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**Article**

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# Triage as a core sorting strategy in extreme core arrival scenarios

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## Abstract

Surveys have indicated that the remanufacturing industry is concerned about the necessity of agile and prioritized core sorting due to its potential benefits to optimal core inventory and condition assessment, both at equipment and component levels. As such, core sorting holds a pivotal role in remanufacturing operations, however, extreme core arrivals, its stochastic nature and resulting sorting issues, warrant targeted modelling and analysis. This paper is devoted to triage as an agile sorting strategy in extreme arrival scenarios that can be utilized as a complementary core sorting strategy. A statistical model of extreme core arrivals is developed based on Extreme Value (EV) theory and related Generalized Extreme Value (GEV) and Fréchet (Fisher-Tippett type-II) distributions. The model is applied to extreme arrivals of valves in an industrial valve repair shop. Using a large sample size, distribution parameters are estimated and the stochastic behaviour of the extreme valve arrivals is evaluated and verified. An analogy between medical triage and remanufacturing triage is discussed, the results and applicability of extreme value analysis in remanufactured valve arrivals is presented, and a generic framework for prioritization of triage strategies is introduced.

**Keywords:** Generalized Extreme Value (GEV); Triage; Remanufacturing; Sorting

## Introduction

Typically, upon arrival, cores are sorted according to their quality level [1]. Sorting operations are of great concern for cost of quality (COQ) activities [2], due to uncertain core quality, quantity, and return timing. Acquired core condition often has high quality variability, which, along with extreme quantity variability and the likelihood of non-remanufacturability of some cores, imposes prioritization in core sorting processes. In some circumstances, such as extreme arrivals of remanufactured cores, due to scarcity of available operational and time resources, agile and perhaps inaccurate sorting, *i.e.* triage, is beneficial under operational, timing, inventory, and market requirements.

As such, extreme value core arrivals, its stochastic nature and resulting sorting issues warrant targeted modelling and analysis. The main motivation of this research is modelling of less-expected but extreme value core arrivals to remanufacturing facilities and proposing triage as an operational tool and strategy to manage these rare but critical events. Remanufacturing triage can be used to mitigate or even prevent adverse dimensions of unpreparedness such as business sluggishness in highly demanding and

competitive market atmosphere due to lack of accessible resources. Loss of profit due to late supply of remanufactured products to market, customer defection, and other unpredictable penalties are some common consequences of inadequate response of remanufacturing operations that can impact the business system. Common strategies for prediction, planning, scheduling, and timing of remanufacturing operations for core arrivals that are based on traditional central tendency approaches, such as modelling of arrivals by Poisson or Normal distributions, are not sufficient in cases of extremely large or extremely small arrivals of cores. These scenarios can be considered as shock waves to a remanufacturing facility and consequently to its business system.

In this paper, the stochastic behaviour of remanufacturing systems under extreme situations is investigated and a statistical model is developed and applied on an industrial case. Triage as a sorting strategy is based on statistical models of extreme core arrivals, which are formulated from Extreme Value (EV) theory and related Generalized Extreme Value (GEV) and Fréchet (Fisher-Tippett type-II) distributions. The validity of the model is tested by hypothesis testing and comparisons between common, central tendency, and less-likely but adverse extremal tendency are made. Lastly, it is suggested that the EV approach in remanufacturing core management and sorting issues should be considered as a complementary sorting strategy to central tendency approaches in order to have a sufficient level of preparedness for extremal situations. Triage is a typical approach in medicine to address extremal situations, so, a generic analogy between medical triage and remanufacturing triage is described and a generic framework for triage strategy development is introduced.

The next section introduces triage as a complementary core sorting strategy and creates an analogy between remanufacturing triage and triage in medicine. The methodology section presents common statistical models of EV distributions and a brief simulation-based verification case study. The results section applies the developed methods on a data set from an industrial valve shop. Finally, in the discussion section, a generic triage method selection framework is proposed.

### **Triage as a complementary core sorting strategy**

According to current studies and reports, triage is used in some remanufacturing facilities as a core inspection strategy [3], as a part of their main sorting strategy for individual or bulk return that can be as much as 30,000 returns per week, and as an inaccurate but quick and profitable sorting method when the sorting, disposal, and transportation costs are reasonable in comparison to disassembly and reprocessing costs [4]. In medicine, triage is a common patient prioritization and sorting technique based on the gravity of health conditions and availability of medical resources such as, operational resources, manpower, and time. This agile sorting and prioritization technique is of special significance when the normal balance between existing resources and the number of patient arrivals is extremely disturbed.

Medical triage can be defined as, “*the process of determining the priority of patients’ treatments based on the severity of their condition*”. This rations patient treatment efficiently when resources are limited or insufficient for all to be treated immediately. Historically, medical triage has been developed based on various approaches, summarized in Table 1 along with proposed analogies for remanufacturing core sorting [5, 6]. The

