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PROCESS IMPROVEMENT FOR TRADITIONAL MOULD MAKING PROCESS THROUGH GROUP TECHNOLOGY AND RANK-ORDER CLUSTERING ALGORITHM

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ABSTRACT

The current environment of changing market trends that include mass customization, sustainability, environmental impact and localized production drives the manufacturing industry to strive for additive manufacturing because of the versatility of the technology. Injection Moulding Company (IMC) is using traditional manufacturing approaches which compromise its competitiveness resulting in decreased production rate and high operational costs due to lengthy changeover times. The aim of the study was to investigate the usage of group technology and rank-order clustering algorithm as mechanisms to aid the reduction of manufacturing lead time for the traditional mould making process. ABC mould demand classification analysis conducted for the top 16 moulds revealed that the moulds for the switch cover ranked highest in terms of the demand of moulds that were fabricated by IMC. The value stream map revealed that there was room for improvement in terms of push to pull and frequent lot transfer, standardising work, reducing cutting time and process scrap, as well as introducing poka yokes and cellular manufacturing, and it was proposed to reduce material movements and setup times. Through the deployment of group technology and rank clustering algorithm, three mould families and three machine cells were derived. As a result, the mould fabrication process was improved by reducing material movements and reducing setup times.

Keywords: Group technology, Rank-order clustering algorithm.

1. INTRODUCTION

The current environment of changing market trends that include mass customization, sustainability, environmental impact and localized production drives the manufacturing industry to strive for additive manufacturing because of the versatility of the technology (Francis 2018). Rapid tooling is described as the fast production of parts or tools such as mould inserts for traditional manufacturing such as investment and vacuum casting (Equbal, Sood and Shamim 2015). Vertical integration at IMC is fundamentally considered as vital since it gives the organisation some robust degree of control over its operations, having increased market control, and an ability to offer lower prices. Considering the disruption caused by the coronavirus pandemic, vertical integration for IMC conveys a possible advantage over its competitors since independence from suppliers in the value chain enables control over costs. Additionally, during the Covid 19 pandemic, there is substantial unpredictability that characterise relying on third party suppliers.

Vertical integration increases process efficiency, and this promotes greater time efficiency and shorter lead times. However, technology is changing, yet the case study IMC was using traditional manufacturing approaches which compromised its competitiveness resulting in uncompetitive production rate and high operational costs due to lengthy changeover times. As a vertically integrated organisation, IMC is currently facing challenges in providing rapid response with on-hand expertise for evolving project needs, guaranteeing the quality of the product through its full life cycle, and overseeing production that would translate to shorter lead times and on-demand delivery. The key concern for the case study organisation is lengthy production lead time for the mould and die manufacture and this becomes a problem since clients expect quick product delivery. Additionally, product lifecycles have become shorter, and production includes smaller lots sizes in the global village. Hence, it is against the backdrop of these challenges that the aim of the study is to reduce material movements and reducing setup times for the traditional mould making process, increase the production rate and reduce operational costs for the case study organisation by investigating the usage of group technology and rank-order clustering algorithm.

2. LITERATURE REVIEW

Injection moulding is also one of the current operations and processes that characterise the IMC. Moulds and dies are tools that are essential for mass production in present-day manufacturing (Wadhwa 2012). This section focuses on injection moulding given that the first objective of the study is to establish the current operating environment that characterise IMC for the plastic industry, specifically in injection moulding. A mould is a hollow block that is filled with a pliable or liquid material such as plastic, ceramic, metal, or glass material, the raw material sets or hardens inside the mould, thereby taking its shape (Silver and McLean 2008). Articulated moulds are characterised by multiple pieces that are assembled to form the complete mould, and then disassembled to release the final casting, are costly, but essential if the casting has complicated overhangs. On the other hand, several different moulds are used in piece-moulding, with each mould creating a segment of a complex object (Gawdzinska et al. 2018).

