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RESEARCH ARTICLE

Comparative Simulation Study for Configuring Turning Point in Multiple-Robot Path Planning: Robust Data Envelopment Analysis

Hamed Fazlollahtabar[1]

[1]Department of Industrial Engineering, School of Engineering, Damghan University, Damghan, Iran.
Corresponding author. E-mail: hfazl@du.ac.ir

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Abstract
Abstracts should be 250 words. It must be able to stand alone and so cannot contain citations to the paper's references, equations, etc. An abstract must consist of a single paragraph and be concise. Because of online formatting, abstracts must appear as plain as possible.

1. Introduction

One of the important industrial segments is material transportation system (MTS). It is because customers typically demand for shorter delivery time and lower transportation charge. This put the organizations under continuous pressure to implement various operational approaches and policies to achieve both aims. Therefore, minimizing delivery time should be conducted efficiently. Robot is one of the MTS used in manufacturing shop floor to move materials between stations in an automated manufacturing system. Robot is preferred over other transportation approaches due to the flexibility and mobility attributes it could offer.

Material handling is one of the widest spread application processes utilized in manufacturing today. While many manufacturers use material handling robot systems, several are moving toward material handling workcells, which consist of one or multiple robots, doing several tasks at one station. A material handling workcell is one of the most versatile workcells available on the market today. While welding workcells are usually confined to either spot or arc welding applications, material handling workcells can perform a dozen different tasks depending on the end-of-arm-tooling available. In an effort to make manufacturing more efficient, manufacturers are turning more to workcells for material handling. These workcells can perform several tasks within one workcell. Within these workcells, material handlers can work with other robots, CNC machines, or even human workers. They can be used to transfer parts into different machines that are positioned around it at one station, or they can take parts from an assembly robot within the material handling workcell and place them on a turntable or other positioner for a human worker to grab and take to the next area. A robotic manufacturing cell is shown in Figure 1.

According to statistics in 1989 (Gould, 1990), robot systeminstallations with respect to their application types were profiled as following: just-in-time delivery systems (56%), flexible manufacturing systems/flexible assembly system (FMS/FAS) transfer system (13%), storage load transfer, non-AS/RS (12%), AS/RS interface (8%), progressive assembly (7%), mini-load AS/RS interface (1%), and others (3%). Some other applications of AGV systems in non-manufacturing environments include, but are not limited to, delivering mail, messages, and packages in offices, and delivering meals and laundry in hospitals.

2. Robotic manufacturing cell and concept of turning point

In a modern production facility, automation is a central key to creating competitive advantage and responding to the constantly increasing demands on production. We supply future-oriented and highly automated manufacturing cells based on standardized and flexible cell concepts. Robots are ideal for automated cells – spindles are consistently fed, so machine utilization is high, while grouping equipment close together means secondary operations can also be automated and in-process inventory eliminated. Waste is reduced through early detection of quality problems and less floor space is needed. Robotic cellular manufacturing is a flexible approach that enables cost-effective automated production of low- and medium-volume product families.

2.1. Fundamental Idea

The fundamental idea means here a somewhat informal description of the hidden Markov model and its relationship with a time series.

3. Simulation model configuration

Transport jobs are from different cells to others. For each robot, a destination is drawn from a uniform distribution. Robots travel with constant speed. Except for the destination choice, no stochastic behavior is modeled. Begin and end of the trajectories are discarded; obstacles are avoided using the proposed turning point model.

All robots' transportation times in the simulation are set to zero. Thus, only driving robots are considered. For the “without turning point" strategy, only the average driven distance is used to compute a possible job performance without considering the effects of congestion. Hence, a linear relation between the number of robots and transport capacity is assumed. For the “with turning point" strategy, the turning point is used to reduce the number of deadlocks to zero. Thus, congestion results in nonlinear behavior when a large number of robots are employed.