**Table 1** Proposed analogy between medical triage and remanufacturing triage

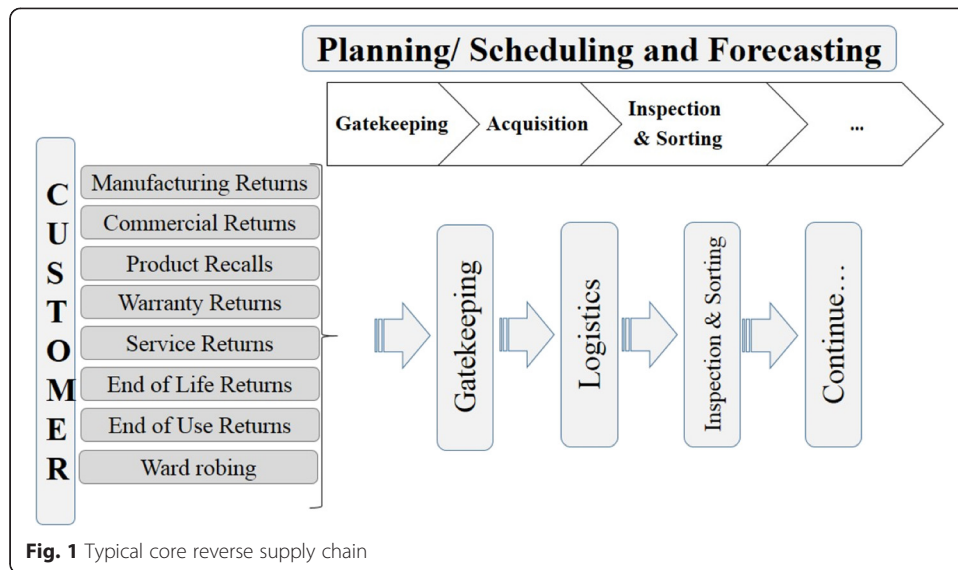
Method	Medicine	Proposed remanufacturing equivalence	Prioritizing factor
Traditional	Little or no formal effort to provide care	No prioritized core sortation	No criteria
Baron Dominique-Jean Larry	Recognition, evaluation and categorization, treatment of the most urgent cases regardless of ranking and deferring less or fatally wounded cases	Condition assessment and processing, the most in demand cores have top priority	Market pull
Wilson	Concentration of treatment on most likely successful cases, some low chance cases will die	Concentrated remanufacturing on cores with high remanufacturability No chance of second life for less remanufacturable cores	Likelihood of success
First Come First Served (FCFS)	Treatment based on order of arrival, regardless of gravity of wounds, rank or any other criteria	Remanufacturing is only based on core arrival order without any other criteria and means equal chance for all for second life	Order of arrival
Great Goodness for Greatest Number (GGGN)	Depriving of urgent cases needing huge amount of attention, time and resources in favor of dozens of other cases	Remanufacturing dozens of cores with high remanufacturability instead of one needing great amount of resources	Number of treatment
Less Severity First Treatment (LSFT)	Prioritizing less urgent cases since they can be treated swiftly and can return to action	Prioritization of cores with less defects regardless of other criteria	Less defects
Maximize the Fighting Strength (MFS)	Most quick return to duty with least expenditure of time and resources	Swift response to market demand and minimization of remanufacturing time, customer urgent requirements	Time

concept of medical triage began in the armed forces [5] where medical demands were extremely greater than available resources. This situation in remanufacturing is equivalent to any situation that disturbs the normally expected stream of cores and creates an extreme core flow to a remanufacturing facility, resulting in an exorbitant gap between the arrival rate and core handling capacity of remanufacturing operations.

One of the goals of sorting of cores based on triage is providing a complementary sorting tool to be utilized along with a primary sorting strategy, such as central tendency sorting approaches. The use of triage sorting is contingent upon the extreme arrivals of cores that can be interpreted as severe unbalance between core arrival and facility remanufacturing capacity. Hence, considering triage as a complementary strategy of core sorting management may be of interest for some facilities, especially those having unexpected, extreme core arrivals. The flowchart in Fig. 1 shows a typical core reverse supply chain in remanufacturing industry under normal operations, but this status can be disrupted by an extreme shock wave of arrivals.

## Methodology

In most investigations in remanufacturing, the focus is on central tendency approaches to deal with remanufacturing core management. Galbreth and Blackburn used normally distributed demand patterns for modelling optimum acquisition quantities [7], Aras et al. modelled both customer demand and product returns as Poisson processes for hybrid manufacturing and remanufacturing systems [8], and Teunter and Flapper assumed normally distributed behaviour for demands to model optimum core acquisitions [9]. In various engineering disciplines, EV has applications to predict less-likely but still probable events with severe impacts such as flood prediction in



hydrology engineering, earthquakes for structural engineering, fatigue strength in extreme mechanical loading, and extreme temperature variations in meteorology [10, 11]. Each of these instances address unusual, extreme value behaviour and not normal behaviours. Other applications in the field of strength of material, electrical engineering, highway traffic modelling, corrosion resistance, and pollution studies have also been reported [12].

Although extreme arrivals of remanufacturing cores are not frequent, they still have some probability of occurrence, and in the case of ignoring such events, remanufacturing systems may incur significant losses. In this research, the nature and behaviour of extreme value core arrivals are studied based on Extreme Value Analysis and a statistical model is developed. Classical EV theory is presented in many statistics resources [10–12]. The foundation of EV theory is the study of the statistical nature and behaviour of maxima, shown below as:

$$M_n = \max\{X_1, X_2, \dots, X_n\}$$

Where,  $\{X_1, X_2, \dots, X_n\}$ , is a set of randomly distributed variables with common distribution function  $F$ . It should be noted that the distribution must be common but *not of a specific type*. Since  $M_n$  is the maximum of the observed data, the distribution of  $M_n$ , confirms:

$$P(M_n < z) = P(X_1 \leq z, \dots, X_n \leq z) = P(X_1 \leq z) \dots P(X_n \leq z) = (F(z))^n$$

Since  $F$  is the parent data distribution, it is necessary to estimate  $F$  from an available set of sample data in order to study  $M_n$ . One common approach to estimate,  $F(F(z))^n$ , is using extreme data. This idea is similar to that used in estimation procedure of the sample mean average. It is noteworthy that, since  $F(z) < 1$ , then for  $z < z_{sup}$ , where  $z_{sup}$  is the smallest value of  $z$  such that,  $F(z) = 1$ ,  $F^n(z) \rightarrow^{n \rightarrow \infty} 0$ , this issue is resolved by defining another variable such as,  $M_n^* = \frac{M_n - b_n}{a_n}$ , where  $\{a_n\}$ ,  $\{b_n\}$ , are sequences of constants with  $a_n > 0$ . Here a well-established theorem known as *extremal types* theorem is presented without proof.