The techniques that are available currently are able to create micron-order precision moulds and dies, contributing to the mass production of products with the same shape and quality in a wide range of areas (Ishizaki, Komarneni and Nanko 2013). The most common mould rubbers are natural latex, polyurethane, epoxy and silicone. There are number of types of moulds and these include injection, blow, matrix, rotational, extrusion, spin and transfer moulding (Vlachopoulos and Strutt 2003).

The injection moulding process is cyclical and is characterised by plasticising and an injection, wherein the plastic is injected into a mould through a heated cylinder (Singh and Verma 2017). As shown in Figure 2.1, a hopper is used to feed the raw materials into the injection moulding machine. The raw material is fed into the screw channel by a rotating screw and is melted due to frictional heat that is generated by rotating the screw, and additionally, heat is transferred by conduction from the heater bands. The pressure builds when the screw moves forward, and thereafter, the screw moves backwards to fill the front end of the screw barrel with molten material. The plasticising stage is accomplished when the barrel is filled with the desired volume of the molten and the screw rotation stops (Fernandes et al. 2014). The injection phase is characterised by four key steps, which are filling, packing, cooling, and ejection. During the filling phase, the unfilled mould is sealed by a clamp unit and the screw is moved forward. In the next step, mould filling is accomplished, and the screw moves with a small displacement or is held in the forward position to maintain pressure, while the material cools down. The cavity pressure is reduced during the cooling phase, and the part cools down and solidifies. Lastly, following adequate cooling, the part becomes stiff, and the mould opens, ejects the part, closes again and the cycle restarts (Singh and Verma 2017).

Group technology (GT) is a philosophy whereby similar parts are identified and grouped together and was adopted to take advantage of their similarities during production (Singh and Rajamani 2012). Sousa et al. (2010) posited that group technology can be exploited to performing similar activities together, thereby avoiding wastage of time on the changes for switching from one activity to another unrelated activity. On the other hand, Huang and Li (2010) proposed a hybrid approach of Group technology and case-based reasoning to design injection mould embracing the notion that the structure of plastic parts is extremely complex and diverse.

Abdelhadi (2018) used the concept of group technology, and that resulted in grouping of machines according to the effect of failure based on the criteria specified by the decision makers. Accordingly, the benefits facilitated the process of maintenance execution through the ordering of spare parts leading to maintenance cost minimisation. To improve the utilisation of machines as well as productivity of additive manufacturing processes under the context of multiple parts production, Zhang and Bernard (2014) proposed the concept of group technology. Based on the GT, a modified group technology for AM under multiple parts manufacturing context is presented. A set of key attributes affecting the additive manufacturing production cost, time, quality and work preparation were identified to represent the parts for grouping and similarity analysis was conducted through the adoption of Grey Clustering method.

The Rank-order Clustering Algorithm (ROCA) was introduced by King (1980) and is used in cell manufacturing systems to optimise a manufacturing process based on key independent variables with weights and reorganisation of machine-product data. The binary weights are computed from a machine part matrix and the cells are formed so that each cell would have approximately the same work load (Amruthnath and Gupta 2016). Danilovic and Ilic (2019) posited that the problems related to cell formation in manufacturing systems are complex NP-hard problems and developed a novel hybrid algorithm for manufacturing cell formation. The goal of the algorithm was to use the specificities of the input instances to narrow down the feasible set for the cell formation problem and derive a more efficient algorithm characterised by higher efficiency and efficacy. The results demonstrated a robust hybrid algorithm that can solve complex cell formation problems and multi-criteria optimisation problems.

On the other hand Jahan and Souri (2020) used multi-attribute decision-making algorithm for cell formation based on similarity in parts design to create a cellular model. An improved algorithm with ROCA and row and column masking methods was proposed and the superiority of the improved algorithm was realised when the results were compared to the previous methods using the productivity index.

The current study considered the applicability of the ROCA in comparative analysis of traditional die manufacturing for injection moulding which were configured using the Rank-order Clustering algorithm. The essence of the study would be to develop a sustainable business case that reduces operational costs or increase the production rate in the manufacture of moulds.

