that the generated model could be employed if any changes occurred on the parameters of the production line so it could be modified when necessary at any time with any problem.

2.2.2.3 **Particle swarm approaches**

In the computational intelligence area, particle swarm optimization is computational method that optimizes a problem by iteratively trying to improve candidate solution with regard to a given measure of quality (Azadeh, Sangari, and Amiri 2012). (Azadeh et al. 2015) proposed particle swarm mathematical model to achieve the optimal inspection policies at serial multistage manufacturing system. The proposed model minimize the total inspection cost by using fuzzy model and crisp model as it is more efficient and has lesscomputational time.

2.3 **Simulation at IAP**

Simulation is used to model any systems efficiently with changing some relationships or parameters to imitate the real world system. It save time and sometimes save cost by applying simulation at manufacturing systems so many researchers used simulation to making sure of its results and to improve the quality of the manufacturing line (Basic et al. 2011). (Maleki and Aghazadeh Shabestari 2018) used enterprise dynamic software for simulation and comparing the results with the optimization model introduced from an integer programming model to allocate inspection stations to the manufacturing process with heuristic approach to minimize the total cost of quality with taking in consideration the prevention and appraisal cost applied at electromotor manufacturing company. The proposed model not only aimed for preventing wastes but also reducing cost burden by using Pareto chart. (Vaghefi and Sarhangian 2009) solving the inspection allocation problem by comparing heuristics with simulation at serial multi stages manufacturing system. (Korytkowski and Wisniewski 2012) optimize the inspection allocation problem by simulation but with multi products manufacturing system with on line inspection stations. (Rakiman and Bon 2013) proposed a model using simulation to optimize the allocation of inspection station to minimize the production line using off line and on line strategy. (Shetwan, Vitanov, and Tjahjono 2011) Dealt with a genetic algorithm model for inspection allocation problem to allocate an appropriate level of inspection by determining the correct number of inspection stations with balancing different cost components. A serial manufacturing system has been conducted to examine the inspection allocation problem; the system consists of ten workstations with performing 100% inspection screen to all produced products. They made a limitation for the number of inspection stations assigned. The improved heuristic model was constrained by inspection time and the number of parts will be inspected. They compared the generated results from the proposed heuristic model by simulation to measure the performance of the proposed one.

(Azadeh et al. 2012) (Azadeh et al. 2015) used simulation to provide better solution for the problem by applying the simulation several times at the same production line with the same solution algorithm to obtain the optimal solution for inspection allocation problem.

3. IAP in smart manufacturing system

In the smart manufacturing/industry 4.0 era, production processes are becoming more flexible and in the same time more difficult to plan. More customized products in irregular batch

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sizes are to be produced. Minimizing the number of defective parts will require companies to create their customized inspection and quality control procedures to match the vibrant manufacturing environment. Research concerning Quality 4.0 and smart inspection is still uncovered except for few studies.

(Kang et al. 2018) worked on goal programming to solve inspection allocation problem at multi-stages manufacturing system by applying off line inspection stations at smart manufacturing system. This research introduced a multi objective optimization model to determine the optimal decision variables that lead to optimal solution for number of inspectors, inspection errors and inspection quantity in a smart manufacturing system. They used goal programming to solve a multi objective optimization model to determine the optimal number of inspectors of different skills required to meet the demand. A case study for three different products where skills of the inspectors were classified as low, medium and high was conducted and they concluded that the level of inspectors has significant effects on inspection performance. This research didn't cover the effect of the learning curve in a technologically based environment on the inspection cost, inspection time and inspection quantity. Advanced techniques such as image processing and advanced sensors were not considered.