Theorem: If there exist sequences of constants  $\{a_n\}$  and  $\{b_n\}$  such that

$$P\left\{\frac{M_n - b_n}{a_n} \leq z\right\} \xrightarrow{n \rightarrow \infty} G(z)$$

Where  $G(z)$  is a non-degenerate distribution function, then  $G(z)$  will belong to one of the following distribution types (Table 2), for more details refer to [10, 11]. Table 2, presents three types of EV distributions with corresponding domains of random variables and names.

In all distributions,  $a$  is positive and  $b$  is real. In the second and third distributions  $\alpha > 0$ . The presented three distributions belong to one family of distributions called *Extreme Value distributions*. These three distributions are the only possible limits for the distribution of normalized extremes (maxima or minima) and does not depend on the distribution,  $F$ , of parent data set.

A common approach in EV theory is combining the three forms of the distribution family into one simple form, called the *Generalized Extreme Value*, GEV distribution and is presented as follows:

$$G(z) = \exp\left\{-\left(1 + \xi\left(z - \mu - \frac{\sigma}{\xi}\right)\right)^{-1/\xi}\right\}; z > b$$

In the generalized format of extreme value distribution,  $\xi\left(z - \mu - \frac{\sigma}{\xi}\right) > 0$  and  $\xi, \mu, \sigma$  are three parameters of the GEV distribution. These three parameters and associated domains are summarized in Table 3.

The GEV converts to Fréchet distribution if the shape factor is positive, and converts to the Weibull distribution if it is negative. For Gumble type, shape factor is approaching zero. The basic advantage of unified GEV format vs. three individual distribution format is the simplification of statistical analysis. Figure 2, illustrates the three types of GEV distributions, Type-I, Gumble, has no upper or lower limiting values, Weibull has just upper limiting value with no lower limiting value, and Fréchet type has lower limiting value and no limiting value in right hand side, respectively.

In order to apply the above results to a set of independent, identically distributed, *iid*, random variables like  $X_1, X_2, \dots, X_n$ , the first step is *blocking* the data set into  $n$  blocks of observations, provided that  $n$  should be sufficiently large. Then *maxima*  $z_i$  of each block is screened and eventually the appropriate GEV distribution can be fitted to the maxima  $\{z_1, z_2, \dots, z_j\}$ . The estimation of distribution parameters in most cases is done by maximum likelihood estimator method, MLE, but other methods can be used, see [10, 11], in this research due to popularity, the estimation of parameters are conducted

**Table 2** Three types of extreme value distributions

Extremals	Type	Name
$G(z) = \exp\left\{-\exp\left(-\left(\frac{z-b}{a}\right)\right)\right\}, -\infty < z < +\infty$	I	Gumble
$G(z) = \begin{cases} 0 & ; z \leq b \\ \exp\left\{-\left(\frac{z-b}{a}\right)^{-\alpha}\right\} & ; z > b \end{cases}$	II	Fréchet (Fisher-Tippet)
$G(z) = \begin{cases} \exp\left\{-\left(-\left(\frac{z-b}{a}\right)^\alpha\right)\right\} & ; z < b \\ 1 & ; z > b \end{cases}$	III	Weibull

**Table 3** The three parameters of the GEV distribution

Parameter	Symbol	Domain
Location	$\mu$	$(-\infty, +\infty)$
Scale	$\sigma$	$(0, +\infty)$
Shape	$\xi$	$(-\infty, +\infty)$

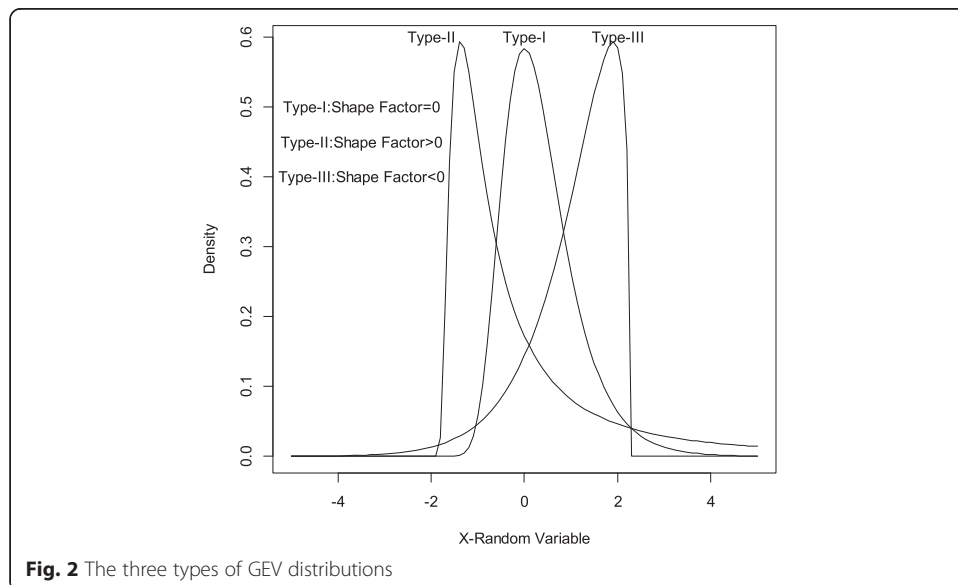
by MLE. At this stage and prior to the analysis of the industrial valve remanufacturing case, the model is applied to a simulated hurricane data set generated by the US Information Technology Laboratory [13]. Cumulative distribution functions for both EV and central tendency approaches are presented in Fig. 3.