3. METHODOLOGY

The research approach embraced group technology philosophy in which similar parts are identified and grouped together was adopted to take advantage of their similarities during production (Debnárová et al., 2014). A mould demand classification analysis was done followed in applying group technology include determining the critical part attributes that represent the criteria for part family membership and allocation of parts to established families.

A mould demand classification analysis was developed to provide a detailed visualization of all steps that characterized the injection moulding process and the steps that were followed include:

- Step 1: Gather preliminary information on the history of product mix from the previous year's demand and the product volumes for each mould from the previous year.
- Step 2: Create a product quantity routing analysis by creating a product quantity routing analysis, by listing all of the moulds built by IMC.

The information required for the GT coding system was divided into two groups, that is geometrical and dimensional data. The mould making process information for GT code followed a chain structure characterised by the following:

- Part type - The material type of each mould was coded and currently, there are 30 diverse material types used by IMC mould making.
- Part weight - wherein the weight of each part was coded and since weight is a continuous variable, the mould weights were divided into ten categories
- Dimensional specifications - These specifications include maximum length, width and height) of each mould.

According to King (1980), considering a binary part-machines n-by-m matrix b_{ij}, the following steps are used:

1. Compute the number $\sum_{j=1}^{m} b_{ij} \times 2^{m-j}$ for each row i;
2. Order the rows in accordance to the descending numbers that were computed previously
3. Compute the numeral $\sum_{i=1}^{n} b_{ij} \times 2^{n-i}$ for each column j
4. Order the columns in accordance to the previously computed descending figures
5. If no reordering occurred on steps 2 and 4, then proceed to step 6, otherwise execute step 1
6. Stop

4. RESULTS AND DISCUSSION

Product analysis was done with the intention to comprehend the demand of different moulds and dies that were produced by IMC. The product listing of the moulds that were produced at IMC were pulled out from the SAP database and it was noted that about 600 different moulds had been fabricated since the last two years. Table 1 shows the annual demand and cumulative percent for top 16 moulds produced by IMC. The results show a total of 144 000 moulds that were produced in year 2020.

Table 1: Annual demand for top 16 moulds produced by IMC

Mould type	Annual demand	Percent of Total	Cumulative Percent
Switch cover	25200	17.50%	17.50%
Smart phone	23400	16.25%	33.75%
Helmet shell	21500	14.93%	48.68%
Air filter housing	11200	7.78%	56.46%
Automotive dashboard	10600	7.36%	63.82%
Television Cabinet	10450	7.26%	71.08%
Battery Casing	9647	6.70%	77.78%
Printer casing	4700	3.26%	81.04%
Power-tool housing	4620	3.21%	84.25%
Automotive bumper	4556	3.16%	87.41%
Plastic syringe	4400	3.06%	90.47%
Remote control	3851	2.67%	93.14%
Toy	2616	1.82%	94.96%
Bottle cap	2440	1.69%	96.65%
Pocket comb	2420	1.68%	98.33%
Wheelie bin	2400	1.67%	100.00%
Total	**144 000**	**100.00%**	

ABC mould demand classification analysis (ABC analysis) was conducted for the top 16 moulds that were produced by IMC. The results in Figure 1 show that under the A-category of the ABC mould demand classification analysis, the moulds for the switch cover, smart phone and helmet shell contributed 48.68% to the total demand of moulds that were fabricated by IMC.