4. Discrete event simulation for multiple-robot cell manufacturing

Discrete event simulation (DES) refers to simulation that employs mathematical and logical models of a physical system to represent state changes at precise points in simulated time. Taking advantages of the computing advancement, DES has been intensively developed for modeling, simulating, and analyzing dynamic and complex systems. This is meant to enable research on advanced industrial system to be conducted. Among simulation-based researches for manufacturing applications include those conducted by Gupta, Singh, and Verma (2010) and Manup and Raja (2016). Consequently, ARENA and Simul8 simulation software are used to model material handling operation within a manufacturing cell. There are several advantages of the Simul8 software particularly in its ability to accommodate mathematical and logical procedure with relative ease through Visual Logic. Furthermore, it is also possible to integrate codes developed using Visual Basic into Simul8 simulation framework.

4.1. Simulation modeling

In this section, the proposed model is implemented using real production data in a simulation environment.

4.2. Simulation process operators

The simulation experiment is carried out in accordance with the procedure follows here. The first test used to verify the simulation result is called chi-square goodness-of-fit test. Its purpose is to test for distributional adequacy. The chi-square test is used to test if a sample of data came from a population with a specific distribution. An attractive feature of the chi-square goodness-of-fit test is that it can be applied to any univariate distribution for which one can calculate the cumulative distribution function. The chisquare goodness-of-fit test is applied to binned data (i.e., data put into classes). This is actually not a restriction since for non-binned data one can simply calculate a histogram or frequency table before generating the chi-square test. However, the values of the chi-square test statistic are dependent on how the data is binned. Another disadvantage of the chi-square test is that it requires a sufficient sample size in order for the chi-square approximation to be valid.

The chi-square goodness-of-fit test can also be applied to discrete distributions such as the binomial and the Poisson rather than continuous ones. The Kolmogorov-Smirnov (K-S) and Anderson–Darling tests are restricted to continuous distributions.

5. Equations

Equations in LaTeX can either be inline or on-a-line by itself. For inline equations use the `$...$` commands. Eg: The equation $H\psi = E\psi$ is written via the command $H\psi = E\psi$.

For on-a-line by itself equations (with auto generated equation numbers) one can use the equation or eqnarray environments D.

$$\mathcal{L} = i\bar{\psi}\gamma^{\mu}D_{\mu}\psi - \frac{1}{4}F_{\mu\nu}^{a}F^{a\mu\nu} - m\bar{\psi}\psi \tag{1}$$

where,

$$\begin{aligned} D_{\mu} &= \partial_{\mu} - ig\frac{\lambda^{a}}{2}A_{\mu}^{a} \\ F_{\mu\nu}^{a} &= \partial_{\mu}A_{\nu}^{a} - \partial_{\nu}A_{\mu}^{a} + gf^{abc}A_{\mu}^{b}A_{\nu}^{a} \end{aligned} \tag{2}$$

Notice the use of `\nonumber` in the align environment at the end of each line, except the last, so as not to produce equation numbers on lines where no equation numbers are required. The `\label{}` command should only be used at the last line of an align environment where `\nonumber` is not used.

$$Y_{\infty} = \left(\frac{m}{\text{GeV}}\right)^{-3}\left[1 + \frac{3\ln(m/\text{GeV})}{15} + \frac{\ln(c_2/5)}{15}\right] \tag{3}$$

The class file also supports the use of `\mathbb{}`, `\mathscr{}` and `\mathcal{}` commands. As such `\mathbb{R}`, `\mathscr{R}` and `\mathcal{R}` produces $\mathbb{R}$, $\mathscr{R}$ and $\mathcal{R}$ respectively.

6. Figures

As per the LaTeX standards eps images in `latex` and pdf/jpg/png images in `pdflatex` should be used. This is one of the major differences between `latex` and `pdflatex`. The images should be single page documents. The command for inserting images for latex and pdflatex can be generalized. The package that should be used is the graphicx package. See Figure 1.