As it can be observed from Fig. 3, the normal distribution predicts *zero* probability for occurrences above 80 units of wind speed. However, an examination of the data set reveals that there are 35 cases out of 1000 that have hurricane speeds of more than 80 and less than 100 units of speed, and the total number of exceeding over 80 is 43 out of 1000.

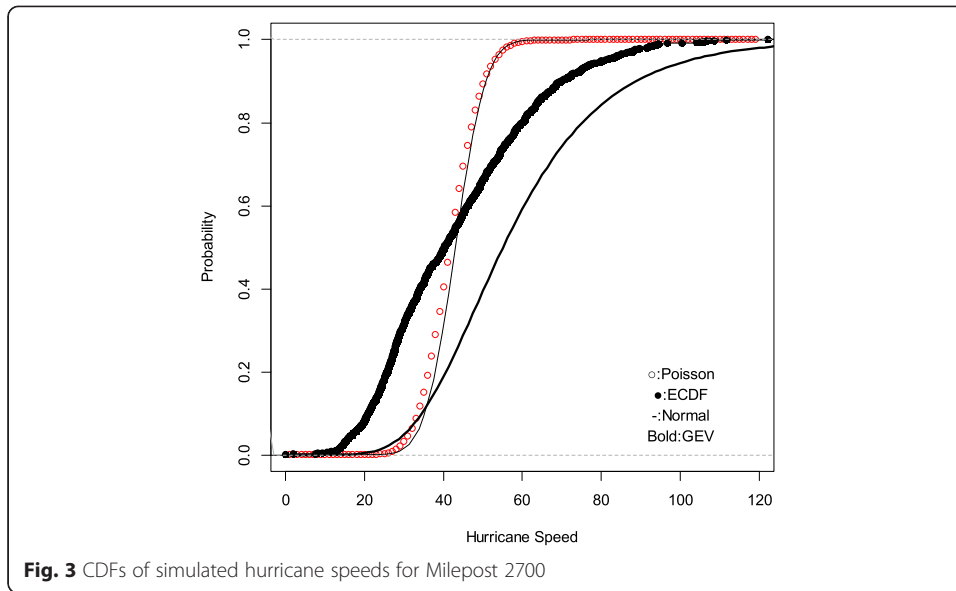
**Results**

The EV approach to core arrival characterization is illustrated with a case study of industrial valve repair/remanufacturing operations. Industrial valves are mechanical devices usually used in connection with pressurized vessels to stop or regulate flow. Safety and relief valves, steam traps, and control valves are three kinds of industrial valves that are widely used in chemical complexes. Safety valves are vital to protecting people and physical assets, and steam traps have the duty of discharging condensate and non-condensable gases from piping systems [14]. Valve maintenance and repair/remanufacturing (repair is an equivalent term used for remanufacturing in valve industry [15]) is of critical importance from both safety and economic perspectives.

Valve arrival data collection was conducted based on formally issued organizational work orders through a Computerized Maintenance Management System (CMMS) in a chemical processing facility for a period of 476 days. The necessity of valve



**Fig. 2** The three types of GEV distributions



remanufacturing and their arrivals to the valve shop is determined based on various dominating factors such as; results of sophisticated condition assessments, calendar-based Preventive Maintenance (PM), premature failures such as jamming and leakage, requests or requirements of operational units, partial or full overhauls, Opportunity-based Maintenance (OM), safety, and economic considerations. It should be noted that the approximate mean remanufacturing capacity of the valve shop is 10 valves per operational day. The investigation period includes all major arrivals listed in Table 4 except full overhauls. There are some arrivals of small quantity, like arrivals due to preventative maintenance plans, premature failures, operational requirements, OM requests, and some small revamps. These small arrivals may be expected or unexpected. Condition assessment of steam traps was conducted by unit operators, thus, degrees of human error factors were experienced. As a result, condition assessment of steam traps was included in maintenance activities and outsourced in order to achieve more reliable assessments and enhance energy management in the steam network. Ultrasonic condition assessments eliminated many human errors, however, an increase in valve arrivals to the repair shop were observed. Industrial disasters were usually followed by management enforcements to take more efficient preventive actions that, in turn, increased levels of extreme safety and relief valve arrivals. Assumptions made in this case study are as follows, it is assumed that the inspection process is error proof, quality of

**Table 4** Summary of factors affecting valve arrivals

Arrival determining factor	Nature of core arrival	Variable type	Amount
Preventive maintenance	Preplanned/prescheduled	Deterministic	Usually small
Outsourced condition assessments	Preplanned/prescheduled	Stochastic	Extremely huge
Premature failures	Unexpected	Stochastic	Usually small
Operational units	Unexpected	Stochastic	Usually small
Partial/Full overhaul	Preplanned/prescheduled	Stochastic	Extremely huge
Opportunistic maintenance	Unexpected	Stochastic	Usually small
Post-disaster preventive actions	Unexpected	Stochastic	Extremely huge
Revamps	Preplanned/prescheduled	Deterministic	Small or huge



cores are assumed to be equal and at such levels requiring complete disassembly and testing, and quantity of arrivals is considered as the sole uncertainty parameter.