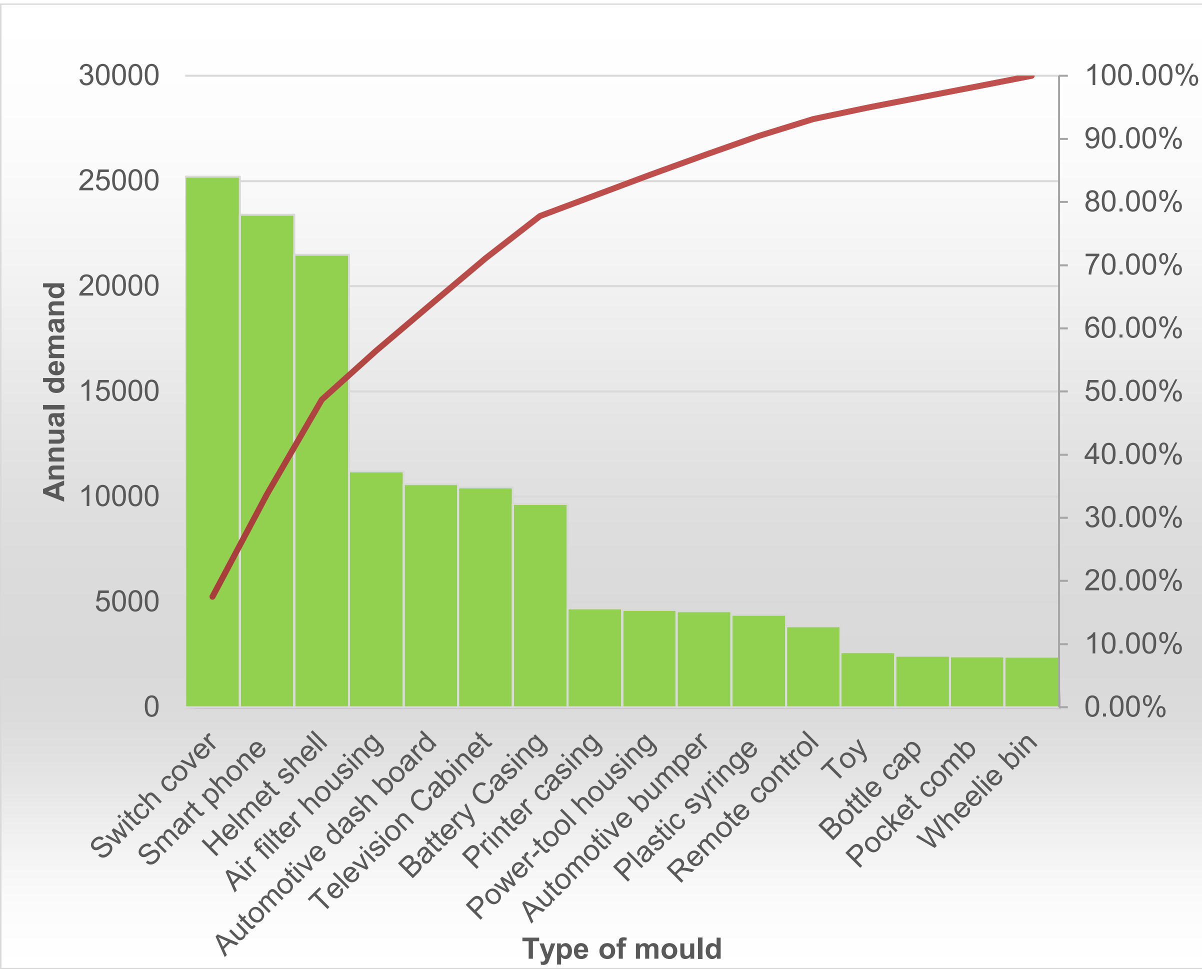

Figure 1: ABC mould demand classification analysis for demand of mould types

The B-category of the ABC mould demand classification analysis consisted of air filter housing, automotive dashboard, television cabinet and battery casing moulds that contributed 29.1% to the total demand of moulds that were fabricated by IMC. On the other hand, the C-category of the ABC mould demand classification analysis contributed 22.22% to the total demand of moulds that were fabricated by IMC.

Table w shows the machine types and top 9 moulds from ABC mould demand classification analysis in the previous chapter. Similar parts were identified and grouped together to take advantage of their similarities during production. Master moulds and master unit dies for quick-change for the traditional injection mould making were proposed through the composite part concept. The Rank-order Clustering algorithm (ROCA) is an easy-to-use and efficient algorithm for grouping machines into cells and in this case was used to group the mould manufacturing equipment. The occupied locations in the matrix were arranged in a randomized manner for the commencing mould-machine incidence matrix that was compiled to document the mould routings for the machine shop.

