

Analysis of Failures and Maintenance Strategies in Water Distribution Networks

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ABSTRACT

Water scarcity is driving Water Utilities to focus on areas of the network where failures are concentrated and recurring [1,2]. Several methodologies are present in the technical literature based on prediction models [3,4] or empirical ones [5-8] which aim to contribute to the identification of the failures.

To support Water Utilities in identifying the better replacement and maintenance strategies to operate on Water Distribution Systems (WDS), this study analyses a multi-year dataset of repair operations (2017-2025) from a large residential service area in Southern Italy (about 1,5 million inhabitants). In particular, failures of main distribution pipes have been analysed separately from those of service connections with the aim of quantifying the contribution of each of this type of failure on the whole failures operated by the Water Utility in almost 9 years. Failure rates have been thus compared on a homogeneous basis by normalizing counts over network length and pipe materials. To carry on this analysis, two operational data streams have been combined: the operational repair order management system and GIS geolocated distribution network failure data. Failures were located indeed by street address, a key step in enabling address-level grouping and subsequent recurrence analysis by measuring recurrence (repeated failures) over time at the address/connection level. Furthermore, by means of photo reports, it has been possible to identify installation factors associated with a higher propensity for failure.

In particular, temporal trends (monthly/yearly) were analysed, and results were categorized by material families (plastic vs metal) and work-priority classes (urgent vs scheduled), allowing intervention classes to be distinguished and related to the materials.

Finally, using geocoding at the work order address level, first-time repairs were distinguished from “returns” (repeat interventions) on the same connection or address. The yearly return rate was calculated per material type and its evolution studied over time to reveal whether the increase in workload was driven by new failures or by repeat operations on assets that had already been affected previously. Data analysis revealed a persistent failure summer peak on monthly basis and an actual increasing trend in the absolute number of repairs. However, by considering the priority of operations it is of evidence that the latter is due to planned operations and not to critical/urgent ones. [Figure 1].

It is worth to highlight that there is a reduction in water loss volumes (about 20% of the initial losses) between the end of 2023 and the end of 2024, indicating that the increased number of repairs do not automatically correspond to a greater number of losses.

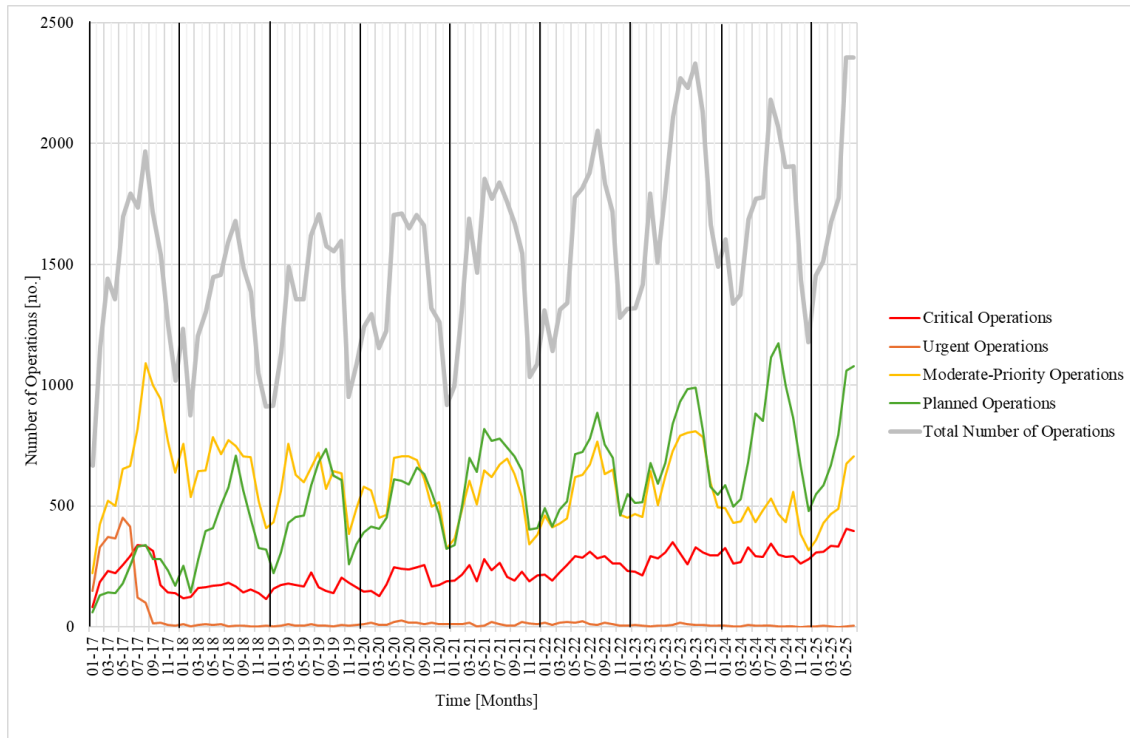


Figure 1. Failure repair operations by priority level

A direct comparison between service connections and distribution pipes yielded significant results. Although the failures count for the period 2017-2025 are divided almost equally between the two subsystems, approximately 55% connections and 45% distribution pipes, the picture changes radically once the data are normalized by length: the failure rate (failures per km) of service connections is consistently and substantially higher than that of distribution pipes. This identifies service connections as the structural weak link in terms of reliability and leaks risk.