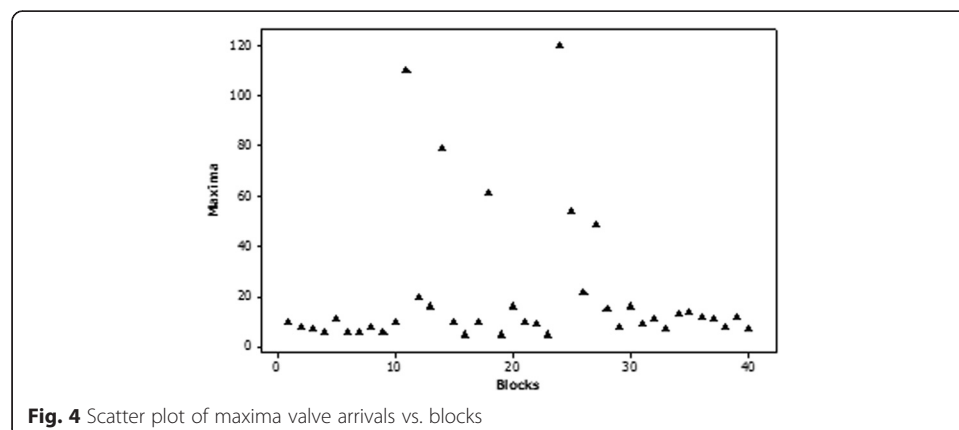
The investigation period is divided to 158 three-day sub-periods and every 4 sub-periods are considered as one block. Maxima of these blocks are extracted as block maxima. Hence, there are 39 blocks and a half block, here for simplicity, the half block is treated as a full block. Figure 4 depicts a scatter plot of the maximum values of the blocks. Extreme values observed in this scatter plot are attributable to reasons such as; post-disaster preventive actions, partial overhauls, outsourced condition assessments, or a combination of factors.

Table 5 presents the descriptive statistics for parent and block maxima data sets. Note that in the EV approach, the type of distribution for the parent sample, from which the maxima blocks are generated, is not of great concern. Figure 5, shows the histogram of maxima blocks.

The extracted maxima of blocks were used to estimate the three parameters of the GEV distribution. Table 6 presents the estimation results yielded by the Maximum Likelihood Method (MLE). The corresponding confidence intervals are included. For the purpose of comparison, results from the Probability Weighted Method (PWM) are also presented.

Figure 6 shows the cumulative distribution function plot for GEV, Experimental Cumulative Distribution Function (ECDF), and two central tendency distributions, Normal and Poisson. Distribution parameters for both central tendency distributions were estimated from the parent data set.

The conformance between the ECDF generated from actual data set and the GEV model can be seen in Fig. 6. This conformance is critical in extreme values of arrivals and is the main motivation for using the GEV. Further investigations reveal that in the case of non-extreme, usual arrivals, there is an observed conformance between Poisson and ECDF distributions. It can be inferred from Fig. 6, that for arrivals greater than approximately 20 for Poisson and greater than 40 for Normal distributions, the corresponding CDF's yield zero probability of occurrence while the CDF of the GEV distribution yields 7.37 % of occurrence probability. Investigation of the actual data set reveals that in 10 cases core arrivals were greater than 40, which indicates that the observed probability is approximately 5.7 %.



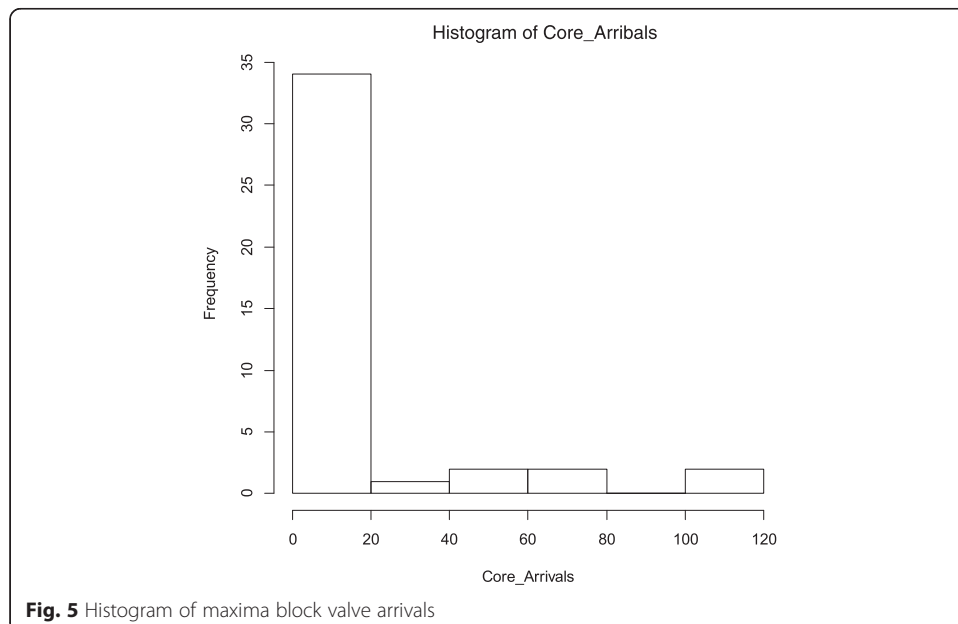
**Table 5** Descriptive statistics for Weekly and Biweekly core arrivals