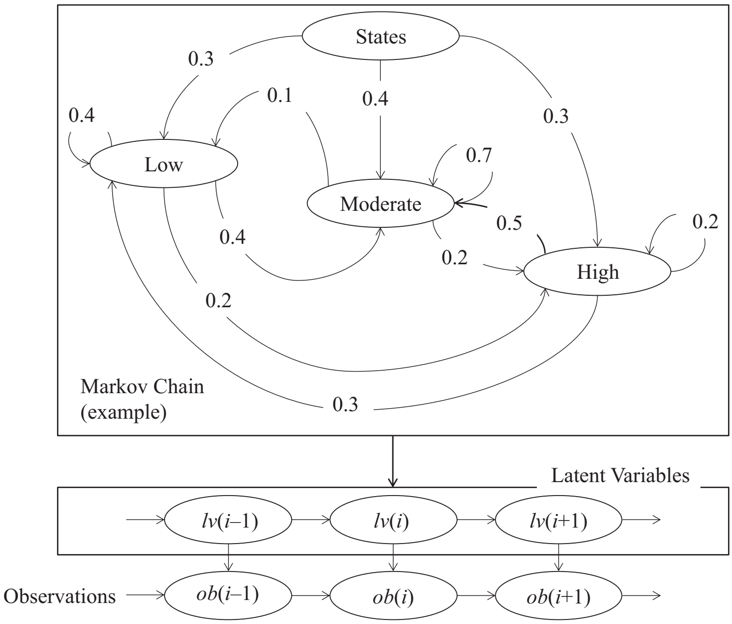

Figure 1. The concept of hidden Markov model.

7. Tables

Tables can be inserted via the normal table and tabular environment. To put footnotes inside tables one has to use the additional “fntable" environment enclosing the tabular environment. The footnote appears just below the table itself. See Table 1.

Table 1. Tables which are too long to fit, should be written using the “table*" environment as shown here

	Element 1			Element 2[1]		
Projectile	Energy	σ_{calc}	σ_{expt}	Energy	σ_{calc}	σ_{expt}
Element 3	990 A	1168	1547 ± 12	780 A	1166	1239 ± 100
Element 4	500 A	961	922 ± 10	900 A	1268	1092 ± 40

[0]**Note:** This is an example of table footnote this is an example of table footnote this is an example of table footnote this is an example of table footnote this is an example of table footnote
[1]This is an example of table footnote

8. Cross referencing

Environments such as figure, table, equation, align can have a label declared via the `\label{#label}` command. For figures and table environments one should use the `\label{}` command inside or just below the `\caption{}` command. One can then use the `\ref{#label}` command to cross-reference them. As an example, consider the label declared for Figure 1 which is `\label{fig1}`. To cross-reference it, use the command `Figure \ref{fig1}`, for which it comes up as “Figure 1". The reference citations should used as per the "natbib" packages. Some sample citations: Alam and Saddik (2017); Chui et al. (2013); Oliveira et al. (2017); Talkhestani et al. (2018).

9. Lists

List in LaTeX can be of three types: enumerate, itemize and description. In each environments, new entry is added via the `\item` command. Enumerate creates numbered lists, itemize creates bulleted lists and description creates description lists. List in LaTeX can be of three types: enumerate, itemize and description. In each environments, new entry is added via the `\item` command. Enumerate creates numbered lists, itemize creates bulleted lists and description creates description lists.

1. This is the 1st item
2. Enumerate creates numbered lists, itemize creates bulleted lists and description creates description lists.
3. Numbered lists continue.

List in LaTeX can be of three types: enumerate, itemize and description. In each environments, new entry is added via the `\item` command.

- This is the 1st item
- Itemize creates bulleted lists and description creates description lists.
- Bullet lists continue.

10. Conclusion

Some Conclusions here.

Supplementary material. To view supplementary material for this article, please visit http://dx.doi.org/10.1017/wtc.2019.116.

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Competing interests. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guides on the care and use of laboratory animals.

Author contributions. R.C. and S.K.H. designed the study, abstracted the data, wrote the first draft, and approved the final version of the manuscript. A.R.E.J., M.R.L., K.L.S., and A.D.P. revised the manuscript and approved the final version.

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