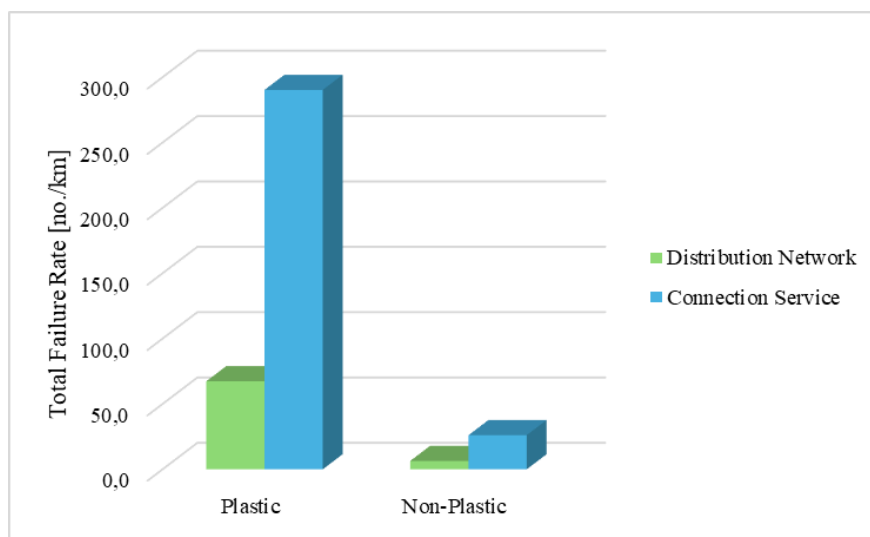


Figure 2.-Total normalized failure rate [no./km] for distribution network and service connections, split by plastic and non-plastic materials.

Geolocating the interventions by street number it is possible to separate initial operations from returns (recurring failures). As shown in Figure 3, the increase in

the number of operations in recent years is driven by returns on plastic connections. The yearly return rate (Returns/Initial) shows an higher increasing trend respect to other materials. The incidence of returns on total operations also increases over time.

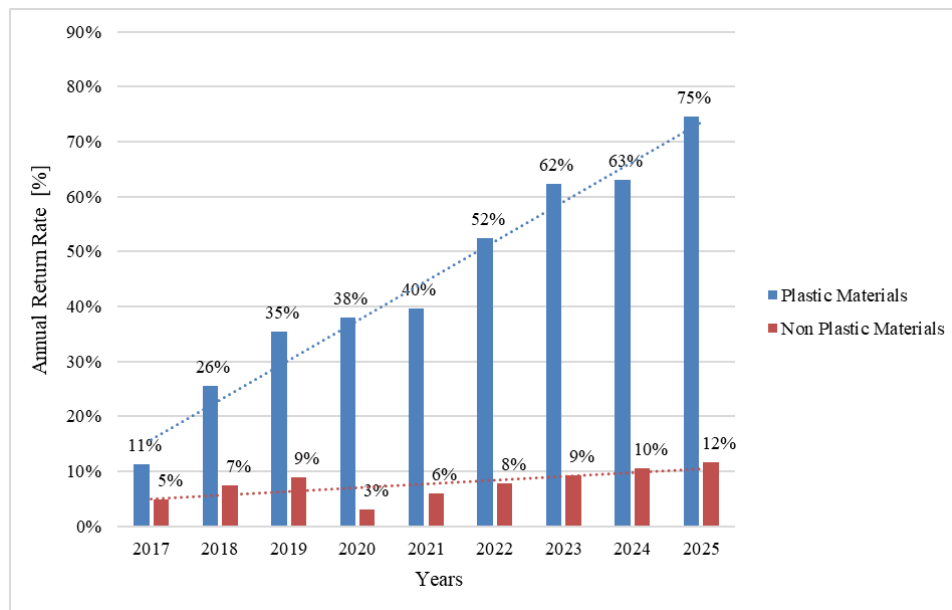


Figure 3.- Yearly service connection return rate by materials.

The analysis of the repair field notes suggests a number of plausible causes for the increased number of failures on the service connections: insufficient installation depth, inadequate substrate, sensitivity of polymers to combined chemical-thermal-mechanical stress, and post-repair pressure transients. This results in a bad behaviour of plastic pipe connections in terms of breaks especially if already repaired by means of the classical collars which are probably of better efficacy on metallic pipes.

Such analyses are of practical application for Water Utilities in order to implement strategic WDS Management actions, which, in this specific case study, should give priority to pipe connections respect to the main distribution.

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