Variable	N	Mean	SE mean	St dev.	mode	Min.	Q1	Med.	Q3	Max.
Parent sample	158	11.84	1.39	17.44	5	0	5	7	10	120
Block maxima	40	20.55	4.32	27.30	10	5	7.25	10	16	120

In the EV approach, return level plays an important role. Return level is defined as a value that is expected to be equalled or exceeded on average once every interval of time ( $T$ -with a probability of  $1/T$ ) [16]. Return level can be evaluated from the fitted distribution by estimating how often the extreme quantiles occur with a certain return level. Therefore, the CDF of the GEV distribution should be obtained and then be equalled to  $(1-1/T)$ .  $T$  is called return period and the corresponding  $z$ -score is return value. Figure 7 shows the return period vs. return level plot for valve arrivals.

The developed model was verified by Pearson’s Chi-squared Goodness of Fit test and Pearson’s Chi-squared method [17]. The hypothesis testing was conducted by considering the null hypothesis as Fréchet distribution versus the alternative that the distribution is not Fréchet. The predicted values resulting from the Fréchet distribution, observed data, and predicted values yielded by normal and Poisson distribution are presented in Table 7. The  $p$ -value of this test is equal to  $0.2931$ , which is significantly greater than any common significance levels such as  $0.01$ ,  $0.05$  or  $0.10$ . Note that the  $p$ -value is considered to be as a measure of the depth of confidence, and suggests that this distribution conforms to GEV distribution type-II.

Like the hurricane sample case, the normal and Poisson distribution are not capable of efficiently predicting extreme cases, particularly in the case of 40 or more arrivals which predicts zero probability for more than 40 arrivals. However, the actual data indicates that there are 10 cases of 158 having more than 40 arrivals. The investigation of the actual data also suggests that even though the probability of extreme arrivals is quite low, it should not be discounted.



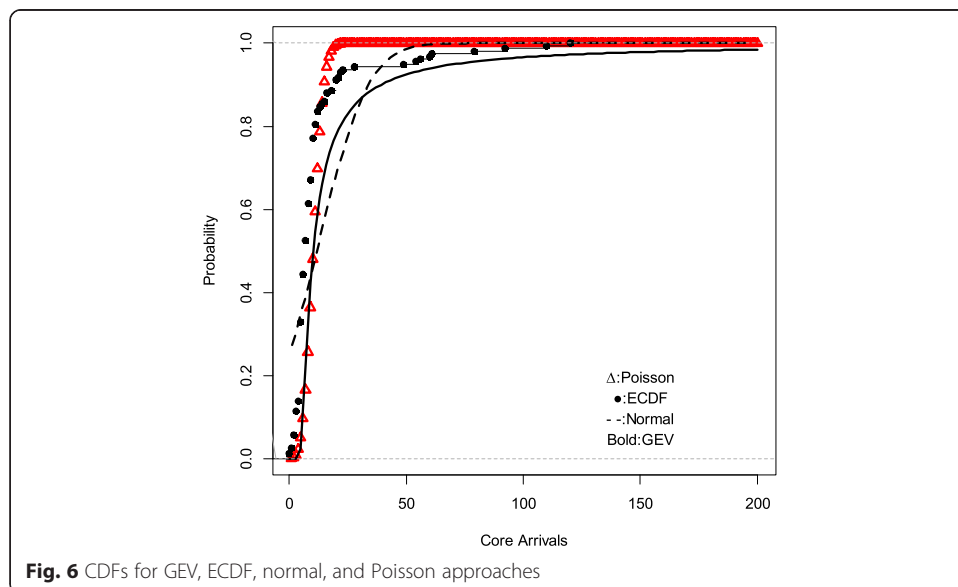
**Table 6** Estimation of distribution parameters

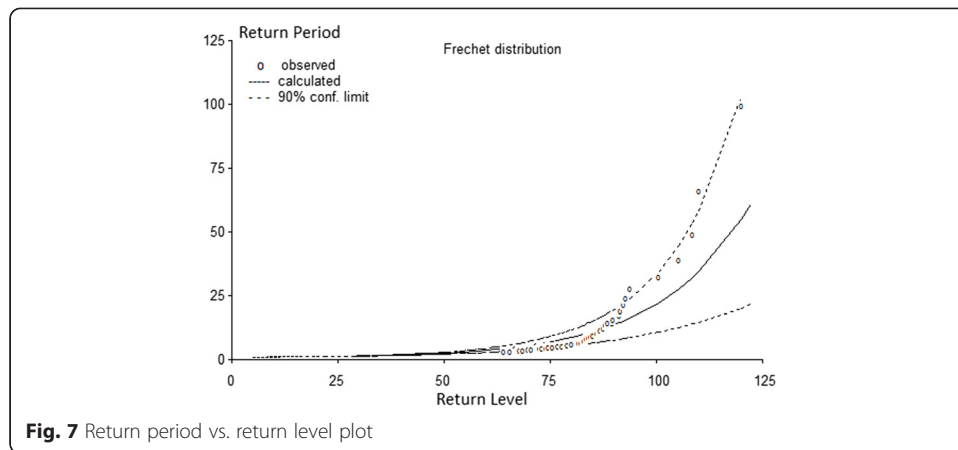
Parameter	Symbol	PWM	MLE	SE	95 % CI
Location	$\mu$	5.5583	8.3540	0.7565	(6.8104,9.8976)
Scale	$\sigma$	3.2649	4.2832	0.9220	(2.7535,6.6628)
Shape	$\xi$	0.5814	0.8903	0.2038	(0.4762,1.3045)