Table 2: Coded parts and machines selected for ROCA

Code	Mould type	Code	Machine type
R	Switch cover	1	Joemars EDM Model 322
S	Smart phone	2	CNC Dielectric Fluid EDM S50
T	Helmet shell	3	Conytrok GS600 high precision CNC
U	Air filter housing	4	Turret milling machine CF-A2
V	Automotive dashboard	5	CNC Wire Cutting EDM DK7740
W	Television Cabinet	6	Aristech CNC 430 Die sinking EDM
X	Battery Casing	7	ONA-S64 penetration EDM
Y	Printer casing	8	Sodick AG35L EDM CNC
Z	Power-tool housing		

ROCA was used to reduce the mould-machine incidence matrix to a set of diagonalized blocks that represented mould families and related machine groups. Commencing with the initial mould -machine incidence matrix shown in Table 5.2, the algorithm that was highlighted in Section 4.6 was followed.

Table 3: Initial mould -machine incidence matrix

	Mould								
Machines	R	S	T	U	V	W	X	Y	Z
1	1								1
2		1					1		
3			1		1			1	
4		1				1	1		
5			1					1	
6						1	1		
7	1			1					
8			1		1				

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1. For each row in the matrix, the series of 1s and 0s (blank entries = 0s) from left to right was read as a binary number. The rows were thereafter ranked in order of diminishing value. The rows were ranked in the same order as they appeared in the current matrix in the event of a tie.

Step 1

	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0		
	R	S	T	U	V	W	X	Y	Z	**DE**	Rank
1	1								1	257	2
2		1					1			132	4
3			1		1			1		82	5
4		1				1	1			140	3
5			1					1		66	7
6						1	1			12	8
7	1			1						288	1
8			1		1					80	6

2. Numbering from top to bottom, the current order of rows was checked to see if it was the same as the rank order determined in the previous step. The results were found to be negative.

Step 2

	R	S	T	U	V	W	X	Y	Z	
7	1			1						2^7
1	1								1	2^6
4		1				1	1			2^5
2		1					1			2^4
3			1		1			1		2^3
8			1		1					2^2
5			1					1		2^1
6						1	1			2^0
DE	192	48	14	128	12	33	49	10	64	
Rank	1	5	7	2	8	6	4	9	3	

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3. Commencing from the top, the rows in part-machine incidence matrix were reordered by listing in decreasing rank order.

Step 3

	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0		
	R	U	Z	X	S	W	T	V	Y	**DE**	Rank
7	1	1								384	1
1	1		1							96	2
4				1	1	1				56	3
2				1	1					48	4
3							1	1	1	7	6
8							1	1		6	7
5							1		1	5	8
6				1		1				40	5

4. The series of 1s and 0s, with blank entries = 0s, were read from top to bottom as a binary number for each column of the matrix. The columns were thereafter read in order of decreasing value. The columns were ranked in the same order as they appeared in the current matrix in the event of a tie.

Step 4

	R	U	Z	X	S	W	T	V	Y	
7	1	1								2^7
1	1		1							2^6
4				1	1	1				2^5
2				1	1					2^4
6				1		1				2^3
3							1	1	1	2^2
8							1	1		2^1
5							1		1	2^0
	192	128	64	56	48	40	7	6	5	
Rank	1	2	3	4	5	6	7	8	9	

5. The current order of columns was found to be the same as the rank order determined in the previous step when numbering from left to right,

The final part families and machine groups at the end of the ROCA were:
I = (R, U, Z) and (7, 1); II = (X, S, W) and (4, 2, 6); III = (T, V, Y) and (3, 8, 5)

The value stream map revealed that there was room for improvement in terms of reducing material movements and reducing setup times through group introducing manufacturing cells. These results demonstrate that the moulds for the switch cover, air filter housing and power-tool housing (coded as R, U and Z respectively) can be processed on cell 1 with ONA-S64 penetration EDM and Joemars EDM Model 322 machines (coded as 7 and 1). Similarly, the moulds for battery casing, smart phone and television cabinet (coded as X, S and W respectively) can be processed on cell 2 with Turret milling machine CF-A2, CNC Dielectric Fluid EDM S50 and Aristech CNC 430 Die sinking EDM (coded as 4, 2 and 6). Lastly, the moulds for helmet shell, automotive dashboard and printer casing can be processed on cell 3 with Conytrok GS600 high precision CNC, Sodick AG35L EDM CNC and CNC Wire Cutting EDM DK7740. However, it was also proposed to initiate radical process improvement by investigating the viability of 3D printed rapid tools for injection moulding.