(Haladuick and Dann 2018) worked on different era of smart manufacturing. They worked on a complex structure manufacturing system which is pressure vessel. The researchers dealt with one objective function which how to optimize the utility of the system or device over its life cycle, they used genetic algorithm to solve two model the first one based on inspection risk and the second one based on maintenance risk and comparing genetic results with exhaustive search and the results have been concluded that genetic algorithm is faster than the exhaustive search by seventh times but giving almost the same results. (Rezaei-Malek, Siadat, et al. 2018) used mixed integer liner programming to solve the problem of allocation inspection and preventing maintenance stations with a bi- objective optimization function to know the time and place for inspection station. They assumed that the cost parameters and demand are uncertain as the fluctuations of the real market and validate the proposed model and verify it with case study with real numerical data. (Illés et al. 2017) introduced a study on the essence of industry 4.0 and the new challenges for the quality assurance of manufacturing processes. They discussed the tools of industry 4.0 which are internet of things, cyber physical systems and big data concepts and the importance of these tool to enhance the quality of mass production systems by minimizing routes of material handling and ensuring communication midst production system substances.

According to literature the IAP can be classified to these main points first the type of production line, second the inspection strategy, third the inspection capability, fourth inspection type, finally the objective of the model and cost components will be taking in consideration. Each of these points is elaborated through sub categories illustrated in table 1.

The results concluded from summarized papers at table 1 are as follow, 87% from the reviewing papers dealing with serial multi stages manufacturing system, 83% from these papers conducted the IAP with full inspection strategy, 66% from the researchers built their mathematical models with two miss classification errors type 1 and type 2. It is clear that the common objective functions is how to minimize the total cost and inspection cost with equal percentage 45% from the reviewing papers and the rest 10% of the papers dealing with profit maximization objective function. Almost 91% from the researchers taking in considerations manufacturing costs, inspection costs, scrap costs and rework cost but only few papers proposed the repairing costs at their models.

4. Conclusion

There are different models for inspection allocation problem, they differ according to the proposed objective function and the production line to be used. Most common objectives set for inspection allocation problem are minimizing the cost of inspection or the total cost of the manufacturing system and /or maximizing the quality of produced products. The reviewed articles didn't cover all possible cost factors that affect the modern manufacturing organizations such as work in process cost, setup rework cost and transportation costs. SA and GA was found to be comprehensively used in solving inspection allocation problem, as it proved that the genetic algorithm has high solution performance. But many researchers neglect to study the effect of changing Genetic Algorithm parameters cross over, mutation and elite percentage on the inspection allocation problem generated model. Inspection time was neglected in most models, however it is very important parameter should be taken in consideration. Another shortage discovered throughout this study is the inclusion of operator's performance in the IAP. It is a vital parameter which has an effect on the performance of inspection process and the quality of produced products.

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Table 1. IAP classification at literature

Author and year	Production line			Inspection strategy		Inspection capability			Objective function			Inspection type		Cost components				
	Serial	Non serial	Assembly line	100% inspection	Sampling inspection	Error free	Type I	Type II	Minimize total cost	Minimize inspection cost	Maximize profit	On line	Off-line	Inspection cost	Manufacturing cost	Scrap cost	Rework cost	Repair cost
(Heredia-Langner, Montgomery, and Carlyle 2002)	√	√		√			√	√		√		√		√	√	√	√	
(Wang 2005)	√			√			√	√	√				√	√	√	√	√	
(Chu 2005)	√			√		√			√			√	√	√	√			
(Carcano and Portioli-Staudacher 2006)		√	√						√			√		√	√	√	√	
(Nahas, Ait-Kadi, and Nourelfath 2006)	√	√		√		√					√	√		√	√		√	
(Shiau, Lin, and Chuang 2007)	√			√			√	√	√			√		√	√	√	√	
(Wang 2007)	√			√			√	√	√				√	√	√	√	√	√
(Van Volsem et al. 2007)	√				√		√	√		√		√		√	√	√	√	√
(Wang 2009)	√			√			√	√	√				√	√	√	√	√	
(Vaghefi and Sarhangian 2009)	√			√		√				√			√	√	√	√	√	

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