**Discussion**

Results suggest that triage can be a critical sorting approach complementary to primary sorting strategies. The stochastic behaviour of extreme value scenarios was investigated in a real set of industrial data collected from remanufacturing of valves. As was expected and indicated by Fig. 6 and Table 7, models developed by GEV are more efficient at predicting stochastic behaviour of extreme core arrivals than common central tendency approaches. The expected return and period level of huge arrivals were obtained, which are important to have sufficient predictions of these two factors for preparedness in remanufacturing systems that encounter extreme arrival disturbances. Results from hypothesis testing for goodness of fit for the model and actual data indicate that the *p-value* of the test is 0.2931, which is satisfactorily greater than common significance levels used in both industry and theory. This indicates an efficient statistical model and, from a practical perspective, a more reliable model for predicting stochastic behaviour of systems and processes. Agile and prioritized patient sorting has been conducted in medicine, but due to common logical similarities between medical triage and agile but perhaps less accurate core sorting in remanufacturing, medicine triage methods can be applicable to remanufacturing core sorting issues as suggested in Table 1. Extreme core arrival modelling is not restricted to GEV models and other statistical models can be used based on necessity, availability of data and facility core processing capacity.

A proposed triage strategy prioritization and selection framework based on the extreme value approach is illustrated in Fig. 8. Prioritization, is critical to core management operations and determines the prospective triage strategy. This step is affected by





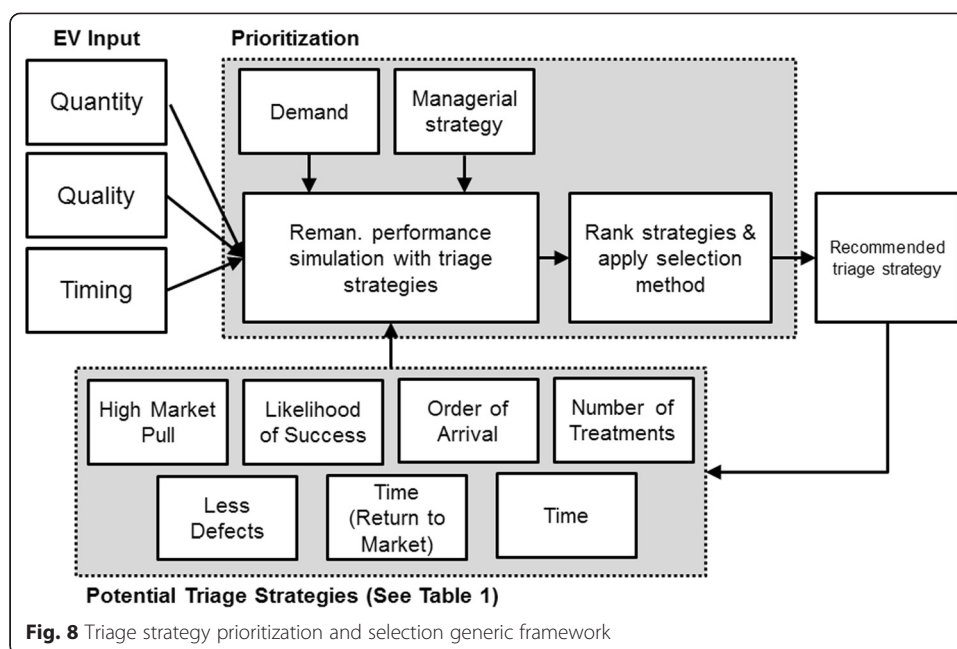
**Fig. 7** Return period vs. return level plot

quality, quantity and timing behaviour of the core arrivals and their prospective interactions, which may demand a multivariate statistical model. In triage scenarios in the presented investigation, quantity is the sole factor assumed to have extremal behaviour, but it is evident that this extremal behaviour can be expanded to quality as well. A wide spectrum of scenarios is possible; for instance along with extreme core flow, quality of admitted cores may be considered approximately uniform, have extreme value characteristics, or all cores may be considered remanufacturable but at different costs [18, 19].

One prospective approach to prioritize and select a proper remanufacturing triage strategy can be as follows; (1) establish extreme value distribution models of quantity, quality, and timing of core returns, (2) simulate remanufacturing operation performance for potential triage strategies (Fig. 8) considering market demand and managerial requirements, (3) rank the performance of triage strategies based on single or multi-objectives (cost, revenue, time to return to normal operation, etc.) and recommend a triage strategy. It should be noted that after selection of the most appropriate triage strategy, a virtual experimental analysis can be set up to determine the significant factors of the process and their effects on the process. Based on Design of Experiments (DOE) techniques, best settings of the process factors can be achieved and even this process can be optimized by methods such as Response Surface Method (RSM).