5. CONCLUSION

Value stream mapping can be deployed as a tool for production flow analysis to reveal the areas where waste occurs and improve the flow of material and information so that the product is delivered to the client on time. The deployment of group technology and rank clustering algorithm to derive mould families and machine cells can improve the mould fabrication process by reducing material movements and reducing setup times.

REFERENCES

Abdelhadi, A. 2018. Maintenance scheduling based on PROMETHEE method in conjunction with group technology philosophy. *International Journal of Quality & Reliability Management*,

Amruthnath, N. and Gupta, T. 2016. Modified rank order clustering algorithm approach by including manufacturing data. *IFAC-PapersOnLine*, 49 (5): 138-142.

Danilovic, M. and Ilic, O. 2019. A novel hybrid algorithm for manufacturing cell formation problem. *Expert Systems with Applications*, 135: 327-350.

Equbal, A., Sood, A. K. and Shamim, M. 2015. Rapid tooling: A major shift in tooling practice. *Manufacturing and Industrial Engineering*, 14 (3-4).

Fernandes, C., Pontes, A., Viana, J., Nóbrega, J. and Gaspar-Cunha, A. 2014. Modeling of Plasticating Injection Moulding–Experimental Assessment. *International Polymer Processing*, 29 (5): 558-569.

Francis, S. 2018. *Evolution of Technology in the Digital Arena: Theories, Firm-level Strategeis and State Policies*. Centre for WTO Studies, Indian Institute of Foreign Trade.

Gawdzinska, K., Nabialek, M., Sandu, A. V. and Bryll, K. 2018. The Choice of Recycling Methods for Single-Polymer Polyester Composites. *Materiale Plastice*, 55 (4): 658.

Huang, Z. and Li, D. 2010. A hybrid approach of Case-Based Reasoning and Group Technology for injection-mould design. *International Journal of Materials and Product Technology*, 38 (2-3): 275-286.

Ishizaki, K., Komarneni, S. and Nanko, M. 2013. *Porous Materials: Process technology and applications*. Springer science & business media.

Jahan, A. and Souri, S. 2020. Cell Formation Based on Similarity in Parts Design Using Multi-attribute Decision-Making Algorithm. In: *Sustainability Modeling in Engineering: A Multi-Criteria Perspective*. World Scientific, 203-227.

King, J. R. 1980. Machine-component grouping in production flow analysis: an approach using a rank order clustering algorithm. *International Journal of Production Research*, 18 (2): 213-232.

Silver, P. and McLean, W. 2008. *Fabrication*. Routledge.

Singh, G. and Verma, A. 2017. A Brief Review on injection moulding manufacturing process. *Materials Today: Proceedings*, 4 (2): 1423-1433.

Singh, N. and Rajamani, D., 2012. *Cellular manufacturing systems: design, planning and control*. Springer Science & Business Media. Vlachopoulos, J. and Strutt, D. 2003. Polymer processing. *Materials science and technology*, 19 (9): 1161-1169.

Sousa Ribeiro, C. and Soares, N. 2010. Group Technology to Soles Design. *Annals of DAAAM & Proceedings*.

Wadhwa, R.S., 2012. Flexibility in manufacturing automation: A living lab case study of Norwegian metalcasting SMEs. *Journal of Manufacturing Systems*, *31*(4), pp.444-454.

Zhang, Y. and Bernard, A. 2014. Grouping parts for multiple parts production in Additive Manufacturing. *Procedia Cirp*, 17: 308-313.