**Table 7** Observed vs. Predicted arrivals for GEV and normal scenarios

Bin	Observed	Predicted probability GEV	Predicted frequency GEV	Predicted probability normal	Predicted frequency normal	Predicted probability poisson	Predicted frequency poisson
0–25	34	0.8298	33	0.7747	31	0.99987	40
0–50	35	0.9263	37	0.9876	40	1	40
0–75	37	0.9542	38	0.9999	40	1	40
0–100	37	0.9672	39	1	40	1	40
0–125	40	0.9746	39	1	40	1	40
0–150	40	0.9794	39	1	40	1	40
0–175	40	0.9827	39	1	40	1	40



## Conclusions

Central tendency core sorting approaches may not be the sole approach to address core sorting in remanufacturing. In extreme value core arrivals, agile and perhaps less accurate sorting strategies are suggested to balance available resource capacity. In remanufacturing business systems, the common approach for modelling of core arrivals is primarily based on utilization of central tendency approaches such as Poisson or Normal distributions that are shown to not adequately characterize EV scenarios. Hence, having targeted models for extreme core arrivals is critical to developing complete sorting strategies. It was shown that the EV approach is a powerful tool to evaluate such rare but highly impactful situations and assist decision makers. A generic framework of triage strategy prioritization and selection is also introduced.

As a contribution to remanufacturing from a practical scope, triage (modelled with EV) can be used as a complementary sorting approach to major sorting strategies. As mentioned, an EV approach assists decision makers to have stronger prediction abilities, especially for gatekeeping and core acquisition purposes, and this will protect remanufacturing business from losses resulting from extreme situations and associated consequences such as overstocking, overproduction, or losses due to sluggish response to market pull. The major contribution of this research is the application of EV theory to remanufacturing core sorting. EV approaches grant unique opportunities to open scopes to future researches, such as investigation of multivariate models for EV scenarios and other triage strategies for optimization of core acquisition in EV scenarios. Overall, results indicate that EV is a powerful tool in dealing with extreme value scenarios in remanufacturing industry and utilization of this tool as a sorting approach in combination with other sorting strategies can enhance remanufacturing operations.

## Competing interests

The authors declare that they have no competing interests.

**Authors' contributions**

SZG and JLR investigated the core flows to remanufacturing service facilities in extreme scenarios, while previous works were dominantly focused on non-extremecases. EV theory used for modelling the extreme events in remanufacturing core flows. A general analogy between triage as an agile sorting strategy in medicine and coretrriage in remanufacturing proposed. A generic framework for triage methods prioritization developed. All authors read and approved the final manuscript.

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**References**

- Gupta, SM, Ilgin, MA: Remanufacturing Modelling and Analysis. CRC Press, Boca Raton (2012)
- Quality Council of Indiana: Handbook of Sustainable Engineering. Indiana: Quality Council of Indiana; (2014)
- Errington, M, Childe, SJ: A business process model of inspection in remanufacturing. *J Remanufacturing* **3**(1), 1–22 (2013)
- Zikopoulos, C, Tagarasa, G: On the attractiveness of sorting before disassembly in remanufacturing. *IIE Transact* **40**, 313–323 (2008)
- Iserson, KV, Moskop, JC: Triage in medicine, part I: Concept History and Types. *Am College Emerg Phys* **49**, 275–281 (2007)
- Iserson, KV, Moskop, JC: Triage in medicine, part II: Underlying Values and Principales. *Am College Emerg Phys* **49**, 282–287 (2007)
- Galbreth, MR, Blackburn, JD: Optimal Acquisition and Sorting Policies for Remanufacturing. *Prod Oper Manag* **15**, 384–392 (2006)
- Aras, N, Verter, V, Boyaci, T: Coordination and Priority Decisions in Hybrid Manufacturing/Remanufacturing Systems. *Prod Oper Manag* **15**, 528–543 (2006)
- Teunter, RH, Flapper, SDP: Optimal core acquisition and remanufacturing policies under uncertain core quality fractions. *Eur J Oper Res* **210**, 241–248 (2011)
- Reiss, RD, Thomas, M: Statistical analysis of extreme values: with application in Insurance, Finance, Hydrology, and Other Fields. Springer, Siegen (2007)
- Mallor, F, Nualart, E, Omey, E: An introduction to statistical modelling of extreme values: application to calculate extreme wind speeds. *Brussel: HUB Research*. **36**, 1 (2009).
- Castillo, E, Hadi, AS, Balakrishnan, N, Sarabia, JM: Extreme value and related models with applications in engineering and science. John Wiley, Hoboken (2005)
- NIST National Institute of Standards and Technology Information Technology Laboratory: Extreme Wind Speeds: Data Sets <http://www.itl.nist.gov/div898/winds/data/hurricane/datasets/file53.txt>. Accessed 10 Dec (2014).
- Mobley, RK, Higgins, LR, Wikoff, DJ: Maintenance Engineering Handbook. McGraw Hill, New York (2008)
- Hauser, W.M., Lund, R.T.: Remanufacturing: Operating Practices and Strategies: Perspectives on the Management of Remanufacturing Businesses in the United States. Department of Manufacturing Engineering, Boston University (2008). [http://www.reman.org/Papers/Reman\\_Database\\_Lund.pdf](http://www.reman.org/Papers/Reman_Database_Lund.pdf). (2012).
- Coles, S, Bawa, J, Trenner, L, Dorazio, P: An Introduction to Statistical Modelling of Extreme Values (Vol. 208). Springer, London (2001)
- NIST: National Institute of Standards and Technology: NIST: Engineering Statistics Handbook. Gaithersburg, MD (2014)
- Ferguson, M.E., Souza, G.C. Closed-loop supply chains: new developments to improve the sustainability of business practices. CRC. Boca Raton, FL (2010)
- Galbreth, MR, Blackburn, JD: Optimal Acquisition Quantities in Remanufacturing with Condition Uncertainty. *Prod Oper Manag* **19**, 61–69 (2010)

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